The Scientific Temper (2024) Vol. 15 (1): 1689-1696
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2024.15.1.17
https://scientifictemper.com/
RESEARCH ARTICLE

Comparative study of print quality attributes on bio-based biodegradable plastic using flexography and gravure printing process

Pankaj Kumar[1*], Ambrish Pandey[1], Rajendrakumar Anayath[2]

Abstract
Printing has revolutionized not only the religious and educational world by providing printing on paper but also the commercial world by providing end-to-end solutions for packaging by printing on materials like plastics. Print quality refers to level of details and sharpness of printed products for wider acceptability. Print quality has an important role in maintaining consistency during printing on selected surfaces to provide desired satisfaction. Printability and runnability of substrates, substrate surface characteristics, and printing ink properties are attributes of print quality and are considered important for determining good quality printing. Solid ink density (SID), Hue error, grayness and ink trapping are some of the important measurable printability factors that play an important role in determining the print quality irrespective of substrates. Gravure printing and flexography printing are high-speed printing suitable for printing on flexible substrates so, attempts were made for explore the mutual compatibilities of new-generation printing substrates with established printing processes, which will prove to be a boon in the future by replacing conventional plastics with bio-based biodegradable plastics in printing for packaging and its other applications. So, multi-color printing on selected bio-based biodegradable plastics were explored for determining printability by measuring and maintaining print quality attributes during print runs.

Keywords: Print quality, Bio-based biodegradable plastics, Flexography printing, Gravure printing, Solid ink density, Hue error, Grayness, Ink trapping

Introduction
Conventional plastics exhibit good printability due to its surface characteristics, strength and ease of treatment of material during print production and deliver excellent print quality even at very high speed (Kumar *et al*., 2023). Due to excellent printability under certain conditions, printing on flexible plastics has quickly revolutionized the industrial and packaging sectors. Printing on different grades of plastics has fueled the growth of packaged items and overall packaging sector. Still, improper disposal of plastic waste, including printed plastic materials, has created a very big problem that every municipal territory faces. Governments are forced to take strict majors against flexible plastic packaging (Iordanskii, 2020) (Walker & Rothman, 2020). Governments and industries are looking for alternatives for plastics and environmentally friendly plastics has emerged as a solution for the same. The sustainability challenge of conventional plastics led to the invention of recyclable, compostable, degradable, bio-degradable and finally, bio-based bio-degradable materials for different purposes (Glaser, 2017). The bioplastics family (Bio-based Plastics, Bio-degradable plastics, Bio-based Biodegradable) has made their mark for considering them as main alternative of conventional plastics for different utilities. Different research groups are developing bio-based plastics in different variants, which can be shaped and modified suitably for new packaging media if print results are suitable for specific applications.

Recent inventions in plastic is bio-based bio-degradable plastics which is changing the perception about use of plastics. The recent ban on less than 50 micron single-use plastic has forced the industry to adopt sustainable

[1]Department of Printing Technology, Guru Jambheshwar University of Science & Technology, Hisar, Haryana, India

[2]DCRUST, Murthal, Haryana, India

***Corresponding Author:** Pankaj Kumar, Department of Printing Technology, Guru Jambheshwar University of Science & Technology, Hisar, Haryana, India, E-Mail: pankajtiwari01@gmail.com

How to cite this article: Kumar, P., Pandey, A., Anayath, R. (2024). Comparative study of print quality attributes on bio-based biodegradable plastic using flexography and gravure printing process. The Scientific Temper, **15**(1):1689-1696.

Doi: 10.58414/SCIENTIFICTEMPER.2024.15.1.17

Source of support: Nil

Conflict of interest: None.

Received: 09/01/2024 **Accepted:** 10/02/2024 **Published** : 15/03/2024

plastics. The big and major players of this field are looking for sustainable plastics with good printability as multi-color printing is the main strength behind the fast-growing packaging industry. Sustainability and biodegradability are the main important strengths of bio-plastics and hence, they will have better acceptability for various applications where they were marginally or sometimes little expensive than conventional plastics if printed suitably in comparison to conventional Plastics (Ezgi Bezirhan Arikan & Havva Duygu Ozsoy, 2015).

Printing in the Modern Era

In this era of ever-growing consciousness for quality and demand of security for products, printing has the capability to provide amicable solutions for every situation. Printing has touched almost every person after its invention, either in form of printed products as packages. Major printing processes are divided according to how they transfer print from the surface to the substrate into impact and non-impact printing processes (Mendiratta, 2017). Gravure printing and flexography printing are high-speed printing methods suitable for printing on flexible substrates. They come under impact processes and use minimum pressure during printing, enabling them to print on thin, flexible materials (Kipphan, 2001). Multi-color printing is the main strength behind fast, fast-moving, rapidly growing packaging industry. It is already established that printing, which decorates packages or differentiates brands by graphic communication, is the backbone of the packaging industry.

