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Colour Characteristics of Alginate-Based Screen Prints Incorporating Aronia Pomace Extract and ZnO

ABSTRACT

*The incorporation of zinc oxide (ZnO) into bio-based printing formulations offers the potential to introduce additional functionality, while its presence may also influence the optical properties and colour development of the resulting prints. This study examined the colour development of halftone and solid screen prints produced on cotton fabric using a sodium alginate-based printing paste containing aronia pomace extract and ZnO. Printing was performed using a screen with a mesh count of 32 threads cm^{-1}. Prints with a nominal tonal value of 50% and solid prints were produced using one to five successive passes. The prints were evaluated using CIE L*a*b* colour coordinates, while colour differences relative to the unprinted cotton substrate were calculated using the CIEDE2000 formula. K/S values were calculated according to the Kubelka-Munk equation. For the halftone prints, increasing the number of passes resulted in a gradual decrease in L*, while ΔE_{00} increased from 3.97 to 9.60 and the hue angle shifted towards red. The K/S value generally increased from 2.22 to 2.55. In solid print areas, the most pronounced reduction in lightness occurred between the first and second pass, after which the hue angle remained relatively stable. The lowest L* value (59.87), the highest ΔE_{00} (19.40) and the highest K/S value (3.90) were obtained after four passes. Applying a fifth pass did not improve the optical response of the solid print. These findings indicate that the number of successive passes influences both colour strength and hue development, with four passes providing the strongest colour response in solid print areas under the investigated printing conditions.*

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KEY WORDS
Aronia pomace, zinc oxide, screen printing, colour strength, halftone printing

1. Introduction

The growing interest in more sustainable textile coloration has encouraged the investigation of natural colourants obtained from renewable resources and agro-industrial by-products. Fruit pomace generated during juice production represents a potentially valuable secondary raw material because considerable amounts of coloured and biologically active compounds may remain in the solid residue after processing (Cucuiet et al., 2026). Recovering these compounds can contribute to waste valorisation while providing alternative colour sources for textile applications (Ružičić et al., 2025).

Black chokeberry (aronia) (*Aronia melanocarpa*) is characterised by a high content of polyphenolic compounds, particularly anthocyanins responsible for its intense red-purple colour. A considerable proportion of these compounds may remain in the pomace after juice extraction, making this by-product a suitable source of natural colourants (Ren et al., 2022). Previous studies have demonstrated the recovery of anthocy-

anins from aronia pomace and its potential application in coloured films and textile materials. However, anthocyanin-based colour systems are sensitive to formulation and processing conditions, which can affect their final hue, lightness and colour strength (Wathon et al., 2019; Hong, 2024; Ugrinović et al., 2025).

Zinc oxide (ZnO) is widely used in textile treatments as a functional inorganic additive due to its potential to provide UV-protective and antimicrobial properties (Li et al., 2012; Kumar et al., 2014). When incorporated into a printing formulation, ZnO may also contribute to the optical response of the resulting print (Lima Lorusso Sampaio et al., 2026). Combining ZnO with a natural colourant obtained from aronia pomace therefore provides a basis for developing coloured textile prints with potential additional functionality. In the present study, the colour characteristics of this formulation were investigated in relation to the number of successive printing passes and the nominal tonal value.

In screen printing, the amount and distribution of paste transferred to the substrate influence the appearance and performance of the resulting print. Ink or paste deposition is affected by the printing formulation, screen characteristics and process parameters, while the deposited amount is directly related to colour strength in conventional printing (Ali et al., 2019). Repeated printing passes can increase the amount of transferred paste, but their effect may differ between halftone and solid areas because these areas differ in nominal surface coverage and interaction with the textile structure. Furthermore, additional passes may not produce proportional colour development once the printed area has received a sufficient deposit.

Accordingly, the aim of this study was to investigate the effect of one to five successive printing passes on the colour characteristics of 50% halftone and solid screen prints produced on cotton fabric using a sodium alginate-based paste incorporating aronia pomace extract and ZnO.

