# Pigment printing with natural plant dyes

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**Professional paper****

*Due to increasing environmental awareness and the need to apply the circular economy, natural dyes are increasingly used in the textile sector. In this research, pigment printing is carried out with natural plant dyes, i.e. plant extracts from walnut leaves, pomegranate peels and onion peel. The composition of the printing paste and the fixation parameters are optimised. A print screen is created to assess the quality of the print, focussing on the sharpness of the print. Pastes with Prisulon DCA 90 or Tubivis Star, a universal thickening agent for textile printing, were compared without and with the addition of aluminium salt. A launder and rub resistance test were carried out on printed cotton fabrics. The results were analysed spectrophotometrically using a Datacolor 850 spectrophotometer. It was found that fixing the printed textile fabric with a paste containing the thickening agent Prisulon DCA 90 with aluminium salts and natural plant dye for 240 seconds at 180°C led to the best results in terms of wash and rub resistance. The natural dyes and their concentrations are selected according to the design idea with a view to the desired implementation in the textile design on the final product.*

***Keywords:*** *natural dyes; pigment printing; fixation; laundering fastness; rubbing fastness*

**Stručni rad****

## Pigmentni tisak s prirodnim biljnim bojilima

*Zbog sve veće ekološke svijesti i potrebe za primjenom kružnog gospodarstva, prirodna bojila se sve više koriste u tekstilnom sektoru. U ovom istraživanju pigmentni tisak se provodi s prirodnim biljnim bojilima, odnosno biljnim ekstraktima iz lišća oraha, kore nara i ljuske luka. Sastav tiskarske paste i parametri fiksiranja su optimizirani. Šablona za pigmentni tisak je izrađena za procjenu kvalitete otiska, fokusirajući se na oštrinu otiska. Uspoređivane su paste s univerzalnim ugušćivačima za tisak na tekstilu Prisulon-om DCA 90 ili Tubivis Star-om, bez i s dodatkom aluminijeve soli. Ispitivanje postojanosti na pranje i trljanje provedeno je na otisnutim pamučnim tkaninama. Rezultati su analizirani spektrofotometrijski koristeći Datacolor 850 spektrofotometar. Utvrđeno je da je fiksiranje otisnute tekstilne tkanine pastom koja sadrži ugušćivač Prisulon DCA 90 s aluminijevim solima i prirodnim biljnim bojilom tijekom 240 sekundi na 180°C dovelo do najboljih rezultata u pogledu postojanosti na pranje i trljanje. Prirodna bojila i njihove koncentracije odabrane su prema dizajnerskoj ideji s ciljem implementacije u dizajn tekstila na konačnom proizvodu.*

***Ključne riječi:*** *prirodna bojila; pigmentni tisak; fiksiranje; otpornost na pranje; otpornost na trljanje*

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# 1. Introduction

Natural dyes and pigments can be obtained from various sources: minerals, plants and animals. Natural dyes have been used since prehistoric times. The first applications of natural dyes on textile fibres began in Mesopotamia and India around 4000 BC. It is assumed that pigments were used for dyeing in these first dyeing experiments, which were easily removed from the fabrics through rubbing and laundering due to their weak mechanical bond to the fibres, so that the dyeing process was not really successful. It is assumed that the method of mordant dyeing was discovered by chance. The discovery of the first synthetic dye changed natural dyeing habits and synthetic dyes replaced almost all natural dyes. Today, disagreements about the risks of using synthetic dyes and a growing environmental awareness are leading to an increased interest in natural resources, environmentally friendly products and new strategies. Natural dyes are agriculturally renewable, sustainable, plant-based dye sources. The ability to obtain the colourant from renewable natural sources makes natural dyes an attractive class of dye for a more sustainable world [1].

Natural dyes can be applied to fibres not only by dyeing, but also by printing. Textile printing is one of the most important and versatile methods of designing and colouring textiles. Ancient human mixed dyes such as charcoal or earth colours with oils and applied them to various materials in lines with their fingers. Dyeing fabrics with plant dye extracts and made a variety of approaches possible. Patterns can be created by applying wax to obtain a resistant dyeing liquid or by enclosing areas to obtain an adherent and reserved area. The word printing refers to a process in which dye is added to the material through pressure. And it is undeniable that the first textile prints were made from printing blocks with a relief printing surface, which were then dyed and printed onto the fabric [1-4].