Printing on Plastics and Bioplastics

Printers' has faced challenges in printing on plastics since its invention. The printability of plastics can be made good for printing at very high speed with certain treatments like corona. The gravure printing process prints large plastic family (conventional plastics), especially flexible plastics and the flexography printing process at high speed with very good print quality for packaging applications directly or in form of laminates. Printing on plastics usually comes under flexible printing, in which the gravure printing process and flexography printing process are leading printing processes in this field.

Flexography printing process

Flexography printing comes under relief method of printing, and printing is done using flexible plates. The process was first invented and patented in 1890 by Bibby, Baron and Sons. It is also known as the aniline process of printing. Major applications of flexography printing are packaging jobs, polythene, and plastic carry bags of low to high quality. A wide variety of papers, paper boards, polyester and plastic films, metal foils, and many other packaging substrates can be printed using the flexography printing process (Mendiratta, 2017). A flexography printing machine equipped with a common Impression cylinder (CIC) arrangement is suitable for high-speed printing on plastics as well as bio-based biodegradable plastics. Modern flexography printing machines with CIC arrangements and GTT technology for anilox have excellent print quality and compete with gravure printing quality for packaging applications (*Vision CI Flexo*, 2023).

Gravure printing process

The gravure printing process is an intaglio method of printing in which image and non- image areas are separated physically. The image areas lie in recessed part (in the form of cavities) while non-image areas lie on the surface of image carrier. The intaglio process was invented by Fox Talbot in 1806 and rotogravure process was invented by Karl Klic in 1878. The gravure printing process can quickly print on a wide variety of light and low-grade papers, boards, plastic films, and metallic foils. The gravure process is suitable for extremely long-run jobs, packaging and security printing jobs like labels, wrapper, currency, postage stamps, stock and bond certificates. The gravure process is capable of producing very good color printing results of uniform quality throughout the run. The average print run in roto-gravure starts from 1 million prints, making this process affordable and cheap (Kipphan, 2001).

Print Quality and Print Quality Attributes

Print quality refers to particular characteristics that determine print outcomes that can meet print buyer satisfaction. Print quality has an important role in maintaining quality and consistency during print production to provide the desired level of satisfaction to the print buyer. Printability and runnability of substrates, substrate surface characteristics, and printing ink properties are attributes of print quality and are considered important for determining good printing. solid ink density (SID), Hue error, grayness and ink trapping are some of the important measurable printability factors that play an important role in determining print quality.

Bio-Plastics

Bio-plastics are a type of plastic that incorporates a certain proportion of bio-based content in their composition. They offer various properties similar to conventional plastics, making them suitable for a range of applications, including packaging due to their excellent properties like - flexibility, durability, and moldability. The production of bioplastics generally involves processes such as fermentation, polymerization, or chemical synthesis, depending on the specific source material. Bioplastics is offering a sustainable solution to reduce dependence on fossil fuels and lower carbon emissions. However, challenges exist in terms of scalability, cost-effectiveness, and the potential competition of bioplastic sources. The development and adoption of bioplastics represent a significant step towards more environmentally friendly and sustainable approach to plastic production and consumption.

This bio-based content is typically derived from renewable resources such as corn, sugarcane, or other plant-based materials. Incorporating this renewable content can help reduce the overall environmental impact of the plastic, as it reduces the reliance on non-renewable fossil fuels in manufacturing (Figures 1 and 2).

Biodegradable bioplastics

Biodegradable bioplastics can be derived from both renewable and fossil-based resources. It can decompose naturally through light, heat, water, moisture, oxygen, and microorganisms, forming harmless byproducts and leaving no harmful residues under specific conditions. They break down into natural elements such as water, carbon dioxide, and biomass. Biodegradable bioplastics are suitable for various applications, including disposable packaging and products where a limited lifespan is desired.

As per ASTM, bio-degradable plastics are defined as: "A degradable plastic in which the degradation results from the action of naturally-occurring microorganisms such as bacteria, fungi and algae." (ASTM D883–17, 2017)

Bio-based biodegradable plastics

Biobased biodegradable plastics are those plastics that come from renewable resources such as corn, sugarcane, or other plant-based materials and undergo degradation through the action of biological agents, such as enzymes or microorganisms (Kharb & Saharan, 2022). These plastics are designed to break down into simpler, natural compounds over time, eventually integrating back into the environment without leaving behind harmful residues.