2. Materials and methods

2.1. Materials

A plain-weave cotton fabric with a surface mass of 123.36 g m^{-2} and thread densities of 23 threads cm^{-1} in the warp direction and 21 threads cm^{-1} in the weft direction was used as the printing substrate. Modified sodium alginate (CHT-NV, CHT Germany GmbH) was used as the thickening agent, while zinc oxide (ZnO, Sigma Aldrich, USA) and aronia pomace extract were used to prepare the printing paste.

Aronia pomace was extracted with 80% methanol by maceration for 24 h, followed by ultrasonication for 18 min and filtration. The pomace was subsequently re-extracted with fresh 80% methanol by repeating the same maceration, ultrasonication and filtration procedure. The combined filtrates were concentrated under reduced pressure using a rotary evaporator at 40 °C, transferred to Petri dishes and dried to constant mass at 50 °C. The dried extract was then redissolved in 60% methanol to obtain a concentration of 200 mg mL^{-1}.

The sodium alginate-based printing paste was prepared by dispersing 6 g of modified alginate in 69 mL of distilled water at room temperature under continuous stirring until homogeneous. Subsequently, 25 mL of the aronia pomace extract and 0.3 g of ZnO were incorporated into the alginate paste and mixed until a homogeneous formulation was obtained.

Printing was performed using a semi-automatic Screenprinter S-300 at a speed of 0.08 m s^{-1} and a constant squeegee pressure. A screen with a mesh count of 32 threads cm^{-1} was used, and the printing form contained a halftone area with a nominal tonal value of 50% and a solid area. Both areas were printed using one to five successive passes without intermediate drying. After printing, the samples were dried in an oven at 45 °C. The samples were designated H1-H5 for the halftone prints with a nominal tonal value of 50% and S1-S5 for the solid prints, where the numbers indicate the number of successive printing passes.

2.2. Colour measurement

The colour characteristics of the unprinted cotton substrate and the printed samples were measured using a Konica Minolta CM-2600d spectrophotometer. Measurements were performed using illuminant D65, a 10° standard observer, d/8 measurement geometry, an 11 mm measurement aperture and the specular component included (SCI) mode. Spectral reflectance was recorded over the wavelength range from 360 to 740 nm at 10 nm intervals. Each sample was measured five times, and the mean values were used for further analysis. Colour was expressed using the CIE L*a*b* coordinates, chroma (C*) and hue angle (h°).

Colour differences between the printed samples and the unprinted cotton substrate were calculated using the CIEDE2000 formula (Luo, Cui & Rigg, 2001). Parametric factors of kL = 2 and kC = kH = 1 were applied to account for the textured surface of the textile substrate (Mirjalili et al., 2019). Colour strength was calculated from the measured reflectance according to the Kubelka-Munk equation (1):

$$K/S = \frac{(1-R)^2}{2R} \quad (1)$$

where R is the decimal reflectance, K is the absorption coefficient and S is the scattering coefficient. The K/S values were determined at 360 nm, corresponding to the lowest reflectance within the measured spectral range (Kašiković, 2012).

3. Results and discussion

The colour characteristics of the printed samples were evaluated to determine how the number of successive printing passes affected colour development in the halftone and solid areas. The visual appearance of the samples and the corresponding CIE L*a*b* coordinates, chroma (C*), hue angle (h°), colour difference relative to the unprinted cotton substrate (ΔE_{00}) and colour strength (K/S) are presented in Table 1. The results show that the optical response depended on both the number of printing passes and the nominal tonal value of the printed area.