## 1.1. Pigment printing

Pigment printing is one of the most popular, most economical and certainly the oldest direct printing techniques. More than 50% of the total production of printed textiles is pigment printing [5]. In pigment printing, the bonding of the dye to the substrate depends primarily on the choice of a binder that forms a polymer film and fixes the pigment to the surface of the textile substrate. Pigment printing is suitable for all types of textile materials, mainly due to the system of mechanical bonding of pigments to textiles. If the right binders, crosslinkers and pigments are selected for a particular textile material, pigment printing can achieve appropriate resistance properties.

## 1.2. Printing paste

Printing paste consists of thickeners, dyes and additives. The most important component of the printing paste is the thickener, as it ensures that the dyes and additives are applied to the textile in the contours of the chosen pattern. In other words, the thickener prevents the printing paste from flowing outside the contours defined by the stencil pattern. The most important properties of the thickener are that it acts as a mechanical carrier of dyes and additives, overcomes the capillary forces of the fabric and keeps the components of the printing paste in a homogeneous whole [5]. Thickening agents are categorised according to their origin into natural and synthetic.

From an environmental point of view, pigment printing pastes based on synthetic thickeners are more suitable than other forms of printing pastes. Furthermore, pigment printing has a wide range of applications. It is used for clothing, bed and table linen and bathroom textiles. Pigments used in this work preserve the colour in the printing paste. They are the most common and most important group of dyes. Pigments account for about 75% of all printing processes because they are so simple and convenient and do not require much equipment [6]. Pigments are coloured, insoluble chemical compounds that have the property of absorbing light in the visible spectrum, but have no affinity to the textile material and are mechanically bound with the help of binders [7]. According to their chemical structure, they can be divided into the groups of azo dyes, anthraquinones, indigoides and phthalocyanine dyes. The pigment must have sufficient light resistance and a certain temperature resistance. Friction resistance is somewhat weaker and depends primarily on the binder.

Additives in the preparation of printing paste enable the solubility and dispersion of the dye and ensure that all components of the printing paste are retained in a homogeneous form [5]. The additives used in this work for the preparation of printing paste are fixing agents, binders and urea. Fixing agents are used to accelerate bonding and binders are used in pigment printing to create a polymer film. Urea is a hygroscopic additive that not only improves the solubility and utilisation of the dye, but also slows down the evaporation of water during drying, thus facilitating the dye-fibre reaction [8]. It should be noted that there must be no chemical reaction between the components of the printing paste.

## 2. Materials and chemicals

The textile fabric used for the research 100% cotton in satin embroidery were supplied by TTT d.o.o. Croatia. Surface mass of fabric was 191.45 g/m$^2$ and yarn density of warp/weft 26/25 yarns/cm.

The thickener of natural origin Prisulon DCA 90 and the thickener of synthetic origin Tubivis Star were used in this research. Prisulon DCA 90 is a non-ionic thickener in powder form and Tubivis Star is a liquid anionic thickener. The properties of the thickener Prisulon DCA 90 (CHT) are: stable against electrolytes, easy to wash out, good penetration, sharp contours, high surface flatness, high purity [9]. The properties of the thickener Tubivis Star (CHT) are: stable against electrolytes, high colour yield and high surface flatness [10].

Pigments used in this research were natural plant dyes extracted from walnuts, *Juglans regia* L., onions, *Allium cepa* L. and pomegranates peels, *Punica granatum* L. green walnut shells and young walnut leaves contain juglone (Fig.1a) and other chromophores, which are responsible for producing brown colours. The peels of red onions are rich in flavonoids, the most abundant of which is quercetin (Fig.1b), which is responsible for the yellow colour. The peel of the pomegranate contains approximately 28% tannins (Fig.1c), which are responsible for the yellow colour [11]. Extraction was carried out according to previous researches [12].

