Comparative Study of Different Inkjet Printheads Performance in Context to Dot Gain on Gloss Coated Substrate using Taguchi's Grey Relational Analysis (GRA)

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ABSTRACT:

Domestic and commercial printers all around the globe rely on inkjet technology. As the technology for inkjet printing has progressed, it has found new uses in areas such as the packaging industry and the printing of high-quality publications. Print quality has been fine-tuned via a series of tests and revisions to ensure that this cutting-edge technology delivers satisfactory printouts. Quality printing often employs the usage of gloss coated sheets. For this reason, dot gain efficiency is essential on gloss coated paper. This study compares the dot gain performance of several commercial inkjet printheads on gloss coated paper. Taguchi's Grey Relational Analysis (GRA) is used as a novel statistical method for comparing the efficiency of several inkjet printheads.

Keywords: Inkjet; printhead; dot gain; grey relational analysis; gloss coated

1. INTRODUCTION AND BACKGROUND:

The inkjet printhead is the fundamental component of any inkjet printing press. On the basis of printhead, Continuous inkjet and Drop-on-Demand inkjet (1) are the two major types of inkjet printing presses (2). The inkjet printers produce dots from nucleated droplets (3) that are spherical due to surface tension forces, and the smallest possible dot is round (4). The most popular printing substrate is paper (5) and it has a very significant role in printing industry. The common types of paper are gloss coated and uncoated papers. Printing press performance is influenced by the technology, ink, and paper used (6). If the dot area of print is larger than the present value in the computer, then the inks must have spread (diffused) over the surface of paper, making the dot area a quantitative measure of print quality. The ink-spreading problem, commonly known as dot-gain, may degrade print quality (7). Dot gain analysis is the most critical factor that must be taken into account when printing with inkjet printheads because of the unique qualities of the paper. This research work is emphasising on implementation of statistical tool named Grey Relational Analysis (GRA) which can be helpful to the printers in decision-making for selecting the particular machine or materials. In this research work, we have successfully implemented this statistical tool to find out the end result.

The dimensions and shapes of dots produced by inkjet are highly dependent on substrate characteristics, particularly the kind of coating used (4). Furthermore, the clarity of the picture is dependent on the precision with which the dots are placed on the paper. Both the physical dot gain, caused by the ink spreading and permeating the paper (8), and the optical dot gain, caused by the paper's porous nature, contribute to the effect. This outcome is the optical dot gain, commonly known as the "Yule-Nielsen effect". Light scattering inside the paper is the source of optical dot gain [6, 8]. Murray-Davies is one of the most recognised and simplest halftone reflectance models (11). An approach was made to describing dot gain and ink interaction in the development of a printer model using the Yule Nielsen Spectral Neugebauer equation and found that the average root mean squared error for spectral accuracy was 0.59 percent and the average colour error was 1.54 ΔE*ab (12). Paper porosity is very influencing factor in dot gain (13).