The degradation process of such plastics often involves the hydrolysis of chemical bonds within the polymer structure, effect of temperature, pH, and the presence of specific enzymes influence the rate and extent of degradation (Gadhave *et al*., 2018). As these plastics degrade into natural components, they minimize the accumulation of long-lasting pollutants in ecosystems. The use of bio-based biodegradable plastics can contribute to reducing the environmental burden associated with persistent plastic waste.

Printability

Printability is a complex interplay of substrate properties, ink characteristics, and printing machine settings. Printability refers to the ability of a substrate to accept ink evenly and produce high-quality printed results irrespective of the printing process. Printability can be measured, managed and maintained objectively to get desired results (Kumar Gargp *et al*., 2016). Some of the important and objective print parameters are SID, Hue error, grayness and ink trapping. All these print parameters are established and are measurable, manageable and maintainable during large and repeated print run.

SID

SID or ink film thickness refers to the amount of printing ink applied to a printed surface to achieve a solid or opaque color, irrespective of the process of printing. It is also known as print density (Jangra *et al*., 2013).

Hue error, also known as color error or color deviation, refers to the difference between desired color and the actual color produced in print production. Hue error is a common phenomenon in printing and plays an important role in achieving the desired color by minimizing error in different colors. The mathematical formula for calculating hue error is as follows.

Hue Error = (Hue2 - Hue1)

Grayness

Grayness indicates the presence of gray in a color that makes it appear less saturated. Greyness are used to check for color consistency throughout the press run (x_Rite, n.d.). Grayness are presented in % and calculated using the following formula.

$$G = \frac{D_L}{D_H} X\ 100$$

where

D_L = Lowest density of C, M or Y

D_H = Highest density of C, M or Y

Ink trapping

Ink trapping is a printing technique that involves overlapping of colors to prevent gaps or white spaces from appearing between them, which can happen due to misalignment or spreading of ink. (Jangra *et al*., 2023) This process is particularly crucial in high-speed multi-color printing, where multiple ink layers are applied one after another. By creating

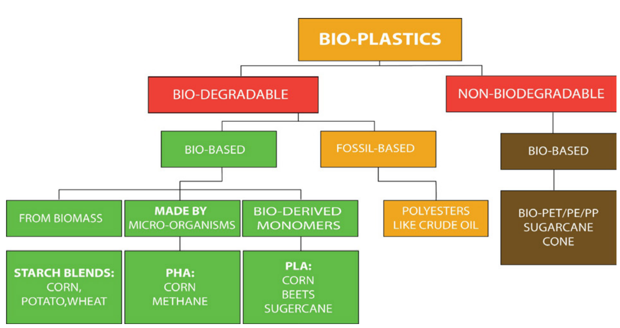

Figure 1: Categorization of bioplastic

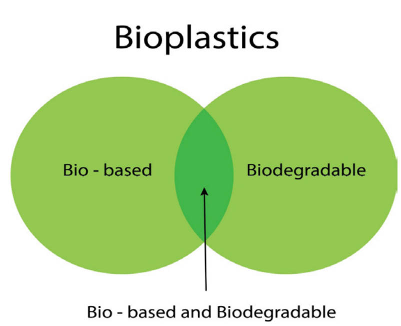

Figure 2: Categorization of bioplastic

an overlap between colors, ink trapping ensures a seamless and vibrant final print. Frank Preucil in 1953 has introduced ink trapping formula.

Research Objective

The major objective of the research is to carry out a comparative study of print quality attributes on bio-based biodegradable plastic using flexography and gravure printing.

Materials and Methodology

Print quality attributes are measured to get objective results for the printability of selected materials by incorporating different elements in test charts to be printed. Elements of test chart for determining print quality were selected depending upon the requirements for both processes. To study print quality attributes on bio-based biodegradable plastic using flexography and gravure printing process, the following steps are followed which are tabulated in Table 1.

Table 1: Description of prin run sequence

S. No.	*Print run sequence*	*Printing process*	
		Flexography	*Gravure*
1	Test chart development	Master Test Chart developed by incorporating technical elements as per requirement of research.	
2	Preparation of image carrier	Photopolymer plates from Kodak-NX	K5 Smart Hlio Klischograph
3	Substrate used for printing	Bio-based biodegradable (maize based)	
4	Selection of printing ink	Flexography Standard Inks (DIC)	Gravure Standard Inks (DIC)
5	Printing/Proofing machine	Bobst Vision CI Flexo	Shivam
6	Colorimetric measurement	X-rite, Exact spectrophotometer	

Data Analysis

In order to carry out a comparative study of print quality attributes on bio-based biodegradable plastic using flexographic and gravure printing, various print quality attributes taken into consideration, including SID, Hue error, grayness and ink trapping whose data interpretation is presented below.