One of the components of printing paste in this research is potassium aluminum sulfate dodecahydrate, $KAl(SO_4)_2 \cdot 12\ H_2O$ (Kemika). It is widely used in the textile printing process due to its beneficial properties, ease of use, low price and less toxicity than other options. It stabilises the viscosity of printing paste, resulting in an even and precise application on textile material. Its use also improves the fastness to laundering and rubbing of natural dyes, and in particular the base colour does not change [13].

The additives used to produce of printing pastes are fixing agent Tubifix ML 55 (Bezema AG), binder Tubifast AS-BN (Bezema AG) and urea.

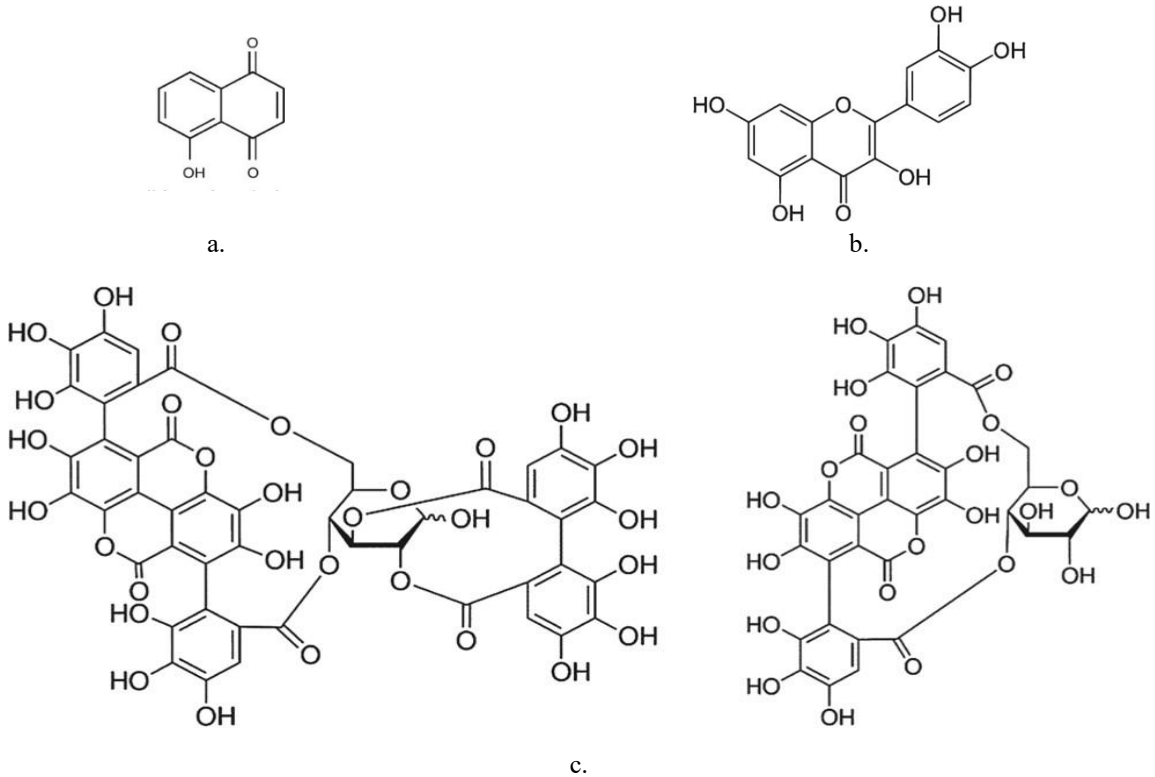
## 3. Experimental

### 3.1. Printing pastes preparing

Based on preliminary research and design decisions three printing pastes were selected for the analysis. One is based on the thickener Tubivis Star and other two are based on the thickener Prisulon DCA 90.

For printing paste with thickener Tubivis Star (T) the concentration used is 8%. In addition to the thickener Tubivis Star, urea, fixing agent, binder and pigment was selected for the preliminary tests.

For Prisulon DCA 90 the dry matter content of the pastes is 9%. In addition to the thickener Prisulon DCA 90, urea was added to the pastes. Plant pigment from pomegranate extract was selected for all preliminary tests and for optimisation of printing pastes. Water was added to the printing pastes as



a. b. c.