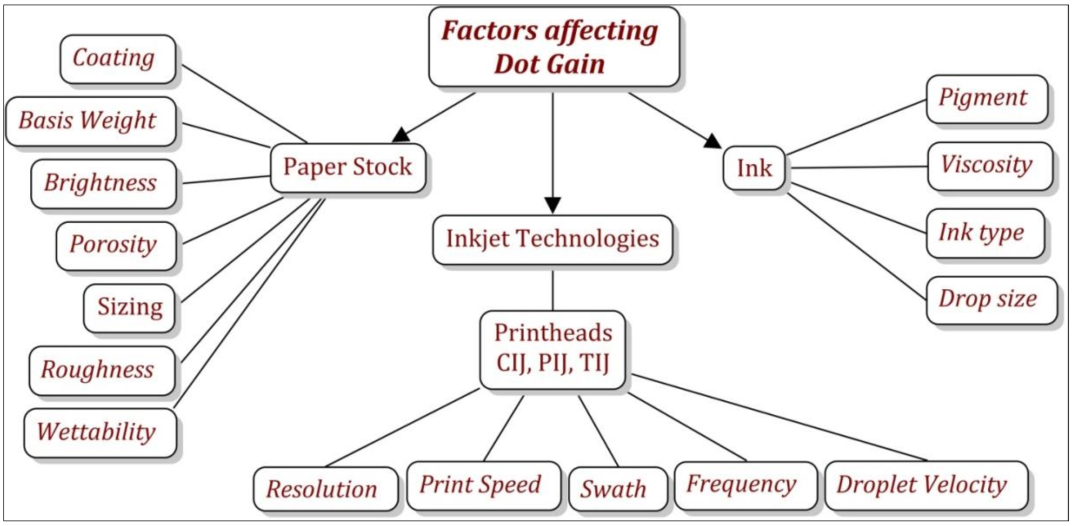

Figure 1. Various factors affecting dot gain in inkjet printing

Most of the Dot gain values were computed and examined using the Murray-Davies equation and the Yule-photon Nielsen's modification. The study has shown that inkjet papers have better surface properties because they produce less dot gain than non-inkjet papers. Inkjet papers, like non-inkjet papers, have a peak in dot gain at around 40%-50% tint (7,14). Chu & Li studed the effect of paper properties on dot gain based on Grey Relational Analysis and found the impact of various paper properties on dot gain (15). Different coating on papers shows different value of dot gain likewise $CaCO_3$ (16) shows more dot gain as comparison to SiO_2 (17). Dot reproduction is better with a significant quantity of ink left on the surface, since penetration is less (18). Wetting causes dot gain when there is a lot of ink on the surface (19). Low dot gain and circular dot form are keys to effective printing (20). The consistency in size and shape (21) of the dots is enhanced by the high smoothness of the surface (22). Dot gain values were lower for calendared-coated paper substrates (23). Variations in coating pigment mixtures had no influence on dot gain (24). In a research work, it has been found that on uncoated paper, tone value increases were minimal. The coatings on the surface raised the dot gain in coated papers; therefore, coating has significant influence on dot gain. However, dots were more stable on flat surfaces (8). Figure 1 shows various factors that affecting dot gain while printing the paper stock by inkjet printing press.

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The concept of the Grey System was first initiated in the year 1982 (25). Grey Relational Analysis (GRA) statistical tool was proposed by Deng Julong in 1989 (26). Apart from the different application (27), this theory is also applied in decision making, grey target models, control systems and models etc effectively (28). This theory has been successfully implemented in various sectors of education, business, production, electronic equipments, mechanical engineering etc (29). It has been come to know that the Grey Relational Analysis was used rarely in analysis of print performance (30) and quality factors (31). The figure 2 shows the step by step progression of GRA equations.

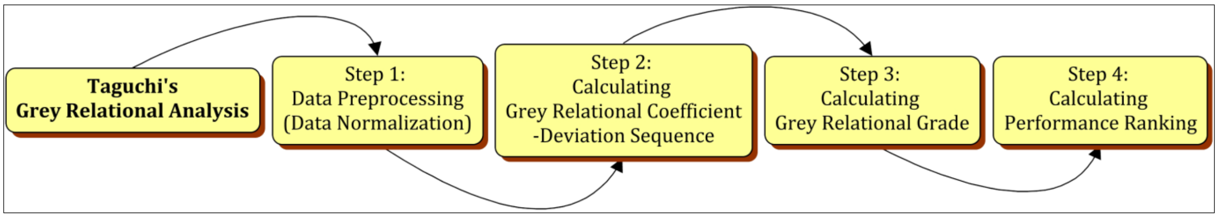

Figure 2. Grey Relational Analysis Sequence

2. MATERIALS & METHODOLOGY

In recent years, digital printing is growing at exponential rate. Amongst the digital printing, Inkjet printing process is getting popular because of its wide applications. So, analyzing the print performance of different inkjet printheads on gloss coated paper is important. Dot gain is one of the importance factors that require utmost attention. Therefore, this research work is executed on below mentioned hypothesis: (i) dot gain occurs on gloss coated paper stock while printing with digital inkjet printing technologies; (ii) Continuous inkjet and Drop-on-Demand inkjet printheads performs equally in case of dot gain on gloss coated paper stock; (iii) GRA statistical tool gives significant information to compare the dot gain analysis on gloss coated paper when printed with different inkjet printheads.

According to the objective of the research work, gloss coated paper of 90 g/m^2 considered which is commonly used in printing industry. Four paper types were collected and tested their paper properties in a certified laboratory. After testing, one paper types was finalized which was having values near to the standard values. The values measured are shown in Table 1.

