GRAPE POMACE EXTRACT AS A COLORANT FOR TEXTILE PRINTING APPLICATIONS

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Abstract

The growing need to reduce the negative impact on the environment and human health, as well as to meet the growing demand for eco-friendly textiles, has led to the development of environmentally friendly printing techniques and the use of natural dyes in the textile industry. Grape pomace is important waste material in winemaking, and has been extensively studied for its potential as a source of compounds with biological properties, especially anthocyanins, pigments responsible for the red, purple, and blue colors in grapes. The aim of this paper was to examine the potential use of natural dye extracted from grape pomace of domestic cultivar crna Mirisavka (GPCM) in preparation of printing paste with alginate, citric acid, and tannic acid for printing on cotton fabric. Special focus was placed to achieve process color magenta, by adjusting the pH value of the extract obtained. The natural dye from GPCM was extracted using maceration with 80% methanol, followed by sonication to enhance the yield of bioactive compounds. GPCM extract demonstrated significant antioxidant activity measured by FRAP, DPPH, and $ABTS^{+}$ tests, and moderate antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. The pH-dependent stability of anthocyanins in GPCM extract was examined, demonstrating a magenta tone at acidic pH (pH 2-4) and color degradation at higher pH values. Cotton fabric printed with two different concentrations of GPCM extract (100 mg/L and 50 mg/L) showed good antioxidant and antibacterial activity. Based on the obtained results, it can be concluded that GPCM extract can be an environmentally friendly solution for the development of antibacterial and antioxidant textiles, with potential application in the production of protective clothing in healthcare institutions, as well as for the production of decorative home textiles, for the production of children's toys and textiles for packaging.

Keywords: Grape pomace extract; Antibacterial activity; Antioxidant properties; Anthocyanins; pH stability, Screen printing

Introduction

The textile production process is considered potentially harmful due to its negative impact on the environment. Today, the main goal of the textile industry is to maintain product quality and to develop new manufacturing techniques that promote environmental sustainability, worker health, and consumer satisfaction [1]. The use of synthetic dyes became one of the major problems, what led to an increase in finding eco-friendly practices [2,3], especially with the development of eco-friendly natural dyes and biomordants for textile dyeing [4,5]. Natural dyes are better than synthetic dyes due to environmental friendliness, lack of toxicity and allergenicity, etc. [6-8]. Despite the somewhat higher overall production cost, natural inks offer added value through their biodegradability, potential functional properties (e.g., antioxidant or antimicrobial activity), and environmental sustainability. These aspects may outweigh the economic disadvantages in niche applications such as eco-friendly textiles or functional materials [1,3].

For the extraction of biodegradable and ecologically friendly natural dyes a wide variety of plant, floral, fruit-based materials can be used [9]. Among the fruit based materials, grapes are one of the most widely produced crops globally, with a wine production estimated at 235 million hectoliters [10]. About 75% of grapes are used for wine, producing a large amount of by-products, mainly grape pomace, consisting of skins, pulp, seeds, and stalks. The disposal of this waste creates environmental concerns due to its capacity to pollute the soils and reduce the availability of other ingredients [11]. However, having a high content of bioactive compounds makes grape pomace valuable for various applications, including human health benefits [12].

Grape pomace has been extensively studied for its potential as a source of bioactive compounds with antimicrobial and antioxidant properties [12-16]. The main bioactive compounds in grape pomace are: polyphenols, including phenolic acids, flavonoids such as anthocyanins (AC), etc. [12,15,16]. AC are the pigments responsible for the red, purple, and blue colors in grapes [12,17]. AC, particularly those found in red grape varieties have the potential to be used as natural dyes for textile applications [17]. The AC content in grape pomace can vary significantly depending on the grape variety, climate, and winemaking process [18,19]. Therefore, it is important to investigate the AC profile of different grape pomace sources to identify the most suitable ones for natural dye applications.

Additionally, factors like pH, temperature, and the presence of other compounds like ascorbic acid and maltodextrin can affect the stability of AC and their performance as dyes [20]. The color of AC is highly dependent on the pH of the environment [21-23]. At low pH values (pH < 3), AC exist predominantly in the red-colored flavylium cation form [24-26]. As the pH increases, the AC molecules undergo structural transformations, leading to changes in their color [21,22,26]. In slightly acidic to neutral pH

(pH 3-7), AC can exist in various forms, including the colorless hemiketal and the blue-violet quinoidal base forms [24-26]. In alkaline conditions (pH > 7), AC tend to become more yellow or green in color due to the formation of the chalcone form [27,28]. The stability of AC is also influenced by pH value, with the most stable form being the flavylium cation at low pH values [24-26,29], which is responsible for the magenta color [30]. Beyond their coloring properties, AC from grape pomace also exhibit antioxidant and anti-inflammatory activities, which can be beneficial for various applications, including food, cosmetics, and pharmaceuticals [12,15]. The synergistic effects of AC and other polyphenolic compounds in grape pomace extracts have also been reported to have antimicrobial properties, which could be leveraged for textile applications [13,31].