**Fig.1** Chemical structure of: a. juglone in walnut bark; b. quercetin in onion peel and c. tannin derivatives in pomegranate bark [11]

required to dissolve the plant pigment. The difference between the pastes is that one was produced without (P) and the other with a metal salt (PAl), i.e. with potassium aluminium sulphate dodecahydrate ($KAl(SO_4)_2 \cdot 12\ H_2O$). The composition of textile pastes is listed in the Table 1.

**Tab.1** Composition of textile pastes

| **Printing paste components** | **T** (Tubivis Star) | **Prisulon DCA 90** | |
|---|---|---|---|
| | | **P** (without metal salts) | **PAl** (with metal salts) |
| thickener / g | 100 | 100 | 100 |
| pigment / g | 2 | 2 | 2 |
| urea / g | 0.5 | 0.5 | 0.5 |
| fixing agent /g | 1.6 | - | - |
| binder / g | 25 | - | - |
| $KAl(SO_4)_2 \cdot 12\ H_2O$ / g | - | - | 0.2 |

### 3.2. Printing and fixation

The printing process was carried out by manual screen-printing, using the following tools: a manual, flat screen printing table, a polyurethane squeegee with a wooden handle and an aluminium screen of 40 × 50 cm with a mesh size of 62 threads/cm$^2$.

As the method used was hand screen-printing, the squeegee angle was kept between 7-10°, with optimum pressure to ensure even transfer of the printing paste to the surface of the textile substrate. After pre-printing, the fixation was carried out on the thermopress at 180°C and the duration of the fixation was optimised (30s, 40s, 60s, 120s and 240s).

### 3.3. Colour fastness analysis

The printed samples were tested for laundering fastness and rubbing fastness. The laundering fastness test was carried out after thermal fixing on a laboratory thermopress.

The test was carried out in accordance with the ISO 105-C06:2010 (A2S) *Textiles - Tests for colour fastness - Part C06: Colour fastness to domestic and commercial laundering* using 0.5 g/l industrial detergent Kemopon 30 (CHT Bezema), bath ratio 1:30, temperature 30 ± 2°C, duration 40 minutes, in the laboratory device Polycolor, Mathis.

The colour fastness to rubbing was tested according to the standard ISO 105-X12:2016 *Textiles -Tests for colour fastness— Part X12: Colour fastness to rubbing*. The rubbing fastness test was carried out using a laboratory crockmeter according to the dry method using Crockmeter (AATCC, Lowell).

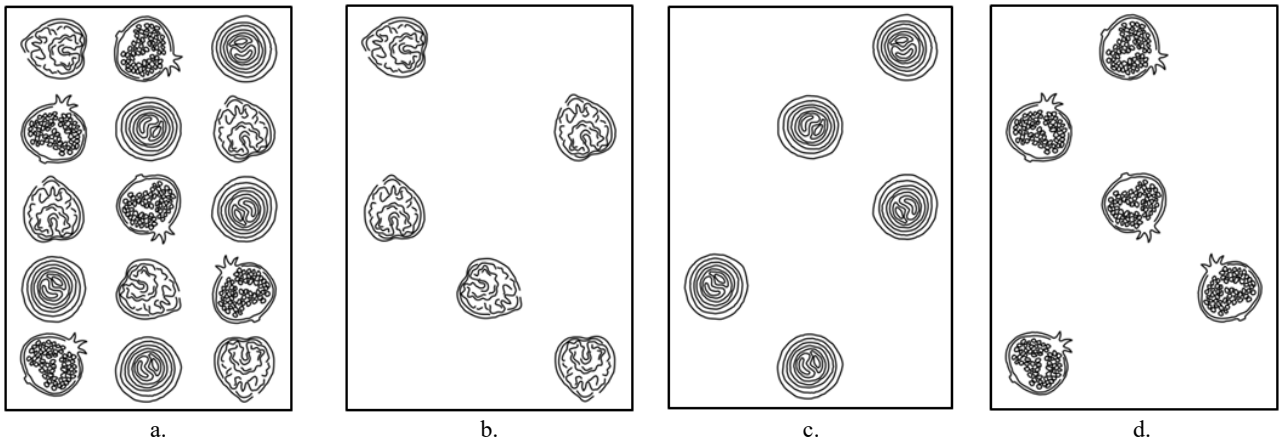
The colour fastness results were objectively determined by spectrophotometric measurement with a Datacolor 850 remission spectrophotometer (with constant instrument aperture, D65, using the d/8° geometry).

