Comparison, Evaluation and Development of Bio-Based Screen-Printing Inks

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Abstract

Screen printing is a well-established printing technique that typically uses petrochemical inks, which can be problematic both for the environment and recycling. This study investigates the development and characterization of bio-based screen-printing inks as a sustainable alternative. Various bio-based inks using materials such as starch, chitosan and cellulose were formulated, and their viscosity was analyzed using a rotational rheometer. The print quality was examined by screen printing tests on various substrates and subsequent visual and color density assessment. Rubbing fastness and light fastness were determined using a crockmeter resp. xenon light.
The results show that the print quality is only slightly dependent on the viscosity, although there is an optimum viscosity range. A higher polymer concentration in the ink led to a slightly improved resistance to rubbing, while the light fastness was exclusively influenced by the pigment used. Several bio-based formulations showed equivalent or better print quality than the petrochemical reference ink, especially in terms of edge sharpness.
These findings highlight the potential of bio-based screen-printing inks for a more environmentally friendly printing industry. The study shows that sustainable formulations with renewable raw materials are a promising alternative to conventional inks.

Keywords: Screen-printing, bio-based inks, sustainability, viscosity, rubbing fastness, light fastness

1. Introduction

Screen printing is widely used, particularly for textiles and graphics. However, the printing inks usually consist of petrochemical components that pose environmental and recycling challenges. In particular Mineral Oil Aromatic Hydrocarbons (MOAH), which have been identified in recycled paper, can be potentially harmful to health (Wagner and Oellig 2019).
One promising approach to reduce this environmental impact is the use of bio-based screen-printing inks. While paper made from alternative renewable resources such as grass fibers is already established as a printing material, there is a lack of sustainable inks that do not require petroleum. Waste products such as chitosan are of particular interest here, as they do not compete with foods (Behr and Seidensticker 2018).
This work investigates the development and characterization of bio-based screen-printing inks based on natural polymers such as starch, chitosan and cellulose. The aim is to analyze the

rheological properties and evaluate their processability in screen printing. In addition, the visual appearance, rubbing fastness and light fastness will be tested to evaluate the potential of these inks as a sustainable alternative to conventional screen-printing inks.

2. Materials and methods

Three different bio-based screen-printing inks were produced (see section 2.1) and characterized, with a conventional screen-printing ink (*Papyroprint Black*, Siebdruckversand, Magdeburg, Germany) used for comparison (abbreviated with "Ref" as reference). These were then characterized regarding their rheology (see chapter 2.2) and printed on different substrates using screen printing. The print result was examined visually and in terms of color density as well as rubbing fastness and light fastness (see section 2.3).

Table 1: Recipe for the bio-based ink formulation A (binder without pigment) according to M. Kahn, which is mainly composed of common household food ingredients and food additives (with indication of the E number) (Kahn 2023).

Ingredient	Quantity		Manufacturer/supplier
Flour-water suspension			
Demineralized water	39.0	ml	
Acetic acid (diluted to 2% V/V)	32.5	ml	Th. Geyer, Renningen, Germany
Wheat flour (T405)	8.5	g	Aurora, Hamburg, Germany
Starch-water suspension			
Corn starch	1.8	g	Mondamin/Unilever, Hamburg, Germany
Demineralized water	6.5	ml	
Powdered sugar	1.4	g	Südzucker, Mannheim, Germany
Honey	0.4	ml	Langnese, Bargteheide, Germany
Apple pectin	0.5	g	Eurovera, Ober-Mörlen, Germany
Preservative mixture			
Common salt (NaCl)	4.1	g	Bad Reichenhaller, Heilbronn, Germany
Citric acid (E330, $C_6H_8O_7$)	1.4	g	Purux, Laaber, Germany
Sodium benzoate (E211, C_6H_5COONa)	0.5	g	Sigma-Aldrich, St. Louis, United States
Sodium nitrate (E251, $NaNO_3$)	1.6	g	Carl Roth, Karlsruhe, Germany
Potassium nitrate (E252, KNO_3)	0.5	g	Carl Roth, Karlsruhe, Germany
Aluminium sulfate (E520, $Al_2(SO_4)_3$)	1.4	g	Carl Roth, Karlsruhe, Germany
Total mass without pigment	**100.0**	**g**	

2.1 Preparation of bio-based inks

The preparation of the bio-based colors always takes place in a water bath (*W16*, Harry Gestigkeit, Düsseldorf, Germany) with a stirrer (*DLH*, Velp Scientifica, Usmate, Italy) attached on top. Temperatures are measured either in the water bath or in the beaker (Type K thermocouple), which is noted in the respective sections. The inks are stored in the refrigerator.