SID

SID of cyan, magenta, yellow and black color on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) are presented below:

- *Cyan color SID*

SID on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) for cyan color is graphically presented in Figure 3. The minimum and maximum measured value for SID for cyan color on bio-based biodegradable plastic were recorded between 0.9851 and 1.1771 and 1.0696 and 1.2673 for flexography and gravure printing, respectively. Flexography printing exhibited a minimum standard deviation (0.0461).

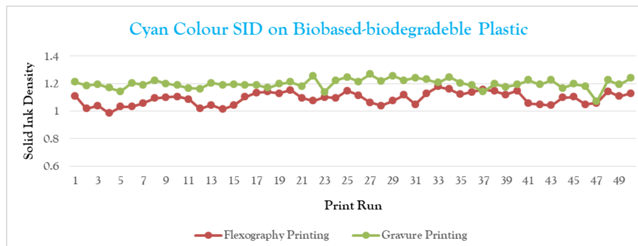

Figure 3: Cyan color SID for flexography and gravure printing

- *Magenta color SID*

The representation of data for SID using flexographic and gravure printing on bio-based biodegradable plastic for magenta color is graphically presented in Figure 4. The minimum and maximum measured value for SID using flexographic and gravure printing were recorded between 1.0794 to 1.1242 and 0.9907 to 1.3385, respectively. Flexography printing exhibited a minimum standard deviation (0.0105) for magenta color printing.

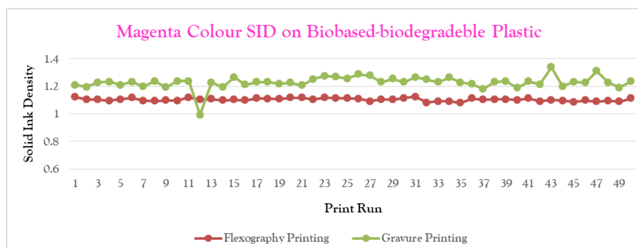

Figure 4: Magneta color SID for flexography and gravure printing

- *Yellow color SID*

Figure 5 presents the data recorded for SID for yellow color on bio-based biodegradable plastic using flexographic and gravure printing. The minimum and maximum measured values for SID for yellow color on bio-based biodegradable plastic using flexographic and gravure printing were recorded between 0.6794 and 0.9910 and 1.3190 and 1.4978, respectively. The minimum standard deviation (0.0356) was exhibited by gravure printing.

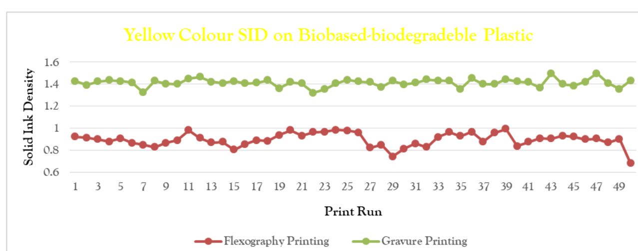

Figure 5: Yellow color SID for flexography and gravure printing

- *Black color SID*

Measured values for SID using flexographic and gravure printing at 120 LPI on bio-based biodegradable plastic