Table 1. Measurement of paper properties

Sr. No.	Paper properties	Gloss Coated

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1	Brightness (%)	83.5
2	Gloss (%)	98.4
3	Roughness (ml/min)	10.8
4	Opacity (%)	89.1
5	Porosity (ml/min)	116.0

The selected paper was then printed by different inkjet printheads i.e. CIJ, PIJ and TIJ under the standard printing conditions (Temp.: 25° C & Relative humidity: 55%). The type of ink that used of aqueous based ink. A master test chart was prepared with inclusion of hitting target of dot gain. The colour patches containing dot percentage value at 25%, 50% and 75% dot areas were measured using calibrated x-rite eXact spectrophotometer under standard viewing conditions. The figure 3 shows the methodology followed to execute this research work.

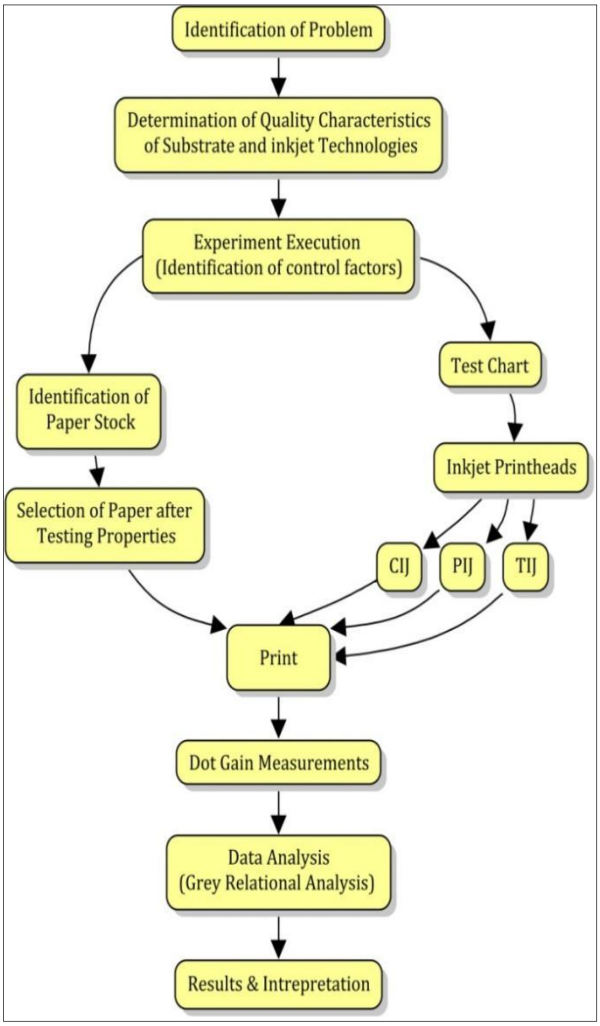

Figure 3. Research Methodology flow chart

2.1. Implementation of GRA

The GRA methods involves following steps of calculations. It involves following steps:

I. Data Preprocessing
II. Grey Relational Coefficient
III. Grey Relational Grade

IV. Performance Ranking

Step 1: Data Pre-processing

In the data pre-processing step, data is to be converted into normalized form. This conversion is to be done using equation (1) & (2) as per the requirement. If the data is, higher is better or beneficial attributes then equation (1) is to be used. If the data is, low is better or non beneficial attributes, then equation (2) is to be used accordingly.

Beneficial attributes (higher is better):

$$x_i^*(k) = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \quad \text{...... (1)}$$

Where,

$X_i{*}_I$ (k) = value obtained after the grey relational generation

min $x_i(k)$ = lowest value of $x_i(k)$ for the k^{th} response

max $x_i(k)$ = highest value of $x_i(k)$ for the k^{th} response

Non-Beneficial Attributes (Lower is better):

$$x_i^*(k) = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \quad \text{....... (2)}$$

Where,

$X_i{*}_I$ (k) = value obtained after the grey relational generation

min $x_i(k)$ = lowest value of $x_i(k)$ for the k^{th} response

max $x_i(k)$ = highest value of $x_i(k)$ for the k^{th} response

Step 2: Grey Relational Coefficient

a. Deviation Sequences: Deviation sequence can be calculated by given equation.

$$x_i^*(k) = 1 - \frac{\left| x_i^o(k) - x_i^o \right|}{\max x_i^o(k) - x_i^o}$$

.... (3)

b. Grey Relational Coefficient: The Grey relational coefficient is determined as follows:

$$\xi_i(k) = \frac{\Delta\min + \xi\Delta\max}{\Delta_{oj}(k) + \xi\Delta\max}$$

.... (4)

Where;

Distinguished Coefficient (ξ) lies in between 0 and 1. Here, we are taking its value as 0.5.