2.1.1 Bio-based ink formulation A (according to M. Kahn)

Recipe A is a formulation by the artist Maurice Kahn (The Israel Museum 2025). Conventional petrochemical screen-printing inks caused him to experience health issues. This prompted him to develop a starch-based formulation to replace the harmful ingredients (Palestrant 2017). The recipe (Kahn 2023) was slightly adapted, e.g. acetic acid was used instead of household vinegar, resulting in the composition listed in Table 1.

First, the flour-water suspension (as listed in Table 1) is prepared while stirring (450 rpm) by gradually adding the flour to the pre-mixed liquids. The heating plate is set to a target temperature of 85 °C. At a measured temperature of 80 °C of the water bath (after ~20 minutes), the flour-

water suspension thickens. The previously mixed starch-water suspension is now added at 600 rpm and stirred for 4 minutes. Stirring speed is then increased to 900 rpm, a mixture of pectin and sugar and the honey are added and stirred for a further 6 minutes. After this time, the previously prepared preservative mixture is added and stirred for two minutes at 1000 rpm.

2.1.1 Bio-based ink formulation B (according to G. Bubenik)

Recipe B originates from the artist Gernot Bubenik, who developed a bio-based screen printing ink in the 1980s and 1990s as part of the ecological workshop he founded (Bubenik 2025). The recipe has been slightly modified so that the originally volumetric values are given as mass (Pietzcker 2025).

The cellulose glue and the shellac wax soap are prepared first. The cellulose glue is preferably prepared one day before the ink is produced by gradually adding Tylose to cold water while stirring (450 rpm). The speed is then increased to 1000 rpm. As soon as a white, viscous mass has formed, the prepared glue is left to sit in the refrigerator for at least 12 hours.

Table 2: Recipe for the bio-based ink B (binder without pigment) according to G. Bubenik (Pietzcker 2025). Ingredients marked with an asterisk (*) are changed as part of the variations (see 2.1.1, the quantities below correspond to S9).

Ingredient	Quantity		Manufacturer/supplier
Starch-water suspension			
Demineralized water	60.2	ml	
Corn starch	9.8	g	Mondamin/Unilever, Hamburg, Germany
Cellulose glue			
Tylose MH 300 P2	0.48	g	Kremer Pigmente, Aichstetten, Germany
Demineralized water	11.52	ml	
Shellac soap *			
Shellac Wax, bleached	1.8	g	Kremer Pigmente, Aichstetten, Germany
Demineralized water	4.6	ml	
Marseille Soap, needles	2.6	g	Kremer Pigmente, Aichstetten, Germany
Gelatin/water mix			
Gelatin G1890	0.6	g	Sigma-Aldrich, Schwerte. Germany
Demineralized water	6.0	ml	
Glycerin 86 %	2.4	ml	Kremer Pigmente, Aichstetten, Germany
Clove oil	2	gtts	Kremer Pigmente, Aichstetten, Germany
Total mass without pigment	**100,0**	**g**	

To make shellac wax soap, boiling water is first added to the Marseille soap. It is stirred by hand with a stirring rod or spoon. The dissolved soap is then placed in a water bath at 95° and the shellac wax is added while stirring constantly. After ~12 minutes, a homogeneous mass has formed. It is crucial that the consistency is smooth and without lumps.

To produce the binder, the water bath is set to a target temperature of 90 °C. As soon as the water bath has reached this temperature, the pre-mixed starch-water suspension is placed in the beaker and stirred at 450 rpm for ~ 5 minutes until the starch starts to set.