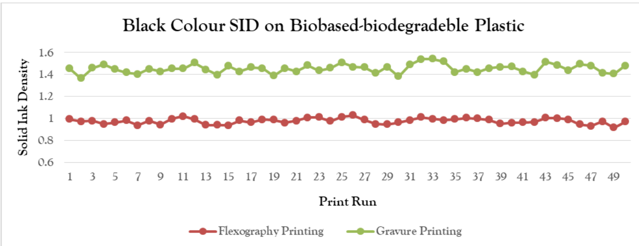

Figure 6: Black color SID for flexography and gravure printing

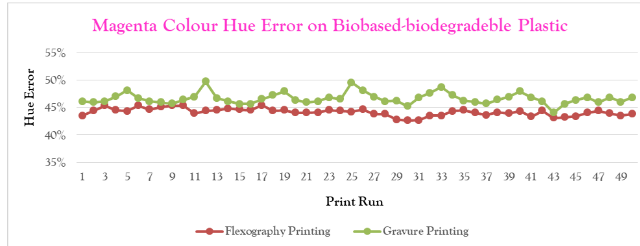

Figure 8: Magneta color hue error for flexography and gravure printing

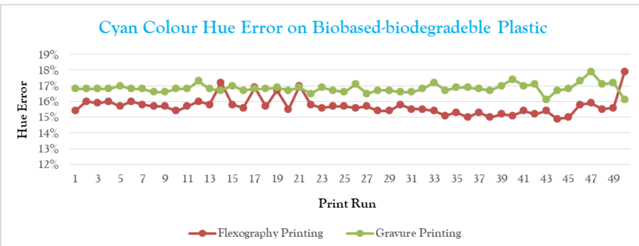

Figure 7: Cyan color hue error for flexography and gravure printing

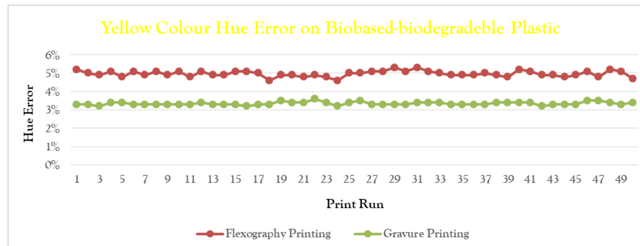

Figure 9: Yellow color hue error for flexography and gravure printing

for black color are graphically presented in Figure 6. The minimum and maximum measured value for SID on bio-based biodegradable plastic were recorded between 0.9171 to 1.0275 and 1.3635 to 1.5417, respectively using flexography and gravure printing. Flexography printing exhibited a minimum standard deviation (0.0256).

Hue error

Hue error of cyan, magenta, yellow and black color on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) are presented below:

- *Cyan color Hue error*

Hue error on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) for cyan color is graphically presented in Figure 7. The minimum and maximum measured value for SID for cyan color on bio-based biodegradable plastic were recorded between 14.90, 17.90, 16.10 and 17.90% for flexography and gravure printing, respectively. Minimum standard deviation (0.0029) was exhibited by gravure printing.

- *Magenta color Hue error*

The representation of data for hue error using flexographic and gravure printing on bio-based biodegradable plastic for magenta color is graphically presented in Figure 8. The minimum and maximum measured value for hue error using flexographic and gravure printing were recorded between 42.60 to 45.40% and 44.00 to 49.70%, respectively. Flexography printing exhibited a minimum standard deviation (0.0067) for magenta color printing.

- *Yellow color Hue error*

Figure 9 presents the data recorded for hue error for yellow color on bio-based biodegradable plastic using

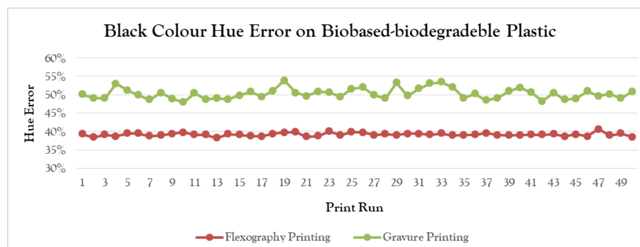

Figure 10: Black color hue error for flexography and gravure printing

flexographic and gravure printing. The minimum and maximum measured value for SID for yellow color on bio-based biodegradable plastic using flexographic and gravure printing were recorded between 4.60 and 5.30. 3.20 and 3.60%, respectively. Minimum standard deviation (0.0008) was exhibited by gravure printing.

- *Black color Hue error*

Measured values for hue error using flexographic and gravure printing at 120 LPI on bio-based biodegradable plastic for black color are graphically presented in Figure 10. The minimum and maximum measured value for SID on bio-based biodegradable Plastic were recorded between 38.20 to 40.60% and 48.00 to 53.90% respectively using flexography and gravure printing. Flexography Printing exhibited minimum standard deviation (0.0044).

Grayness

Grayness of cyan, magenta, yellow and black color on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) are presented below:

- *Cyan color grayness*

Grayness on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) for cyan color is graphically presented in Figure 11. The minimum and maximum measured value for SID for cyan color on bio-based biodegradable plastic were recorded between 15.70 and 19.50% and 10.70 and 14.30% for flexography and gravure printing, respectively. Flexography printing exhibited minimum standard deviation (0.0068).

- *Magenta color grayness*

The representation of data for grayness using flexographic and gravure printing on bio-based biodegradable plastic for magenta color is graphically presented in Figure 12. The minimum and maximum measured value for grayness using flexographic and gravure printing were recorded between 16.90 to 19.90% and 14.00 to 16.40%, respectively. Both flexography and gravure printing exhibited the same standard deviation (0.0054) for magenta color printing.