Cantika and Hendrawan emphasized that a number of methods can be used for application of natural dyes on textile [32]. One of them, screen printing, can be used to add leaf and floral patterns to textiles [33]. Screen printing is eco-printing method and the waste generated is environmentally friendly since the fabrics and dyes used are made from natural materials [34]. According to Amutha and Annapoorani, natural dyes can be printed directly onto fabrics with a suitable formulation [35].

Screen printing, a versatile and widely utilized printing technique, relies on various types of inks to achieve desired colors and effects. Also, the curing process has a huge impact on the print performance [36]. Natural inks, being biodegradable and environmentally friendly, offer a sustainable alternative to synthetic counterparts, as they reduce environmental pollution and can be sourced from renewable resources. Moreover, the unique properties of natural inks, such as bioactivity and low toxicity, align with global trends toward greener production methods, and the growing demand for environmentally conscious products [37,38]. Magenta is one of the primary colors in the subtractive color model (CMYK), alongside cyan, yellow, and black. It is essential for creating a wide spectrum of colors through blending [39]. The inclusion of a natural magenta ink in screen printing not only offers an environmentally friendly alternative but also enables the creation of visually appealing and intricate patterns on textiles, enhancing both their aesthetic and functional value [40]. A natural printing process should be developed in order to lessen negative effects on health and the environment.

There is a significant body of research on the potential applications of grape pomace in the food, cosmetic, and pharmaceutical industries, but minimal data is available on the performance of cotton fabrics dyed with grape pomace extract as a natural colorant, and alternative to synthetic dyes, for textile printing applications [41,42]. Magenta printing paste can be prepared from grape pomace extract and can be used commercially for sustainable textile printing practices. Antibacterial and antioxidant properties of extract and printed textile are, also, very important, and will be investigated to uphold the use of grape pomace. The results will offer essential informations on the resource efficiency and economic opportunities of using natural dye from grape pomace in eco-sustainable printing of cotton,

for example in sustainable fashion, home textiles, etc. Also, phenol-rich extracts have the ability to prevent oxidative and microbial damage, and offer the possibility of application in the development of natural antioxidant and antimicrobial dyes for textile printing.

Materials and methods

In this study, the potential use of GPCM for obtaining extract through ultrasonic extraction was investigated. The obtained extract GPCM were analyzed for their antioxidant and antibacterial properties, as well as spectrophotometric characteristics. The optimal pH value of the extract, at which the AC content was the highest, was determined, and cotton fabrics were printed using an alginate paste modified with extract GPCM, citric acid, and tannin. The entire research process is schematically presented in Figure 1.

Figure 1

GPCM extract preparation

GPCM used in this study was collected as a by-product during juice preparation. After collection, GPCM was stored at a low temperature (-20 °C) until processing to preserve the biological activity of phenolic compounds. Also, prepared crude extracts of *Vitis vinifera* L. grapes are stored at -20°C until further analysis [43]. GPCM was subjected to maceration in 80% methanol for 24 hours with occasional stirring, then treated with ultrasound for 18 minutes to enhance extraction efficiency. Ultrasound is environment-friendly, inexpensive, fast and efficient extraction technology for phenolic components due to acoustic cavitation caused by the ultrasound wave passage. Acoustic cavitation results in rupture of cell walls, allowing solvent penetration and improving mass transfer, leading to an increase in extraction yield and shortening extraction time [44]. Azmir et al. stated that moisture content, sample, sample size, solvent employed, temperature, frequency and probe time are the factors that may influence the extraction process in the ultrasound assisted extraction [45]. Many researchers have used ultrasound for a more efficient preparation of medicinal plant extracts [46,47].

After maceration and sonication, obtained GPCM extract was filtered to remove solid particles. The filtered extract was further concentrated using a vacuum evaporator at 40 °C, then dried in Petri dishes at 50 °C. The resulting dry GPCM extract was dissolved in 60% methanol to a final concentration of 200 mg/mL.

Regulation of pH value and spectrophotometric analysis

The pH value of the prepared GPCM extract was 4.3 (U0). The pH values of U0 were adjusted at: pH 2 (U2), pH 4 (U4), pH 6 (U6), pH 7 (U7), pH 8 (U8), pH 10 (U10), and pH 12 (U12) using 0.1 M hydrochloric acid (HCl) for acidification, and 0.1 M sodium hydroxide (NaOH) for alkalization. For precise measurement HANNA HI 2211 pH meter was used.