The shellac wax soap is added and stirred at 750 rpm for a further 5 minutes. Meanwhile, the gelatine/water mix is prepared so that the gelatine can swell. The paste is removed from the water bath and stirred at 1000 rpm for a further 3 minutes. The glycerin is then added. When the paste has cooled to 70 °C under steady stirring, the gelatine/water mix is added. At a paste temperature of 60 °C, the cellulose glue and the clove oil (as a natural fungicide) are added and stirred for another 5 minutes. The detailed quantities can be found in Table 2.

2.1.1 Bio-based ink formulation C (originating from the authors)

Recipe C was determined iteratively by the authors through preliminary tests. Comparable formulations using chitosan, some of them for textile applications (Abdou *et al.* 2013, Zhang *et al.* 2016, Rondanini 2019), did not perform satisfactorily in preliminary tests, which is why the formulation listed in Table 3 was developed.

Preparation takes place in a water bath. Chitosan is added to the water at room temperature and stirred at 450 rpm. The water bath is set to 90 °C. As soon as the chitosan solution reaches 40 °C (after 8-9 minutes), the 3% (V/V) acetic acid is added. The starch-water suspension is prepared separately. When the chitosan solution reaches 75 °C, half of the starch-water suspension is added, and the process continues at 600 rpm. At 77 °C (~5 minutes later), the rest of the starch-water suspension is added. At 79 °C (~5 minutes later), Methocel is added and stirred at 800 rpm for one minute. The paste is removed from the water bath and allowed to cool at room temperature for 15 minutes while stirring. The detailed quantities can be found in Table 3.

Table 3: Recipe for the bio-based ink C (binder without pigment). Ingredients marked with an asterisk (*) are changed as part of the variations (see 2.1.1, the quantities below correspond to C1).

Ingredient	Quantity		Manufacturer/supplier
Chitosan-solution			
Demineralized water	29.6	ml	
Chitosan, M.W. 600,000-800,000 Da *	1.0	g	Fisher Scientific. Schwerte, Germany
Acetic acid (diluted to 3% V/V)	29.6	ml	Th. Geyer, Renningen, Germany
Starch-water suspension			
Demineralized water	29.6	ml	
Corn starch	10.0	g	Mondamin/Unilever, Hamburg, Germany
Methocel A4M	0.2	g	Kremer Pigmente, Aichstetten, Germany
Total mass without pigment	**100,0**	**g**	

2.1.1 Variations during ink development

As binders without pigment have been prepared, formulation A is used to determine a suitable pigment content. Iron oxide Black *318* (Kremer Pigmente, Aichstetten, Germany) is used as pigment. Pigment contents of 0 (binder only), 10, 12.5 and 15 % w/w are added and investigated (abbreviations P0, P10, P12.5, P15). Formulation B is tested for different proportions of shellac wax soap. The shellac wax soap was varied with 3, 6 and 9 % w/w (S3, S6, S9). In formulation C, the chitosan content is varied with 1, 2 and 3 % w/w (C1, C2, C3). In addition, the suitability of a pigment based on algae was tested in a further preliminary study (see 3.4).

2.2 Ink characterization

A rotational rheometer (*KINEXUS Lab+*, Malvern Panalytical, Malvern, UK) with a plate-plate configuration (plate diameter 40 mm, gap 200 µm) was used to measure the viscosity characteristics. The sample volume is 0.3 ml, the sample temperature is 25 °C. The range of shear rates considered relevant is from 0.1 1/s (leveling the ink) to 1000 1/s (flooding) to around 2500 1/s (printing). To be able to represent higher printing speeds, tests were carried out in the range from 0.1 1/s to 6000 1/s. Four measuring points were recorded per decade.

2.3 Screen printing and evaluation

The inks were applied using a screen-printing machine (*K15Q SL*, Kammann, Löhne, Germany) with a 77-55Y screen (squeegee velocity 0.1 m/s). The substrate used was always gray cardboard (*GKH* 300g/m^2, Igepa, Hamburg, Germany), except for the variation examined in 3.4. In this case *GKH* was tested as well as *Max White Cotton* (300 g/m^2, Gmund, Gmund am Tegernsee, Germany, abbreviated to "MWC") and *California Duo* (450 g/m^2, IGEPA, Hamburg, Germany, abbreviated to "CD").