Δmin- minimum value obtained from Deviation sequence

Δmin- minimum value obtained from Deviation sequence

Δ_{0j} –absolute value difference between the target sequence and comparison sequence

Step 3: Grey Relational Grade

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k \xi_i(k) \quad \text{...... (5)}$$

Where,

n= quantification of process responses

ξi(k) = Grey relational coefficient

ω_k (k) is 1 (Weight).

Finally, collected data was analyzed with Grey Relational Analysis, interpreted and represented in meaningful way.

3. RESULTS

The calibrated x-rite eXact spectrophotometer under standard viewing condition was used to measure the dot gain values at different locations. The value of dot gain was measured at 25% dot area (Highlight side), 50% dot area (middle tone) and 75% dot area (Shadow tone) of the print image using different inkjet printheads on gloss coated papers. Table 2 has shown data of mean value (in percentage) of dot gain at 25 %, 50% & 75% dot area.

Table 2. Measured values of Tone Value Increase

Printheads	25 % Dot Area				50 % Dot Area				75 % Dot Area			
	K	C	M	Y	K	C	M	Y	K	C	M	Y
CIJ	10.49	13.66	12.60	13.60	14.18	15.58	18.63	20.48	11.68	14.79	13.56	13.85
PIJ	8.08	11.46	9.29	11.41	9.22	13.02	14.42	13.52	8.02	10.62	14.63	10.68
TIJ	9.57	12.6	11.5	12.6	11.5	18.5	17.4	17.5	9.44	11.4	11.8	11.3

		9	1	3	2	9	0	5		0	1	9

Step 1: Data preprocessing

Normalization of Data: The dot gain is the non-beneficial (low is better) attribute in print production. Therefore, data was converted into normalized form using equation (2). Table 3 has shown the normalized values of dot gain data at 25 %, 50% & 75% dot area.

Table 3. Normalized form of data shown in Table 2

Print heads	25 % Dot Area				50 % Dot Area				75 % Dot Area			
	K	C	M	Y	K	C	M	Y	K	C	M	Y
CIJ	0	0	0	0	0	0.542	0	0	0	0	0.382	0
PIJ	1	1	1	0.161	1	1	1	0.340	1	1	0	0.229
TIJ	0.382	0.441	0.329	0.071	0.537	0	0.293	0.143	0.610	0.812	1	0.177

Step 2: Calculating Grey Relational Coefficient.

a. Calculating Deviation Sequence: The value of Deviation sequence is required to calculate Grey Relational Coefficient. So, Table 4 has shown deviation sequences values using equation (3).

Table 4. Calculating Deviation Sequence

Print heads	25 % Dot Area				50 % Dot Area				75 % Dot Area			
	K	C	M	Y	K	C	M	Y	K	C	M	Y

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CIJ	1	1	1	1	1	0.458	1	1	1	1	0.618	1
PIJ	0	0	0	0.839	0	0	0	0.660	0	0	1	0.771
TIJ	0.618	0.559	0.671	0.929	0.463	1	0.707	0.857	0.390	0.188	0	0.823

b. Calculating Grey Relational Coefficient: For the purpose of calculating the Grey Relational Coefficient, the equation (4) was used. Here, the maximum value is 1, minimum value is 0 and Distinguished Coefficient (ξ) is 0.5. Table 05 has shown Grey Relational Coefficient values.

Table 5. Grey Relational Coefficient for dot gain at different dot area

Print heads	25 % Dot Area				50 % Dot Area				75 % Dot Area			
	K	C	M	Y	K	C	M	Y	K	C	M	Y
CIJ	0.333	0.333	0.333	0.333	0.333	0.522	0.333	0.333	0.333	0.333	0.447	0.333
PIJ	1	1	1	0.373	1	1	1	0.431	1	1	0.333	0.393
TIJ	0.447	0.472	0.427	0.350	0.519	0.333	0.414	0.369	0.562	0.727	1	0.378

Step 3: Calculating Grey Relational Grade (GRG)

While analyzing the dot gain print quality factors, similar value of ω_k (k) = 1 was assumed as a standard value for black, cyan, magenta and yellow inks. Now, equation (5) is used to determine the Grey Relational Grade. Table 6 has shown values obtained for grey relational grade.