The spectrophotometric analysis of the pH adjusted extracts was performed using a Perkin Elmer Lambda 25 UV/VIS spectrophotometer with glass cuvettes and 60% methanol as the control sample. The absorbance (A) and transmittance (T) of the adjusted extracts were measured in the visible spectrum range of 360–740 nm.

Antibacterial activity

In this study, to determine the antibacterial activity of GPCM extract was used the agar dilution method to obtain the minimum inhibitory (MIC) and minimum bactericidal (MBC) concentrations [48]. Two bacterial cultures, *Escherichia coli* ATCC 25922 and *Staphylococcus aureus* ATCC 25923 were used. For this study, bacterial cultures were prepared from the logarithmic phase and by direct colony suspension [48,49].

A standard inoculum of *E.coli* from the logarithmic growth phase was prepared in the following way. Namely, the culture was seeded on Miller Hinton agar plates (MHA) and incubated at 37 °C for 24 h. After that, 3–5 isolated colonies were transferred to a 5 mL tube containing Miller Hinton broth (MHB) and incubated for the next 2–6 h. On the other hand, *S.aureus* was inoculated from agar slants onto Nutrition agar plates. The prepared agar plates were then incubated for 24 h at 37 °C. Thereafter, two or three colonies were collected directly into the MHB.

After incubation for 2–6 h or after preparation of the colony suspension, the culture density was determined spectrophotometrically (at 620 nm), using the 0.5 McFarland standard (1.5×10^8 cfu/mL) for comparison. The cultures were then diluted properly and their density was adjusted to 1.5×10^6 cfu/mL.

Agar Dilution Method

A series of dilutions in agar was prepared by adding an appropriate amount of GPCM extract to the dissolved medium (MHA) cooled to 45°C. The final concentration of the extract in the medium was in the range of 10-40 mg/mL (10, 20, 30, and 40 mg/mL). Then, the substrates were shaken well, and poured into sterile Petri dishes. After the medium had hardened, the cultures were seeded in 10 µL drops

on the surface of the agar plates and incubated at 37 °C for 24 h. The inhibition zones of the growth of the microbial cultures were measured. The highest dilution of the tested extract that inhibited the visible growth of bacteria was considered as the MIC value. From the plates that showed no visible signs of growth/cloudiness in the MIC determination, the test microorganisms were inoculated onto sterile MHA plates. The plates were then incubated at 37 °C for 24 h. The lowest concentration that showed no growth of the test organisms was considered as MBC. The medium without extract was used as a control.

Antioxidant activity

The total phenolic content (TPC) was determined spectrophotometrically using a modified Folin-Ciocalteu method [50]. Non-flavonoids (NF) were quantified using the formaldehyde precipitation method [51], which precipitates flavonoids, and the remaining NF were then measured using the aforementioned Folin-Ciocalteu method. Total flavonoids (TF) were calculated as the difference between TPC and NF.

The concentration of AC was determined using the spectrophotometric method described by Somers and Evans [52]. This method measures the total concentration of AC, ionized AC, colorless AC, and polymeric forms, as well as the degree of AC ionization.

The antioxidant analysis was performed using the following methods: FRAP [53], DPPH [54], and modified $ABTS^{+}$ [55]. The data for calculating antioxidant properties were measured using a UV-VIS spectrophotometer (Milton Ray Spectronic 1201).

Preparation of printing paste

The alginate paste CHT-NV was prepared by adding 69 mL of distilled water at room temperature to 6 g of modified alginate. Continuous stirring was applied until a homogeneous paste was formed. To the prepared paste, 25 mL of GPCM extract (at concentrations of 50 mg/mL (sample E50) and 100 mg/mL (sample E100)) was added, and, as binders, 8 g/L of cross-linking agent citric acid [56], and 2 g/L of tannin to stabilize the color [57].

Momotaz et al. observed that the antibacterial activity was superior to that of binder when the fixation process was carried out using mordant. Mordants facilitate better binding of antibacterial agents to the fabric fibers, leading to more stable and long-lasting antimicrobial properties. Tannins as natural mordants can form complexes with antibacterial compounds, enhancing their retention on the textile surface, which may improve their effectiveness [58].

Spectrophotometric analysis and the determination of AC content in adjusted extracts revealed that a pH of 2 is suitable for achieving a magenta color. Added citric lower the initial extract's pH (4.3) to pH 2, which additionally contributes to the stability of AC in acidic conditions and enhances the overall antioxidant activity of the sample.