The visual assessment was carried out using images obtained with a microscope (VR-5200, Keyence, Osaka, Japan). The optical density for black was measured using a densitometer (*SpectroDens Premium*, Techkon, Königstein, Germany) An average of five measurements was calculated. Rubbing resistance was tested in accordance with DIN EN ISO 105-A03:2019 using a crockmeter (*M238BB*, SDL Atlas, Rock Hill, USA) Three measurements were averaged. The light fastness was determined using a sunlight weathering device (*Suntest XLS+,* Atlas MTS, Mount Prospect, USA) under xenon light and an irradiance of 42 W/m^2 and compared with a blue wool reference.

3. Results and discussion

3.1 Formulation A

Formulation A was tested for different pigment contents and compared with the reference ink; the results are summarized in Figure 1. The viscosity of formulation A without pigment is always below the reference; when pigment is added, there is a large overlap along the curve of viscosity. The viscosity increases with higher pigment content. In a shear rate range from 0.1 1/s to around 10 1/s, small differences in viscosity between the pigment proportions are measurable; beyond this, the deviation is negligible. This may be due to the separation of possible pigment agglomerates caused by higher shear rates (Mezger 2016). The visual evaluation (Fig. 1, right) shows the best edge sharpness for P10 and surpasses the commercial reference in this respect. The color density for black, rubbing fastness and light fastness can be found in Table 4. The color density increases with increasing pigment content; however, it does not reach the commercial reference. An optical density of 1.28 is achieved for the best formulation in terms of edge sharpness (P10). The rubbing fastness for all bio-based formulations is also below the commercial reference of 4 with 2-3. The light fastness reaches 8 in all cases and is on a par with the reference. In general, the visual print result can be considered better than that of the reference ink.