Table 6. Grey Relational Grade obtained from Table 05

Printheads	25% Dot area	50% Dot area	75% Dot area
CIJ	0.444	0.507	0.482
PIJ	1.124	1.144	0.909
TIJ	0.565	0.545	0.889

Step 4: Ranking of printheads as per Grey Relational Analysis

Table 7 presents the rank of different printheads as per their performance of dot gain.

Table 7. Ranking of performance of Printheads

Printheads	25% Dot area	50% Dot area	75% Dot area
CIJ	3	3	3
PIJ	1	1	1
TIJ	2	2	2

4. DISCUSSION

The amount of dot gain is a major indicator of print quality. While it is impossible to totally get rid of, it is manageable. In Figure 4, to 7, we get a visual depiction of the data in Table 2.

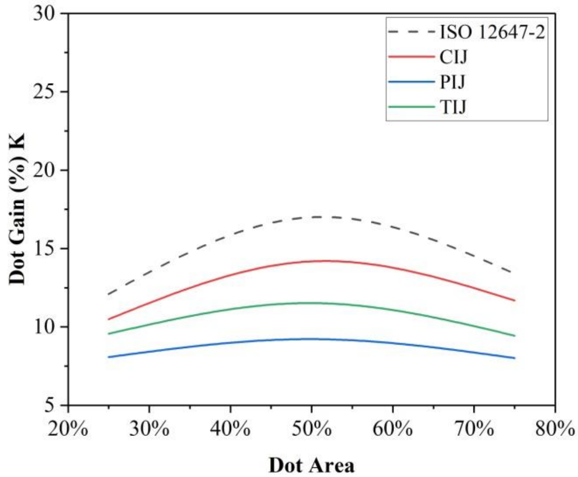

Figure 4: Dot Gain for Black ink on 90 g/m^2 gloss coated paper

Figure 4 represents the dot gain for cyan ink on 90 g/m^2 gloss coated paper at 25%, 50% and 75% dot area printed with different inkjet printheads. The dotted line represents the ISO 12647-2: 2007 white backing standard values of dot gain accepted worldwide for gloss coated paper. Here, it is shown than all three printheads gives low dot gain values for black ink. PIJ printhead gives lowest values at 25%, 50% and 75% dot areas when compare to other printheads followed by TIJ and then

CIJ. It means that dot gain is acceptable for black ink on gloss coated paper.

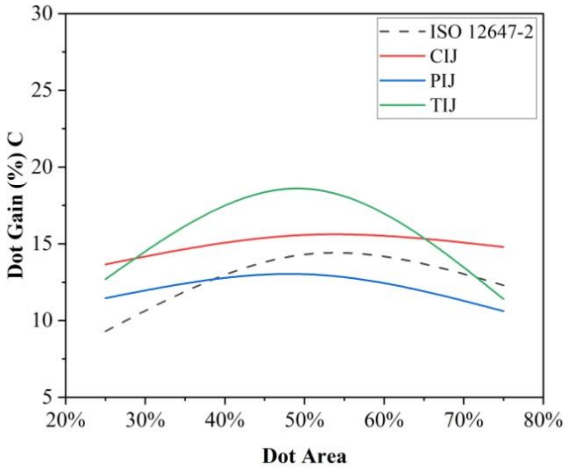

Figure 5: Dot Gain for Cyan ink on 90 g/m^2 gloss coated paper

The figure 5 shows the dot gain for cyan ink on 90 g/m^2 gloss coated paper printed with different inkjet printheads. Here, the value of dot gain for CIJ is more at 25% and 50% according to the ISO 12647-2: 2007 values but it is under below for 75% dot area. For TIJ, all dot gain values at 25%, 50% and 75% exceeds to the standard value. For PIJ, all values of dot gain at 25%, 50% and 75% is below the ISO a 12647-2 standard value which is more acceptable.