Screen printing of cotton fabrics

For the final experiment, a plain weave cotton fabric with a surface mass of 123.36 g/m², density of 23 threads/cm in the warp, and 21 threads/cm in the weft was used as the printing substrate. The cotton fabric were printed using the semi-automatic screen printing machine S-300. The screen mesh was made of 100% polyester monofilament, with a mesh density of 10 threads per centimeter (25 threads per inch), a thread diameter of 300 μm, a mesh opening of 700 μm, and a thickness of 570 μm. The mesh structure was plain weave. Each fabric sample was printed in two passes. The sieve line used (10 threads/cm), considering the viscosity of the paste, enables a good flow of the paste and adequate coverage. Ahmad et al. used a higher screen density (110 threads/inch), due to the different structure of the paste, to obtain a precise impression [42].

Measuring the color coordinates of printed samples

To describe color reproduction, the CIE LabCh color coordinates and spectral reflectance curves were used. A Konica Minolta CM-2600d spectrophotometer was employed to determine the color coordinates (illumination type D65, standard observer angle 10°, measurement geometry d:8°, measurement aperture 11 mm, spectral range 360–740 nm with a 10 nm step). A graphical representation of the object's spectral response at various wavelengths of the electromagnetic spectrum is referred to as the spectral reflectance curve. It shows the reflectance in the visible spectrum and can provide valuable insights for characterizing the colors of the sample's surface [59].

Antibacterial properties of printed samples

The antibacterial activity of the printed samples was tested using the agar diffusion method [60,61]. The following microorganisms were used for testing: *S.aureus* ATCC 25923 and *E.coli* ATCC 25922. Bacterial cultures were grown on Nutrition agar plates, and a suspension of the cultures was prepared in physiological saline. The density of *S.aureus* and *E.coli* was adjusted spectrophotometrically to approximately 1.5×10^6 cfu/mL. Then, 100 μL of each culture was spread on the surface of sterile MHA plates. The culture suspension was carefully distributed across the entire Petri dish surface using a sterile glass L-shaped rod. Fabric samples were then placed on the inoculated agar surface. The plates were

incubated at 37 °C for 24 hours. After incubation, the inhibition zone (mm) was measured using the following formula:

$$Z_i = \frac{(T - D)}{2} \quad (1)$$

where:

Z_i – width of the inhibition zone (mm),

T – total width of the sample + inhibition zone (mm),

D – width of the sample (mm).

If no inhibition zone (Z_i) is observed, but there is no growth beneath the samples, it is defined as contact inhibition (CI).

Results and discussion

Antioxidant activity of GPCM extract

TPC, TF, and NF contents of GPCM extract were determined spectrophotometrically. The content of the components TPC, TF and NF in the GPCM extract is shown in Figure 2.

Figure 2

TPC was 34.73 mg GAE/g, indicating a high level of bioactive compounds. NF were the dominant group, with 22.12 mg GAE/g, and TF accounted for 12.61 mg GAE/g. The antioxidant activity of GPCM extract was evaluated using the DPPH, $ABTS^+$, and FRAP methods. The DPPH method demonstrated significant radical-scavenging ability (28.09 mM TE/g dry weight), but FRAP method revealed a low iron-reducing capacity (0.52 mM Fe^2/g dry weight), indicating limited direct electron-donating ability. However, the GPCM extract exhibited the highest antioxidant activity according to the $ABTS^+$ method (104.89 mM TE/g dry weight). This suggests that the GPCM extract is effective against various types of free radicals and may contain diverse phenolic components with complementary mechanisms of action. This suggests the potential application of the extract in the development of natural antioxidant dyes for textile printing.

Antibacterial activity of GPCM extract

The GPCM extract demonstrated moderate antibacterial activity against *S. aureus* (MIC 30 mg/mL, MBC 40 mg/mL) and *E. coli* (MIC 20 mg/mL, MBC 30 mg/mL). Similar MIC and MBC values were reported by Peixoto et al. [16], who established a strong correlation between antimicrobial activity and the phenolic content, particularly flavonoids, phenolic acids, and AC. Phenolic compounds disrupt

bacterial membrane function, penetrate the membrane, dissociate in the cytoplasm, and exert toxic effects [62]. Contrary to Peixoto et al. [17], this study found that the grape pomace extract exhibited stronger inhibition of the Gram-negative bacterium *E. coli* compared to the Gram-positive *S. aureus*. However, Fernández-Pérez et al. [63] reported a very low MIC for grape pomace extract of *Vitis vinifera* L. *cv.* Graciano, and that a higher TPC correlated with a higher antibacterial activity of the extracts. The phenolic composition of different *Vitis vinifera* varieties, as well as varying climatic and cultivation conditions, results in differences in phenolic content and, consequently, biological activity.

Regulation of pH value and spectrophotometric analysis

Experimental results showed changes in the color of GPCM extract depending on the pH value. Based on the results presented in Table 1, the changes in the concentration of AC (total, ionized, and colorless) at different pH values, as well as the degree of ionization (α), can be analyzed.