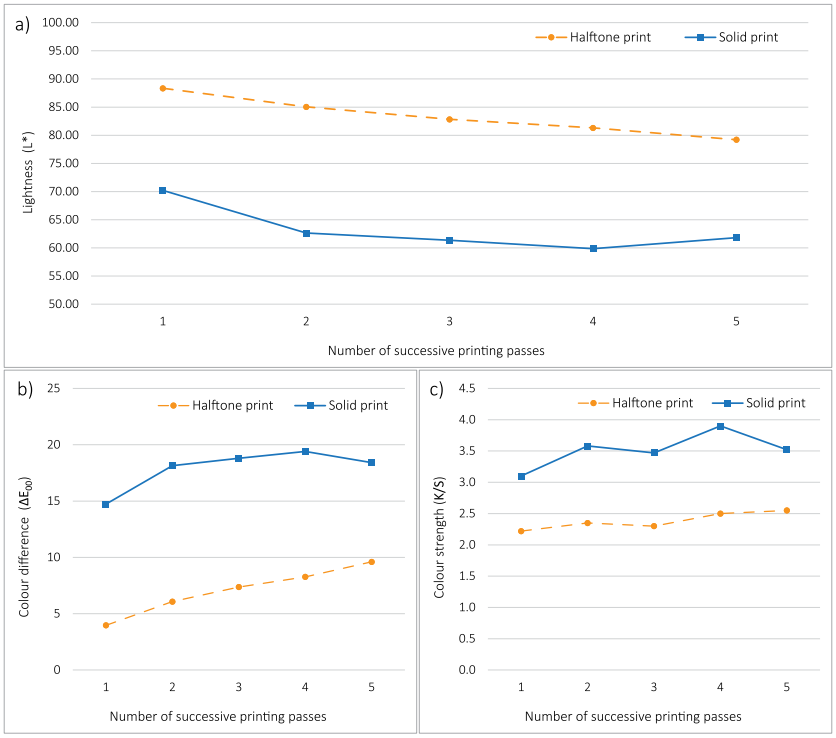
All printed samples were positioned in the positive a* and negative b* regions of the CIE L*a*b* colour space, confirming the presence of combined red and blue colour components. Accordingly, the prints exhibited purple to red-purple shades rather than a purely red colour. The halftone prints had hue angles ranging from 293.76° to 309.55°, indicating a transition from a more bluish-purple shade towards a redder purple shade as the number of passes increased. The solid prints showed higher hue angles, ranging from 321.67° to 331.62°, and therefore exhibited a more pronounced red-purple

Table 1

Colourimetric characteristics and colour strength of halftone and solid screen prints produced using one to five successive printing passes

	Sample images	L*	a*	b*	C*	h°	ΔE_{00} reference unprinted	K/S 360 nm
Unprinted cotton		93.77	2.50	-12.09	12.35	281.68	-	-
H1		88.34	5.39	-12.25	13.39	293.76	3.97	2.22
H2		85.04	6.99	-12.28	14.13	299.66	6.07	2.35
H3		82.83	7.89	-11.78	14.18	303.81	7.37	2.30
H4		81.31	8.67	-11.96	14.77	305.95	8.27	2.50
H5		79.21	9.82	-11.89	15.42	309.55	9.60	2.55
S1		70.22	14.66	-11.59	18.69	321.67	14.73	3.10
S2		62.64	17.26	-10.21	20.05	329.39	18.14	3.58
S3		61.37	17.82	-9.81	20.35	331.16	18.80	3.47
S4		59.87	18.31	-9.89	20.81	331.62	19.40	3.90
S5		61.83	17.13	-9.59	19.63	330.76	18.41	3.52

Note: H – 50% halftone print; S – solid print; numbers 1–5 indicate the number of successive printing passes.



» **Figure 1:** Effect of the number of successive printing passes on: (a) lightness (L*), (b) colour difference relative to the unprinted cotton substrate (ΔE_{00}), and (c) colour strength (K/S) of the halftone and solid prints

character. After the second pass, only minor variations in the hue angle of the solid prints were observed, indicating that subsequent passes primarily affected colour intensity rather than the general colour tone.

In the halftone areas with a nominal tonal value of 50%, increasing the number of passes produced a progressive reduction in lightness. The L* value decreased from 88.34 after one pass to 79.21 after five passes, indicating a gradual darkening of the print. At the same time, the a* coordinate increased from 5.39 to 9.82, whereas the b* coordinate remained comparatively stable. This shows that the increase in the number of passes primarily strengthened the red component of the printed colour, rather than producing a comparable change along the blue-yellow axis. This development was also reflected in the increase in chroma from 13.39 to 15.42 and the shift in hue angle from 293.76° to 309.55°, corresponding to a transition from a more bluish-violet appearance towards a redder purple shade.