### 3.4. Realisation of the final product

The creative part of this work relates to the production of a tablecloth with a selected pattern printed with natural plant dyes. More specifically, plant extracts from walnuts, onions and pomegranates were used. The conceptual drawing for the creation of the pattern was created on a computer using the Inkscape programme (version 1.3.2).

A repeat unit, the smallest repeating unit of the conceptual drawing, was defined (Fig.2a). The rapport unit was developed using effects and each effect was separated as a separate drawing. More specifically, three transparent sheets in A4 format were used (Figs. 2b, 2c and 2d).

The idea of the end product is projected with the tools used on the redbubble.com website (Fig.3).



a. b. c. d.

**Fig.2** Image of repeat unit a. and of each segment are presented: b. walnut effect; c. onion effect and d. pomegranate effect



**Fig.3** Projected image of the final product

## 4. Results

### 4.1. Printing, fixation and spectrophotometry analyse

Three printing pastes were prepared and the textile material was printed according to the plan of the experimental part of the work.

The fixing conditions were optimised using a thermopress. The values of the spectral properties were determined with a Datacolor 850 spectrophotometer, namely the lightness $L^*$, the parameter $a^*$, the parameter b*, the chromaticity $C^*$ and the hue $h°$. The results of the spectrophotometric analysis are listed in Table 2 for paste with Tubivis Star (T) and Table 3 for pastes with Prisulon DCA (P and PAl).

As far as the colour is concerned, a shift from yellow to orange can be observed after fixation ($h°$ = 85.08 – 74.61). The lightness decreases with increasing fixation time ($L^*$ = 77.06 – 61.72), i.e. the lowest brightness is for sample T-240 ($L^*$ = 61.72) which correlates with the tone results. Increasing the fixing time results in a greater amount of dye remaining on the material. The chromaticity does not change significantly for the fixed samples ($C^*$ = 37.69 – 36.26), except for the non-fixed sample T-0, which has the lowest chromaticity ($C^*$ = 29.11). Since the numerical values do not change significantly, it can be concluded that the fixation time of 240 s has no negative effect on the spectral properties of the printed sample when Tubivis Star is used for the thickener.

In the samples printed with a paste containing Prisulon DCA thickener without the addition of metal salts (P), the lightness decreases significantly with increasing fixation time ($L^*$ = 77.61 – 58.49). The values for hue and chromaticity also decrease, but not to the same extent ($C^*$ = 29.54 – 26.73, $h°$ = 85.44 – 75.29). From this we can see that with increasing fixation time there is a shift from a yellow tone to an orange tone, which is also less saturated and bright but is an indicator of a higher amount of yellow dye on the material. In the samples printed with a paste containing Prisulon DCA thickener with the addition of metal salts (PAl), the lightness decreases with increasing fixation time ($L^*$ = 85.44 – 65.72), with the lowest brightness in sample PAl-240 ($L^*$ = 65.72)

**Tab.2** Colour parameters of textile printed with a printing paste based on thickener Tubivis Star (T) at different fixation duration

| Sample | Duration of fixation/ s | $L^*$ | $a^*$ | $b^*$ | $C^*$ | $h°$ |
|---|---|---|---|---|---|---|
| T-0 | 0 | 77.06 | 2.50 | 29.00 | 29.11 | 85.08 |
| T-30 | 30 | 65.50 | 9.49 | 36.48 | 37.69 | 75.41 |
| T-40 | 40 | 64.52 | 9.28 | 35.82 | 37.00 | 75.47 |
| T-60 | 60 | 65.24 | 9.06 | 35.88 | 37.00 | 75.83 |
| T-120 | 120 | 64.93 | 9.39 | 35.87 | 37.08 | 75.33 |
| T-240 | 240 | 61.72 | 9.62 | 34.96 | 36.26 | 74.61 |