Table 1

With an increase in the pH of the samples, a decrease in AC concentration is observed, resulting in the loss of the red hue. The color of flavylium cations (red) is transformed into colorless chromenol. At pH values of 7–8, the ionized anhydro base of AC transformed, leading to ring opening and the formation of chalcone, which gave the samples a yellow color. Under basic conditions (pH 10–12), AC undergo further degradation, resulting in a significant reduction in concentration, and the samples acquired a brownish hue due to the presence of degradation products [20]. The proportion of ionized red flavylium cations was the highest at pH 2 (222.43 mg/L), with a degree of ionization of 82.54%, which resulted in an intense red color of the extract.

With increasing pH values, flavylium cations become colorless, that can be noticed by changes in light absorption [64]. Spectrophotometric analysis of transmittance and absorbance showed that samples at different pH values were transparent, but transparency decreased with increasing pH. It is expected for changes in pH values to affect the stability and structure of AC, directly influencing the color components of the sample.

On Figure 3a are presented spectral data of the samples. These data indicate that below 580 nm all samples show complete light absorption with no transmittance. At lower, acidic pH values, where AC content is higher, samples allowed greater transmittance of light in the red region of the spectrum (620–740 nm). In contrast, samples at pH 12 showed nearly complete absorption in the visible spectrum, resulting from AC degradation and the formation of darker products.

Figure 3

The absorption graph (Figure 3b) highlighted the stability of absorption under neutral conditions (U6, U7, U8), while in acidic and basic regions, absorption curves were unstable. In the yellow region (chalcone, 580–600 nm), changes were most evident in samples U2, U10, and U12. Similarly, in the purple region (420–480 nm), shifts in absorption corresponded to the formation of quinonoid bases.

These changes in light absorption and sample color demonstrated the significant impact of pH value on the stability and structure of AC. The results confirmed that an acidic environment is most favorable for preserving the stability and color of AC, while in basic conditions, degradation occured, lead to inactive forms of AC. Quantification results showed that the concentration of AC was the highest at low pH (2), and decreased with increased pH. This is particularly important for applications in the textile industry, where color stability is important for the durability of color.

Color coordinates of the printed samples

After mixing extracts (E50 and E100) with alginate paste and screen printing on cotton fabric, the spectropohtometric coordinates were measured. The results are shown in Table 2. It can be noticed that the samples have high lightness. Color was very subtle, which is expected for natural dye. Chroma rised with higher concentration of extract, and hue was between blue and red axis. Hue angle (292-298°) corresponded with desired magenta tone.

Table 2

The spectral reflectance curves of the printed samples demonstrated the impact of extract on the optical properties of the printed fabric and their potential to achieve magenta hues. Results are shown at Figure 4. At shorter wavelengths (360–460 nm), both samples had similar reflectance levels, with a peak reflectance observed between 440 and 460 nm, indicating the presence of blue tones. In the longer wavelength range (500–700 nm), the reflectance gradually decreased, with notable absorption in the 520–580 nm region, which is critical for the appearance of magenta. The sample printed with a higher extract concentration (E100) showed consistently lower reflectance values across the spectrum compared to the sample with a concentration of 50 mg/mL (E50), suggesting a darker and more intense coloration, particularly in the magenta-relevant range. These results confirmed that the higher extract concentration enhanced the ability to achieve stable and rich magenta tones.

Figure 4

Antioxidant activity of printed samples

TPC, TF, and NF content of printed samples with two extract concentrations are showed in Table 3. Based on the results obtained, it is clear that sample E100 had higher TPC, TF, and NF content compared to sample E50, likely due to the larger amount of extract used.

Table 3

The antioxidant activity of the samples was evaluated using the DPPH, ABTS+, and FRAP methods. The results obtained using these tests showed that the sample E100 exhibited a stronger antioxidant effect than the sample printed with E50, most likely due to the higher content of phenolic compounds in the E100 sample, indicating a higher level of bioactive compounds contributing to the antioxidant properties of the printed sample. Phenol-rich extracts, particularly those high in flavonoids, have potential applications in the protection of textile materials due to their ability to prevent oxidative and microbial damage.

Antibacterial activity of printed samples

Based on the results of the antibacterial activity testing (table 4) of sample E100, the presence of contact inhibition on *E.coli* and *S.aureus* bacteria can be confirmed. The antibacterial activity of the sample E50 on *S.aureus* also showed contact inhibition, while on *E.coli* the effect was weaker and defined as partial contact inhibition (PCI). However, the presence of antibacterial activity in the printed sample in the form of PCI against *E. coli* still represented a significant effect, as *E. coli* is a highly resistant bacterium. The results obtained correlate well with the findings of the antioxidant properties analysis of printed samples.