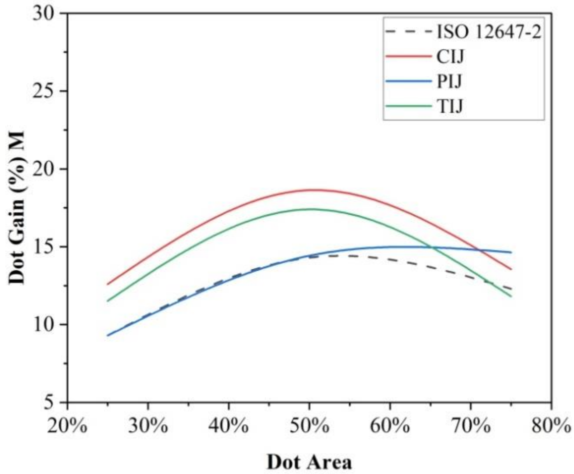

Figure 6: Dot Gain for Magenta ink on 90 g/m^2 gloss coated paper

The Figure 6 represents the dot gain values for magenta ink. The dot gain value for CIJ and TIJ is shown high at 25% and 50% than PIJ printhead. Whereas, it is vice-versa at 75% dot area. But overall PIJ performs better for magenta ink.

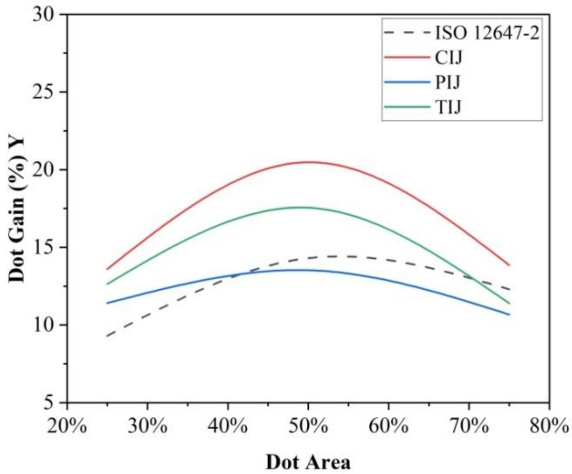

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Figure 7: Dot Gain for Yellow ink on 90 g/m^2 gloss coated paper

The Figure 7 shows the dot gain values for yellow ink. The dot gain value for all three printheads is high at 25% dot area. However, PIJ shows lowest value of dot gain amongst them. At 50% dot area, PIJ shows the lowest dot gain value and which is below the standard value. Dot gain values for CIJ and TIJ is high at 50% dot area and exceeds the standard values. At 75% dot area, the PIJ and TIJ have shown below the standard line, but the PIJ has lowest value of dot gain between these two printheads. CIJ has shown high value for dot gain at 75% which exceeds the standard line. The overall PIJ has shown the lowest value of dot gain for yellow ink.

This demonstrates that, in general, PIJ has lower dot gain values than other inkjet printheads. Taguchi's Grey Relational Analysis approach provides confirmation of this, by placing at PIJ first, TIJ second and CIJ at third. Since droplets in CIJ travels at such a high speed, they may penetrate deeply into the paper and result in a great deal of dot gain. . In thermal inkjet (TIJ), droplets are expelled from nozzles using a heat mechanism, which means that they may be very hot and hence penetrate the paper material. In case of PIJ, the zirconate titanate (commonly used) crystal experiences a piezoelectric effect when an electric current is sent through it. Since no heat is used, the drop velocity may be precisely regulated, may reduce the dot gain in the gloss coated paper stocks.

5. CONCLUSIONS:

From the results of the aforementioned study, it has been shown that dot gain occurs when gloss coated paper printed with inkjet printheads namely CIJ, PIJ and TIJ. Therefore, the hypothesis (i) gets true which stated that dot gain occurs when gloss coated paper printed with different inkjet printheads. It was determined that hypothesis (ii) printhead piezoelectric inkjet printhead, had superior performance at 25%, 50%, and 75% dot regions. With a ranking of 2, thermal inkjet printheads perform better than CIJ but lower than piezoelectric inkjet printheads. When it comes to dot gain, CIJ ranks third in terms of performance and score. Although other factors like type of ink, ink viscosity, speed of drop ejaculation, resolution, and paper –ink interactions is to be taken care while selecting one of these printheads when print to be done on gloss coated papers. When it comes to examining the many elements that affect print quality, hypothesis (iii) the Grey Relational Analysis is the most trustworthy statistical tool available. The printing industry may utilize it as a reliable resource for decision-making of best choice in terms of print quality and other parameters of the printing press.

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Conflicts of Interest

There authors declare no conflicts of interest.

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