**Tab.3** Colour parameters of textile printed with a printing pastes based on thickener Prisulon DCA 90 without metal salts (P) and with a printing paste with metal salts (PAl) at different fixation duration

| Sample | Duration of fixation/ s | $L^*$ | $a^*$ | $b^*$ | $C^*$ | $h°$ |
|---|---|---|---|---|---|---|
| P-0 | 0 | 77.61 | 2.35 | 29.45 | 29.54 | 85.44 |
| P-30 | 30 | 76.97 | 3.31 | 26.52 | 26.73 | 82.88 |
| P-40 | 40 | 74.37 | 3.92 | 27.94 | 28.22 | 82.01 |
| P-60 | 60 | 73.02 | 4.28 | 28.36 | 28.68 | 81.41 |
| P-120 | 120 | 68.77 | 5.20 | 28.01 | 28.48 | 79.49 |
| P-240 | 240 | 58.49 | 6.99 | 26.64 | 27.54 | 75.29 |
| PAl-0 | 0 | 85.44 | 1.81 | 11.73 | 11.87 | 81.25 |
| PAl-30 | 30 | 82.50 | 2.45 | 14.09 | 14.31 | 80.12 |
| PAl-40 | 40 | 78.49 | 2.85 | 20.21 | 20.41 | 81.97 |
| PAl-60 | 60 | 76.50 | 3.48 | 21.41 | 21.69 | 80.76 |
| PAl-120 | 120 | 74.85 | 3.89 | 19.21 | 19.60 | 78.56 |
| PAl-240 | 240 | 65.72 | 5.37 | 20.19 | 20.89 | 75.11 |

and in this case it is also an indicator of a larger amount of remaining dye on the material. The values for hue and chromaticity vary. The lowest numerical value of chromaticity is found in the unfixed sample PAl-0 ($C^*$ = 11.87) and in the longest fixed sample PAl-240 ($h°$ = 75.11).

### 4.2. Results of laundering fastness

The laundering fastness was tested in a Polycolor, Mathis device. The values of the spectral characteristics were determined, namely the total colour difference *dE*, the lightness difference *dL**, the parameter difference *da**, the parameter difference *db**, the chromaticity difference *dC** and the hue difference *dh°* for pastes based on Tubivis Star (T), Table 4, and Prisulon DCA 90 (without metal salts – P and with metal salts – PAl), Table 5.

After laundering fastness the unfixed sample T-0 has the smallest colour difference compared to the other samples (*dE* = 2.34). The unfixed sample also shows the smallest difference in lightness and colour tone (*dL** = -0.69, *dh°* = 0.01). However, if the unfixed sample T0 is ignored, the colour difference generally decreases with increasing fixation time (*dE* = 9.83 – 5.12). The difference in chromaticity varies and is smallest for sample T-60 (*dC** = 0.35). The longest fixed sample P-240 has the smallest colour difference compared to the other samples (*dE* = 2.58) when using paste with Prisulon DCA without the addition of metal salts (P). Specifically, the longest fixed sample P-240 shows the smallest difference in lightness and chromaticity (*dL** = 0.18, *dC** = -2.57). The difference in colour tone is smallest with the unfixed sample P-0 (*dh°* = -0.02), but there is also no significant difference with the longest fixed sample P-240 (*dh°* = 0.09).

The longest fixed sample PAl-240 has the smallest colour difference compared to the other samples (*dE* = 1.77) when using paste with Prisulon DCA with the addition of metal salts (PAl). Specifically, the sample PAl-240, which was fixed for the longest time, shows the smallest difference in colour hue and chromaticity (*dh°* = 0.38, *dC** = -1.44). Similarly, the difference in lightness is smallest for the sample before the longest-fixed sample PAl-120 (*dL** = 0.62), but there is no significant difference for the longest-fixed sample PAl-240 (*dL** = 0.96).

### 4.3. Results of rubbing fastness

The abrasion resistance was tested with a Crockmeter (AATCC, Lowell). The results of the spectrophotometric analysis, namely the total colour difference *dE*, the lightness difference (*dL**), the parameter difference *da**, the parameter difference *db**, the chromaticity difference (*dC**) and the hue difference (*dh°*), for paste based on Tubivis Star (T) are shown in Table 6, and Prisulon DCA 90 (without metal salts – P and with metal salts – PAl) in Table 7.