Table 4

Considering that the extracts were derived from grape pomace, where the MIC and MBC values of the extracts were find low to moderate, the observed antibacterial activity of the printed samples can be considered as a significant result. The improvement in antibacterial activity can be attributed to the reduction of the initial extract's pH from 4.3 to 2 by the addition of citric acid and tannin. These findings also highlighted the potential of the extract, when combined with a suitable binder, to enhance antibacterial efficacy in textile applications.

The functional finishing of textiles with plant extracts has indeed gained attention as an innovative area of research in the textile industry. Many researchers have explored dyeing textiles using plant extracts

such as *Euclea divinorum* [38], *Achillea millefolium* [46,47] and *Allium cepa*, *Zingiber ofcinale* and *Nigella sativa* [58]. However, fewer studies have focused on textile printing using extracts [1,59]. From the studies mentioned, it is evident that antimicrobial properties of dyed textiles are significantly better compared to those of printed textiles.

Conclusion

This study explored the potential of grape pomace from domestic cultivar crna Mirisavka (GPCM) as a natural dye for screen printing applications on cotton fabrics. The results demonstrated that the extract's color properties were highly dependent on pH, with the most intense magenta tone observed at acidic pH values (pH 2). Spectrophotometric analysis revealed significant absorption in the magenta-relevant wavelength range (520–580 nm), confirming its suitability for achieving vibrant and stable colors. The antioxidant activity underscored the extract's potential to protect the fabric from oxidative damage, while its high flavonoid content contributed to its bioactive properties.

The printed fabrics exhibited promising antioxidant and antibacterial activity, particularly with extract at higher concentration (100 mg/mL). These findings suggested that the extract's bioactive components, combined with alginate paste, enhanced antibacterial effects, making it a viable option for functional and aesthetic applications in the textile industry.

The use of grape pomace as a secondary raw material highlighted the potential of waste valorization to create eco-friendly products, reducing environmental impact and promoting sustainability. Investigations into the durability of these materials, color properties, antimicrobial effectiveness, and compatibility with other natural additives, would provide further insights into their industrial applicability.

The potential application of textiles printed with grape pomace extracts would be for the production of ecological antimicrobial children's toys, decorative objects and packaging. Future research will be oriented towards the modification of printing pastes in order to improve the fastness of coloring to washing and UV radiation.

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Declarations

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Table caption list:

Table 1. Quantification of AC in GPCM extract

Sample label	pH value of GPE	AC (mg/L)	iAC (mg/L)	clAC (mg/L)	α
U0	4.3	265.69	73.49	192.20	27.66
U2	2	269.40	222.30	47.10	82.52
U4	4	287.91	61.46	226.45	21.35
U6	6	268.19	59.24	208.95	22.09
U7	7	237.19	52.59	184.60	22.17
U8	8	184.11	65.66	118.45	35.66
U10	10	50.07	ND	-	-
U12	12	63.91	ND	-	-

AC – total anthocyanins; iAC – ionized anthocyanins; clAC – colorless anthocyanins; α – degree of ionization; ND – In samples with high pH values, due to the low AC content, the value of ionized AC could not be detected (ND).

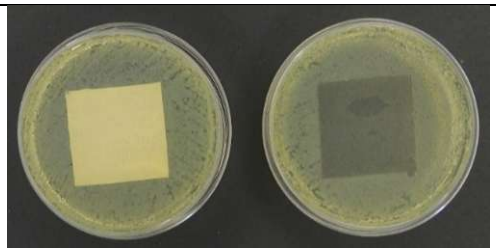
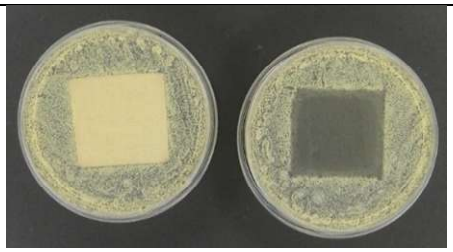
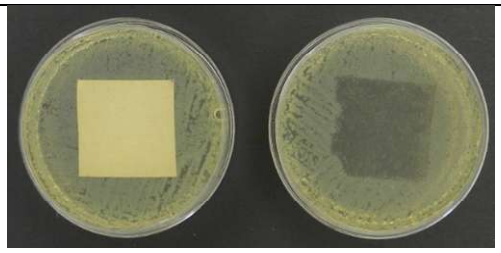
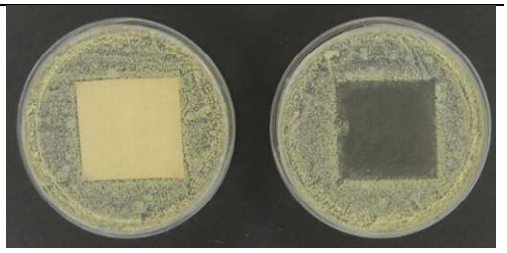
Table 2. Color coordinates of printed samples