The colour difference between the halftone prints and the unprinted cotton substrate increased consistently with each successive pass. The ΔE_{00} value increased from 3.97 after one pass to 9.60 after five passes, demonstrating that each additional pass increased the visual distinction between the print and the substrate. The K/S value showed a generally similar tendency, increasing from 2.22 to 2.55, although a slight decrease was observed after the third pass. The relatively small variation in K/S compared with the more pronounced change in L* and ΔE_{00} suggests that the optical development of the halftone areas was influenced not only by increased absorption but also by the changing contribution of the exposed cotton substrate and the progressive deposition of paste within the screened area.

Solid print areas exhibited a more pronounced colour response than the corresponding halftone areas. After only one pass, the solid print had an L* value of 70.22 and a ΔE_{00} value of 14.73. The greatest change in lightness occurred between the first and second passes, when L* decreased to 62.64 and ΔE_{00} increased to 18.14. Further passes produced smaller and non-linear changes. The lowest lightness, highest chroma, highest colour difference and highest K/S value were obtained after four passes. These concurrent values indicate that the four-pass solid print produced the strongest overall colour response under the investigated printing conditions.

Applying a fifth pass did not further enhance the solid print. Instead, L* increased, while a*, C*, ΔE_{00} and K/S decreased. Because the passes were applied successively without intermediate drying, the additional wet-on-wet application may have altered the distribution or penetration of the printing paste rather than simply increasing the deposited colourant. However, without direct measurements of paste add-on or penetration, this explanation should be regarded as a possible mechanism rather than a confirmed cause. The result nevertheless shows that a greater number of printing passes did not necessarily produce a stronger colour

response and that four passes were more effective than five for the solid print under the applied conditions.

The hue angle of the solid prints increased from 321.67° after the first pass to 329.39° after the second pass and subsequently remained within a narrow range of approximately 329-332°. This indicates that the principal hue development occurred during the first two passes, whereas subsequent applications mainly affected lightness, chroma and colour strength. Overall, the results demonstrate that successive printing altered both the intensity and hue of the prints, but the magnitude and pattern of these changes differed between the halftone and solid areas.

A direct comparison of the two printed areas shows that the solid prints consistently exhibited lower L* and higher C*, ΔE00 and K/S values than the corresponding halftone prints. This difference reflects the greater proportion of the substrate covered by the printing paste in the solid areas. However, while the colour response of the halftone prints continued to develop up to the fifth pass, the solid prints reached their strongest response after four passes. Under the investigated conditions, the fifth pass therefore increased the processing effort without producing an additional improvement in the colour characteristics of the solid print.

The visual appearance of the samples was consistent with the measured colour parameters, showing progressive colour development in the halftone areas and smaller differences among the solid prints produced with three to five passes.

4. Conclusions

This study demonstrated that the number of successive printing passes influenced the colour characteristics of both halftone and solid screen prints produced on cotton fabric using a sodium alginate-based paste incorporating aronia pomace extract and ZnO. In the 50% halftone areas, successive passes produced gradual colour development and shifted the obtained purple shade towards a more pronounced red-purple tone. In the solid areas, the most pronounced colour development occurred during the initial passes, while the strongest overall optical response was obtained after four passes. This sample exhibited the lowest L* value and the highest C*, ΔE_{00} and K/S values.

Applying a fifth pass did not further improve the colour characteristics of the solid print, indicating that increasing the number of passes beyond a certain point does not necessarily enhance colour development. Under the investigated printing conditions, four successive passes provided the most effective colour response in the solid area, whereas the halftone area continued to develop gradually up to the fifth pass. These findings confirm that the number of printing passes should be considered in relation to the nominal tonal value when controlling the appearance of bio-based textile screen prints.

Further research should examine the relationship between the number of passes, actual surface coverage and paste deposition, as well as the functional properties and durability of the resulting prints.

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