**Tab.4** Difference in color of samples printed with printing paste based on Tubivis Star (T) before and after laundering fastness with different fixation duration

| Sample | *dE* | *dL** | *da** | *db** | *dC** | *dh°* |
|---|---|---|---|---|---|---|
| T-0 | 2.34 | -0.69 | -0.20 | -2.23 | -2.23 | 0.01 |
| T-30 | 7.40 | -7.36 | 0.09 | 0.79 | 0.79 | 0.11 |
| T-40 | 9.83 | -9.63 | 1.89 | 0.47 | 0.96 | -1.69 |
| T-60 | 6.20 | -6.18 | -0.26 | 0.43 | 0.35 | 0.36 |
| T-120 | 5.69 | -5.58 | -1.05 | -0.29 | -0.54 | 0.95 |
| T-240 | 5.12 | -4.30 | -2.06 | -1.87 | -2.32 | 1.54 |

**Tab.5** Difference in color of samples printed with printing pastes based on Prisulon DCA 90 (without metal salts – P and with metal salts – PAl) before and after laundering fastness with different fixation duration

| Sample | *dE* | *dL** | *da** | *db** | *dC** | *dh°* |
|---|---|---|---|---|---|---|
| P-0 | 5.74 | 1.98 | -0.41 | -5.37 | -5.39 | -0.02 |
| P-30 | 7.66 | 4.26 | -0.50 | -6.35 | -6.36 | -0.34 |
| P-40 | 9.26 | 5.62 | -0.95 | -7.30 | -7.36 | -0.09 |
| P-60 | 7.10 | 2.89 | -0.61 | -6.46 | -6.48 | -0.41 |
| P-120 | 5.73 | -4.97 | 0.21 | -2.83 | -2.74 | -0.76 |
| P-240 | 2.58 | 0.18 | -0.74 | -2.47 | -2.57 | 0.09 |
| PAl-0 | 6.38 | 2.91 | 0.42 | -5.67 | -5.41 | -1.74 |
| PAl-30 | 3.16 | 1.52 | 0.13 | -2.77 | -2.69 | -0.67 |
| PAl-40 | 8.38 | 3.34 | 0.15 | -7.68 | -7.53 | -1.54 |
| PAl-60 | 7.40 | 2.50 | -0.18 | -6.96 | -6.87 | -1.14 |
| PAl-120 | 3.80 | 0.62 | -0.12 | -3.75 | -3.68 | -0.70 |
| PAl-240 | 1.77 | 0.96 | -0.72 | -1.30 | -1.44 | 0.38 |

**Tab.6** Difference in color of samples printed with printing pastes based on Tubivis Star (T) before and after rubbing fastness with different fixation duration

| Sample | *dE* | *dL** | *da** | *db** | *dC** | *dh°* |
|---|---|---|---|---|---|---|
| T-0 | 1.13 | 0.61 | -0.24 | -0.92 | -0.93 | 0.17 |
| T-30 | 1.20 | 0.55 | -0.66 | -0.84 | -0.98 | 0.43 |
| T-40 | 1.51 | 0.83 | -0.46 | -1.17 | -1.25 | 0.15 |
| T-60 | 1.36 | -1.23 | 0.54 | 0.22 | 0.34 | -0.47 |
| T-120 | 0.53 | -0.02 | -0.18 | -0.50 | -0.53 | 0.05 |
| T-240 | 1.13 | 0.86 | -0.48 | -0.55 | -0.66 | 0.32 |