- *Yellow color grayness*

Figure 13 presents the data recorded for grayness for yellow color on bio-based biodegradable plastic using flexographic and gravure printing. The minimum and maximum measured value for SID for yellow color on bio-based biodegradable plastic using flexographic and gravure printing were recorded between 3.40 and 5.80% and 0.60 and 2.00%, respectively. Minimum standard deviation (0.0035) was exhibited by gravure printing.

- *Black color grayness*

Measured Values for grayness using flexographic and gravure printing at 120 LPI on bio-based biodegradable plastic for black color are graphically presented in Figure 14. Using flexography and gravure printing, the minimum and maximum measured value for SID on bio-based biodegradable plastic were recorded between 85.60 to 90.10% and 89.00 to 92.50%. Flexography printing exhibited minimum standard deviation (0.0063).

Ink trapping

Ink Trapping of red, green, blue and black color on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) are presented below:

- *Red color ink trapping*

Ink trapping on bio-based biodegradable plastic using flexographic and gravure printing (at 120 LPI) for red color is graphically presented in Figure 15. The minimum and maximum measured value for SID for red color on bio-based biodegradable plastic were recorded between 97.70, 99.80 and 80.30% and 89.10% for flexography and gravure printing, respectively. Flexography printing exhibited minimum standard deviation (0.0051).

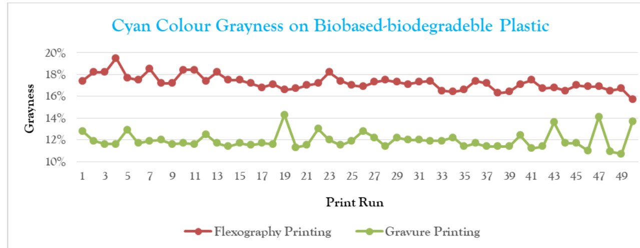

Figure 11: Cyan color grayness for flexography and gravure printing

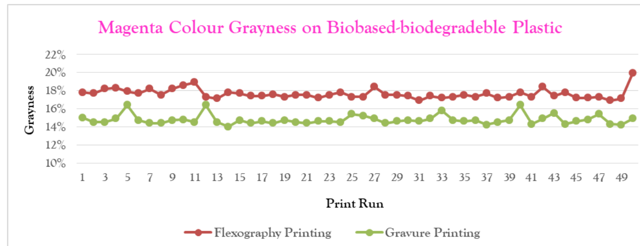

Figure 12: Magneta color grayness for flexography and gravure printing

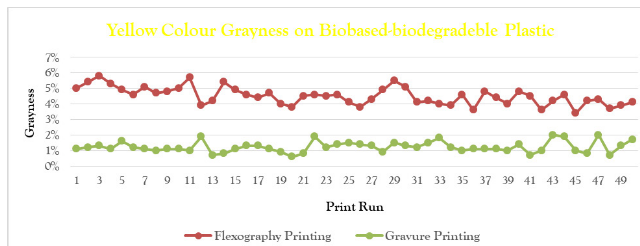

Figure 13: Yellow color grayness for flexography and gravure printing

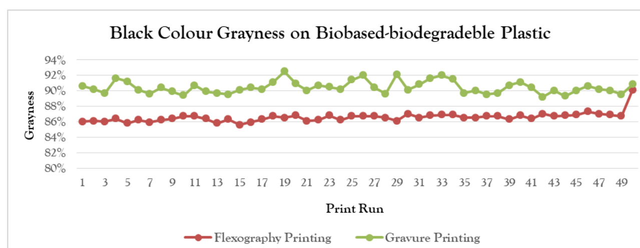

Figure 14: Black color grayness for flexography and gravure printing

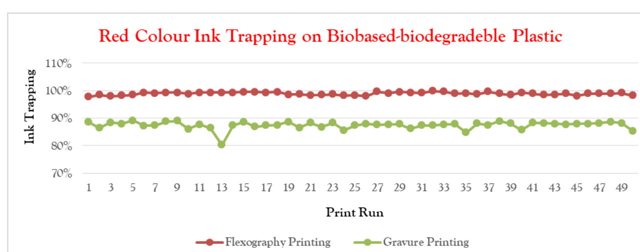

Figure 15: Red color ink trapping for flexography and gravure printing

- *Green color ink trapping*

The representation of data for ink trapping using flexographic and gravure printing on bio-based biodegradable plastic for green color is graphically presented in Figure 16. The minimum and maximum measured value for ink trapping using flexographic and gravure printing were recorded between 88.30 to 99.80% and 62.00 to 74.50%, respectively. Flexography printing exhibited minimum standard deviation (0.0245) for green color printing.