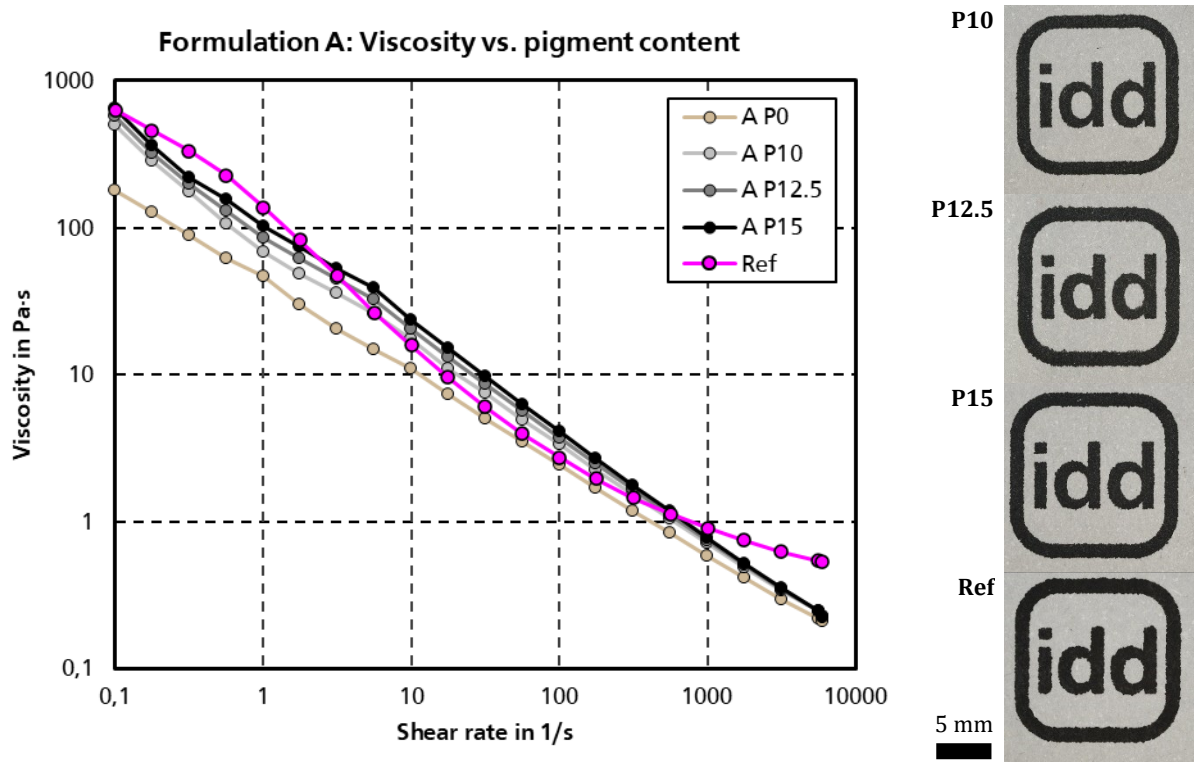


Figure 1: Comparison of formulation A in relation to the pigment content with the reference. Left: Viscosity vs. shear rate; right: Visual assessment of print quality.

3.2 Formulation B

Formulation B was characterized for different proportions of shellac wax soap, the results can be seen in Figure 2. It is noticeable that in the low shear rate range, an increasing content of shellac wax soap leads to an increase in viscosity. In the higher shear rate range, this effect is less noticeable and can no longer be detected above approx. 1000 1/s. Compared to the reference, the viscosity of formulation B is lower than that of the commercial reference up to approx. 10 1/s. The rubbing resistance decreases with increasing content of shellac wax soap (from 4 to 3), with S3 being on a par with the reference. However, when assessing the visual quality, the latter shows significantly inferior properties: the lower opacity is noticeable, which is confirmed by a optical density of 1.01 (see Table 4). The edge sharpness is best for S6, but less crisp than that of the reference. Due to the lack of opacity and the yellowing of the substrate the measured light fastness values are lower than those of the reference (7 vs. 8). Formulation B in general performs inferior to the commercial reference, especially in terms of visual appearance – except for rubbing fastness.