**Tab.7** Difference in color of samples printed with printing pastes based on Prisulon DCA 90 (without metal salts – P and with metal salts – PAl) before and after rubbing fastness with different fixation duration

| Sample | *dE* | *dL** | *da** | *db** | *dC** | *dh°* |
|---|---|---|---|---|---|---|
| P-0 | 0.87 | 0.57 | -0.21 | -0.62 | -0.63 | 0.16 |
| P-30 | 1.50 | 1.50 | -0.03 | -0.10 | -0.10 | 0.02 |
| P-40 | 1.09 | 1.09 | 0.05 | 0.10 | 0.10 | -0.04 |
| P-60 | 0.71 | 0.56 | 0.08 | -0.42 | -0.40 | -0.14 |
| P-120 | 0.30 | -0.07 | 0.13 | 0.26 | 0.28 | -0.08 |
| P-240 | 1.14 | 0.50 | -0.33 | -0.97 | -1.02 | 0.07 |
| PAl-0 | 0.67 | 0.15 | -0.13 | 0.64 | 0.62 | 0.22 |
| PAl-30 | 0.33 | 0.01 | -0.05 | 0.33 | 0.32 | 0.10 |
| PAl-40 | 1.10 | 0.45 | 0.15 | -1.00 | -0.97 | -0.29 |
| PAl-60 | 1.33 | -1.24 | 0.29 | 0.39 | 0.43 | -0.22 |
| PAl-120 | 2.37 | -2.24 | 0.50 | 0.62 | 0.71 | -0.36 |
| PAl-240 | 0.81 | -0.76 | 0.20 | 0.19 | 0.23 | -0.14 |

After rubbing fastness, the smallest difference in colour is found in sample T-120 ($dE$ = 0.53), which lies ahead of the longest fixed sample T-240 ($dE$ = 1.13). Sample T-120 also shows the smallest difference in lightness and colour hue ($dL^*$ = -0.02, $dh°$ = 0.05). The difference in chromaticity is smaller for the longer fixed samples ($dC^* \approx 0.51$) compared to the non-fixed and shorter fixed samples ($dC^* \approx 1.05$).

Sample P-120 ($dE$ = 0.30, $dL^*$ = -0.07), printed with paste without the addition of metal salts, shows the smallest difference in colour, but also the smallest difference in brightness, ahead of sample P-240 ($dE$ = 1.14, $dL^*$ = 0.50), which was fixed for the longest time. The shortest fixed sample P-30 ($dC^*$ = -0.10, $dh°$ = 0.02) shows the smallest difference in chromaticity and colour hue. When metal salts are added to the printing paste, the shortest fixed sample PAl-30 shows the smallest difference in colour, brightness and hue ($dE$ = 0.33, $dL^*$ = 0.01, $dh°$ = 0.10). The longest fixed sample PAl-240 has the smallest difference in chromaticity ($dC^*$ = 0.23) and its value of the colour hue difference is like the value of the colour tone difference of the shortest fixed sample PAl-30 ($dh°$ = -0.14).

### 4.4. Realization of the final product

As part of the creative part of this work, a tablecloth was made with a selected pattern printed with natural plant dyes. The paste used was with thickener Prisulon DCA with the addition of metal salts. Fig.4 shows the realisation of the tablecloth.



**Fig.4** Final product

## 5. Conclusions

The analysis of the spectral properties shows that satisfactory fixation results were achieved at 180 °C for 240 s. After analysing the preliminary tests, the thickener with the trade name Tubivis Star was discarded as no satisfactory results were obtained. More specifically, it showed lower rubbing fastness and lower laundering fastness compared to the thickener Prisulon DCA 90, as can be seen from the spectral properties obtained. After testing both print pastes based on the thickener Prisulon DCA 90, the printing paste without the addition of aluminium salt was discarded. The reason for this is that it exhibited

lower rubbing fastness and lower laundering fastness, which is also evident from the spectral characteristics obtained in Tables 5 and 7. In fact, the sample fixed with the printing paste based on the thickener Prisulon DCA 90 with the addition of aluminium salt for 240 s at 180 °C showed the least colour change. In other words, this sample showed the best result and achieved good fastness properties to laundering and rubbing.

It can be said that it is of great importance to enable the widest possible use of natural dyes in the textile industry, but also in other areas. Natural dyes are non-toxic and biodegradable, unlike synthetic dyes, which often have harmful effects on ecosystems and human health. In addition, the production of natural dyes requires fewer resources and causes less pollution. This is in line with global efforts to reduce the impact of the fashion and textile sector on the environment. As an example of such a practise, a tablecloth printed with natural plant colours was produced as part of the creative part of this work.

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