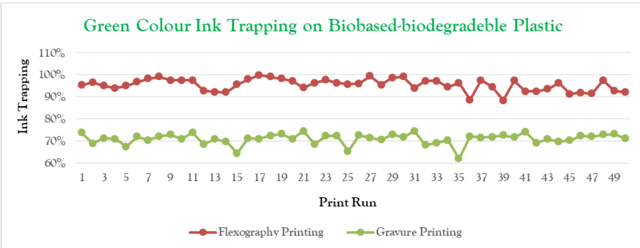

Figure 16: Green color ink trapping for flexography and gravure printing

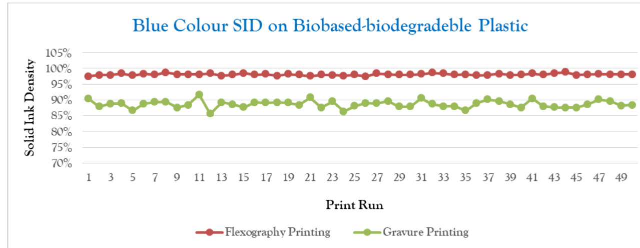

Figure 17: Blue color ink trapping for flexography and gravure printing

Table 2: Print quality attributes on bio-based plastic using flexographic and gravure printing

Printing Parameter		*Cyan*		*Magenta*		*Yellow*		*Black*	
		Mini.	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*
SID	Flexography	0.9851	1.1771	1.0794	1.1242	0.6794	0.9910	0.9171	1.0275
	Gravure	1.0696	1.2673	0.9907	1.3385	1.3190	1.4978	1.3635	1.5417
Hue Error	Flexography (%)	14.90	17.90	42.60	45.40	4.60	5.30	38.20	40.60
	Gravure (%)	16.10	17.90	44.00	49.70	3.20	3.60	48.00	53.90
Grayness	Flexography (%)	15.70	19.50	16.90	19.90	3.40	5.80	85.60	90.10
	Gravure (%)	10.70	14.30	14.00	16.40	0.60	2.00	89.20	92.50

Table 3: Ink trapping on bio-based plastic using flexographic and gravure printing

Printing Parameter		*Red*		*Green*		*Blue*	
		Mini.	*Max.*	*Mini.*	*Max.*	*Mini.*	*Max.*
Ink Trapping	Flexography (%)	97.70	99.80	88.30	99.80	97.50	98.80
	Gravure (%)	80.30	89.10	62.00	74.50	85.60	91.70

- *Blue color ink trapping*

Figure 17 presents the data recorded for ink trapping for blue color on bio-based biodegradable plastic using flexographic and gravure printing. The minimum and maximum measured value for SID for blue color on bio-based biodegradable plastic using flexographic and gravure printing were recorded between 97.50, 98.80, 85.60 and 91.70%, respectively. Flexographic printing exhibited minimum standard deviation (0.0028).

Results and Discussion

Comparative study of print quality attributes on bio-based biodegradable plastic using flexographic and gravure printing was made by considering various print quality which included SID, hue error, grayness and ink trapping. Information collected for various print quality parameters is tabulated in Tables 2 and 3.

Observation

Earlier in 2020 print related experiments for evaluating printing performance was carried out on starch films as an environmentally friendly packaging materials (Żołek-Tryznowska & Holica, 2020). This research explored the possibility of printing on biodegradable packaging material. Our study was carried out with the objective to compare print quality attributes on commercially available bio-based biodegradable plastic using flexography and gravure printing process for packaging applications. The selected bio-based biodegradable plastics were used as printing substrate for flexography and gravure multi-color printing under standard press room conditions. The basic print quality parameters SID, Hue error, grayness and ink trapping are some of the important printability factors which were measured for determining the print quality on bio-based biodegradable substrates.

Conclusion

A Comparative study of various print quality attributes using flexographic and gravure printing on bio-based biodegradable plastic was made by considering SID, hue error, grayness and ink trapping as various print quality attributes. During the study, the observations indicated that the values of print quality parameters SID, hue error, grayness and ink trapping) were freplicating repeatedly Also these values were in the standard range of printing quality while printing on bio-based biodegradable plastic using flexography and gravure printing. The conclusion is explained as:

SID

The ink density range for all process colors (Cyan, Magenta, Yellow, and Black) was found to be higher for gravure printing. Regarding print consistency, Gravure printing demonstrated the least deviation for cyan and yellow color, while flexography printing demonstrated the least deviation for magenta and black colors.