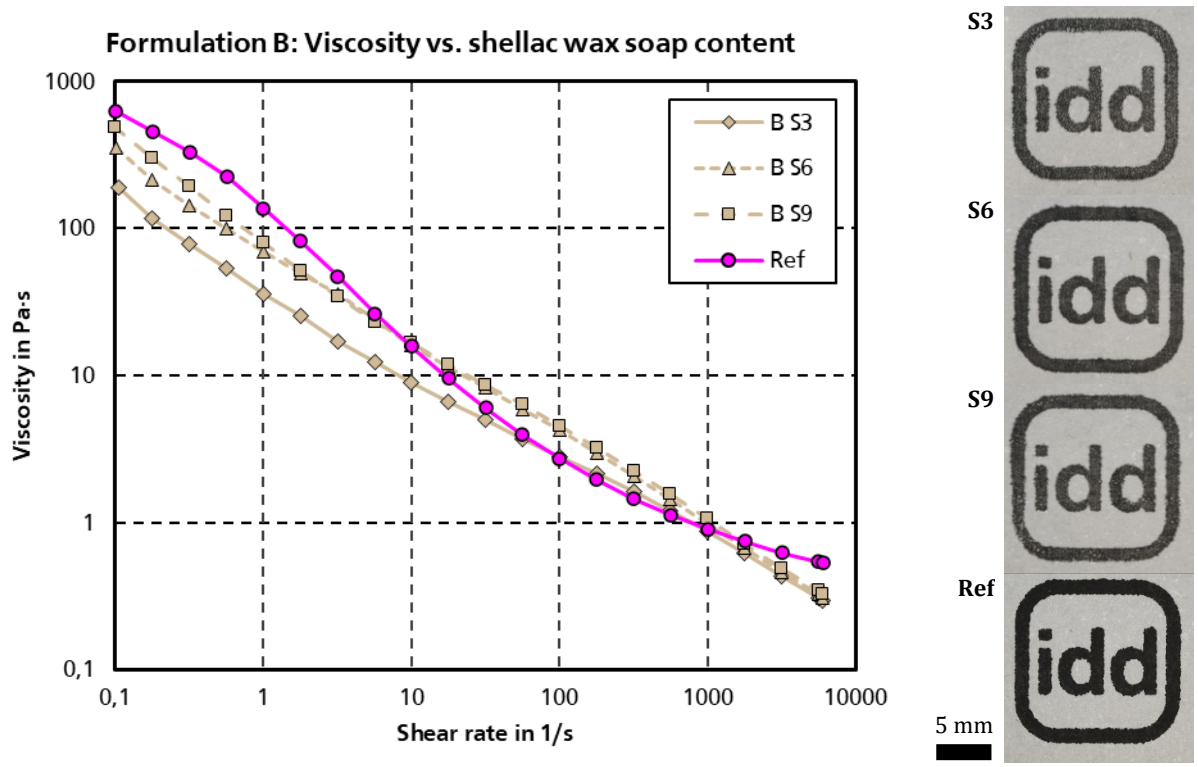


Figure 2: Comparison of formulation B in relation to the shellac wax soap content with the reference. Left: Viscosity vs. shear rate; right: Visual assessment of print quality.

3.3 Formulation C

Different proportions of chitosan were tested with formulation C. The viscosity as a function of the shear rate differs only slightly for C1 and C2; with a further increase in the chitosan content of 3 % (C3), the viscosity increases noticeably over the entire shear rate range, which can be seen in Fig. 3. The visual assessment of the print appearance for C1 shows the sharpest edges and outperforms the commercial reference. As the chitosan content increases, the edges become less crisp, but the rubbing fastness and optical density increase. The light fastness is excellent in all cases (see Table 4). Formulation C is below the commercial reference in terms of the measured values for rubbing fastness and optical density, but the visual quality of the printed result compared to the reference as well as to A and B can be considered as better or very good.

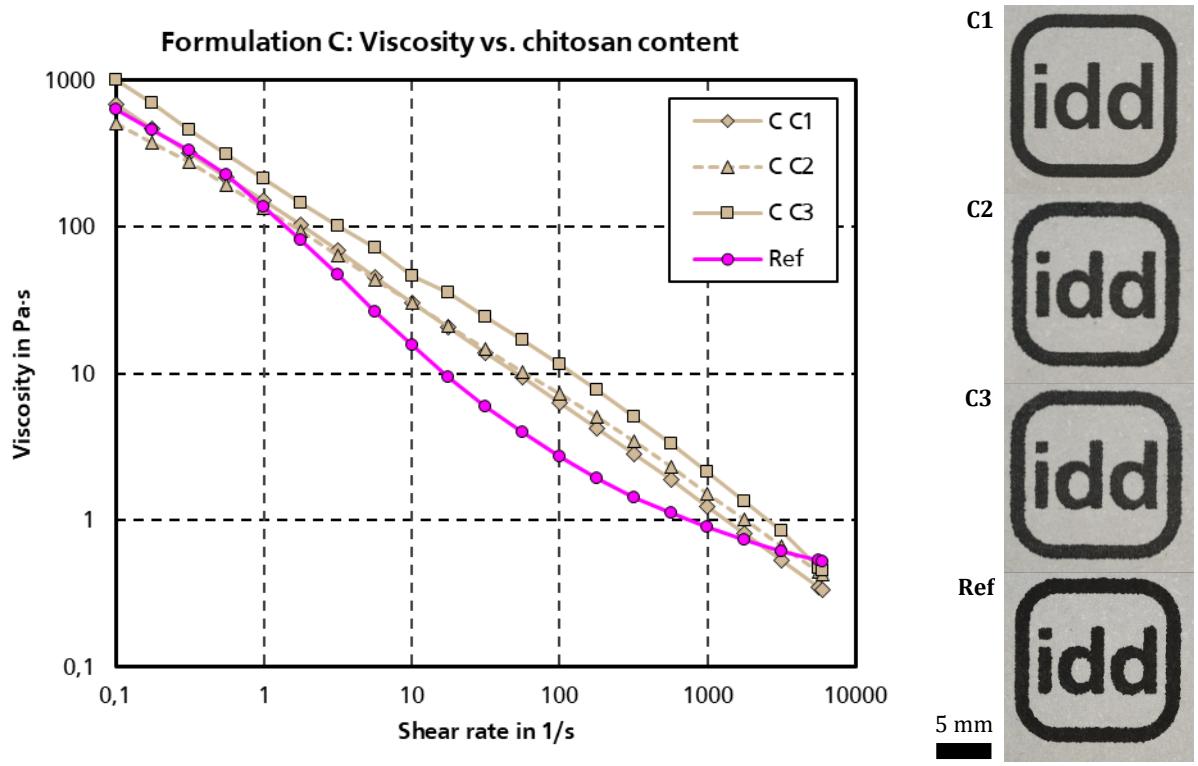
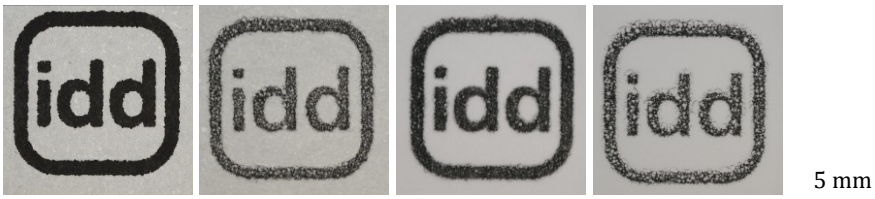