Hue Error

Hue error range for cyan, magenta and black by gravure while for yellow by flexography printing was found more. in terms of print consistency on the basis of hue error, gravure printing demonstrated least deviation for cyan and yellow colors, while flexography printing demonstrated least deviation for magenta and black color.

Grayness

The range for grayness by gravure printing was found more for yellow, while by flexography printing was found more for cyan, magenta and black on bio-based biodegradable plastic. The same standard deviation was observed for magenta color for both gravure and flexography printing. The remaining color flexography demonstrated the least deviation for cyan and black colors, while gravure printing demonstrated the least deviation for yellow.

Ink Trapping

Flexography printing exhibited highest range of ink trapping for all color (Red, Green and Blue). The least deviation was observed for red and blue color for flexography printing and for green printing was minimum for gravure printing.

Acknowledgement

The authors are thankful to all those who helped directly or indirectly while accomplishment of this experimental research activity and duly acknowledge all the technical assistance provided by Department of Printing Technology, GJUS&T and Creative Graphics. Also, GLS Films Industries Pvt. Ltd. (Haryana) for their unconditional and extraordinary support during the carrying out of this study is acknowledged. Technical expertise of Mr. Manoj Kaushik, (Chief Operating Officer, GLS Films Industries Pvt. Ltd.,Haryana) is highly acknowledged and duly appreciated.

References

ASTM D883–17. (2017). Standard Terminology Relating to Plastics. *ASTM International*, *i*, 1–16. https://doi.org/10.1520/D0883-17.2

Ezgi Bezirhan Arikan, & Havva Duygu Ozsoy. (2015). A Review: Investigation of Bioplastics. *Journal of Civil Engineering and Architecture*, *9*(2), 188–192. https://doi.org/10.17265/1934-7359/2015.02.007

Gadhave, R. V., Das, A., Mahanwar, P. A., & Gadekar, P. T. (2018). Starch Based Bio-Plastics: The Future of Sustainable Packaging. *Open Journal of Polymer Chemistry*, *08*(02), 21–33. https://doi.org/10.4236/ojpchem.2018.82003

Glaser, J. A. (2017). New plastic recycling technology. *Clean Technologies and Environmental Policy*, *19*(3), 627–636. https://doi.org/10.1007/s10098-016-1324-7

Iordanskii, A. (2020). Bio-Based and Biodegradable Plastics : From Passive Barrier to Active Packaging Behavior. *Polymers*, *12*(1537).

Jangra, V., Pandey, A., & Anayath, R. K. (2023). *Print consistency evaluation on uncoated paper using various digital print engines*. *14*(3), 735–740. https://doi.org/10.58414/SCIENTIFICTEMPER.2023.14.3.25

Jangra, V., Saini, A., & Sharma, S. (2013). Solid Ink Density in Relation with Dot Gain in Sheet-fed Offset Printing. *International Journal of Science, Engineering & Computer Technology*, *3*(3–4), 173–176.

Kharb, J., & Saharan, R. (2022). Sustainable Biodegradable Plastics and their Applications: A Mini Review. *IOP Conference Series: Materials Science and Engineering*, *1248*(1), 012008. https://doi.org/10.1088/1757-899x/1248/1/012008

Kipphan, H. (2001). Handbook of Print Media. In *Print and Paper Europe* (Vol. 13, Issue 6). https://doi.org/10.1007/978-3-540-29900-4

Kumar Gargp, S., Gupta, V., & Jangrap, V. (2016). Effect of Moisture Content on Printability of Corrugated Board. *International Journal of Scientific Engineering and Applied Science (IJSEAS)*, *2*(5), 269–275. www.ijseas.com

Kumar, P., Pandey, A., & Anayath, R. (2023). Comparative analysis of Solid Ink Density on Conventional and Bio-based plastics using Gravure Process. *European Chemical Bulletin*, *12*(4), 13473–13480. https://doi.org/10.48047/ecb/2023.12.si4.1222

Mendiratta, B. D. (2017). *Elements Of Design And Typography*.

Vision CI Flexo. (2023). www.bobst.com

Walker, S., & Rothman, R. (2020). Life cycle assessment of bio-based and fossil-based plastic: A review. *Journal of Cleaner Production*, *261*, 121158. https://doi.org/10.1016/j.jclepro.2020.121158

x_Rite. (n.d.). *User Guide Manual*.

Żołek-Tryznowska, Z., & Holica, J. (2020). Starch films as an environmentally friendly packaging material: Printing performance. *Journal of Cleaner Production*, *276*. https://doi.org/10.1016/j.jclepro.2020.124265