Figure 3: Comparison of formulation C in relation to the chitosan content with the reference. Left: Viscosity vs. shear rate; right: Visual assessment of print quality.

3.4 Outlook: Pigment and substrate

In addition to the iron oxide black, the suitability of a bio-based pigment (*Algae Black Pigment Grade 4*, Living Ink, Berthoud, USA) with a principally CO_2-negative footprint was also investigated with formulation C. The opacity of the pigment used proved to be insufficient with the previously used 10% (w/w), which is why the proportion was increased to 30% (w/w). Compared to the formulations with iron oxide black, the edge sharpness (see Fig. 4) and opacity (optical density 0.93, see Table 4) are insufficient. It was also investigated whether changing the substrate would improve the quality, but Figure 4 shows no significant improvement here either.



Substrate: FKH Ink: Ref | **Substrate: GKH Ink: C Algae 30%** | **Substrate: MWC Ink: C Algae 30%** | **Substrate: CD Ink: C Algae 30%**

Figure 4: Comparison of formulation C with 30% Algae Black Pigment on different substrates.

Table 4: Comparison of optical density, rubbing fastness and light fastness for the formulations presented. Rubbing fastness ranges from 1 (poor) to 5 (good), the light fastness is indicated according to the blue wool scale with 1 (poor) to 8 (excellent).

Formulation	Optical density	Rubbing fastness	Light fastness
Ref	1.55	4.0	8
A P10	1.28	3.0	8
A P12.5	1.37	2.5	8
A P15	1.40	2.0	8
B S3	1.01	4.0	7
B S6	1.05	3.5	7
B S9	1.09	3.0	7
C C1	1.26	2.0	8
C C2	1.31	3.0	8
C C3	1.32	3.5	8
C Algae 30%	0.93	not investigated	not investigated

4. Conclusions

In terms of viscosity, formulations A, B and C form an envelope around the viscosity graph of the reference. The consistency of the bio-based formulations is therefore comparable to the commercial reference. Visually satisfactory printing results were achieved with formulations A and C, some of which even surpass the commercial reference in terms of edge sharpness. The optical density and rubbing fastness of the bio-based formulations are lower than the commercial reference in all cases. Due to the excellent visual quality and the fact that the inks are petroleum-free and based on bio-based raw materials, further studies on additives that improve these properties are recommended. Lightfastness is largely determined by the pigment - here iron oxide black shows no disadvantages compared to petroleum-based carbon black, although the opacity and optical density are somewhat lower.

Concluding, the bio-based formulations according to Maurice Kahn based on starch as well as the authors' formulation based on chitosan show great potential for increasing sustainability in screen printing.

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