Sample	L*	a*	b*	C	h°
E50	90.35	3.24	-7.74	8.39	292.71
E100	88.81	4.64	-8.87	10.01	297.63

Table 3. Examination of the antioxidant activity of cotton fabric printed with alginate paste modified with GPCM extract

Sample	E50	E100
TPC (mg GAE/g)	1.343 ± 0.136	1.596 ± 0.107
TF (mg GAE/g)	0.17 ± 0.027	0.301 ± 0.226
NF (mg GAE/g)	1.172 ± 0.163	1.294 ± 0.119
FRAP (μmol Fe^{2+}/g)	20.87 ± 0.72	24.98 ± 0.22
DPPH (μmol TE/g)	6.715 ± 0.34	8.443 ± 0.242
$ABTS^{+}$ (μmol TE/g)	22.052 ± 0.997	28.606 ± 1.116

Table 4. Examination of the antibacterial activity of cotton fabric printed with alginate paste modified with GPCM extract on Escherichia coli and Staphylococcus aureus bacteria

Sample	*Escherichia coli*	*Staphylococcus aureus*
E100		
	Contact inhibition (CI)	*Contact inhibition (CI)*
E50		
	Partial contact inhibition (PCI)	*Contact inhibition (CI)*

CI – contact inhibition (100% reduction of microorganisms under the sample
PCI – partial contact inhibition (more than 50% reduction of microorganisms under the sample)
(right side of each petri dish indicates where the sample was removed from the agar plate)

Figure caption list:

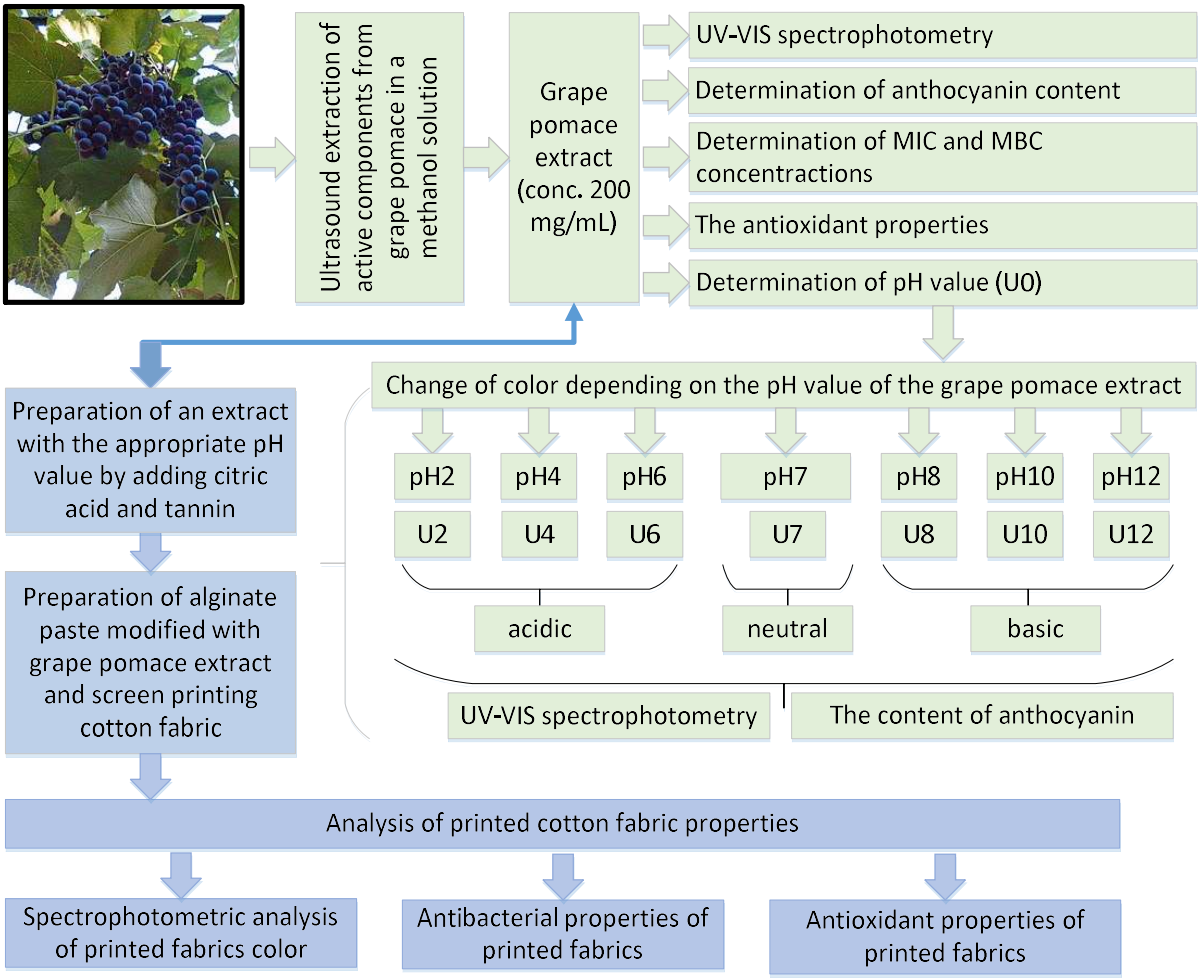

Ultrasound extraction of active components from grape pomace in a methanol solution
Grape pomace extract (conc. 200 mg/mL)
UV-VIS spectrophotometry
Determination of anthocyanin content
Determination of MIC and MBC concentractions
The antioxidant properties
Determination of pH value (U0)
Change of color depending on the pH value of the grape pomace extract
pH2
pH4
pH6
pH7
pH8
pH10
pH12
U2
U4
U6
U7
U8
U10
U12
acidic
neutral
basic
UV-VIS spectrophotometry
The content of anthocyanin
Preparation of an extract with the appropriate pH value by adding citric acid and tannin
Preparation of alginate paste modified with grape pomace extract and screen printing cotton fabric
Analysis of printed cotton fabric properties
Spectrophotometric analysis of printed fabrics color
Antibacterial properties of printed fabrics
Antioxidant properties of printed fabrics

Figure 1

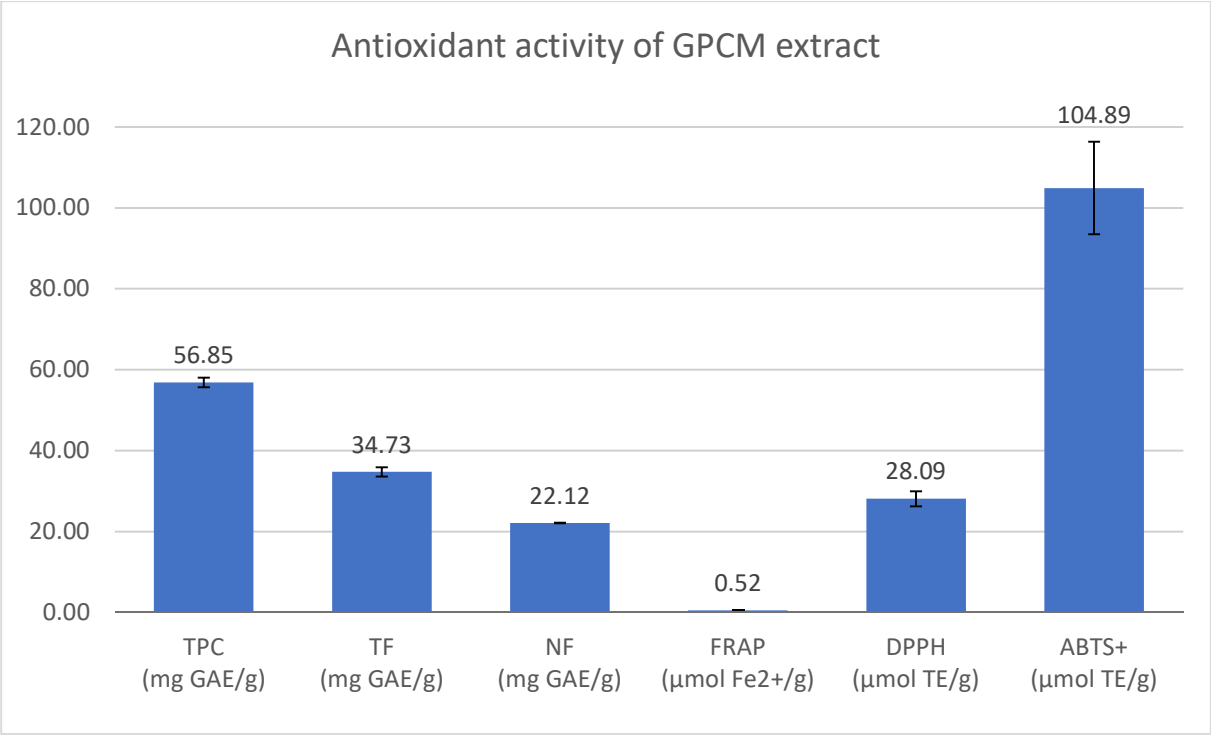

Antioxidant activity of GPCM extract
120.00
100.00
80.00
60.00
40.00
20.00
0.00
56.85
34.73
22.12
0.52
28.09
104.89
TPC (mg GAE/g)
TF (mg GAE/g)
NF (mg GAE/g)
FRAP (µmol Fe2+/g)
DPPH (µmol TE/g)
ABTS+ (µmol TE/g)

Figure 2

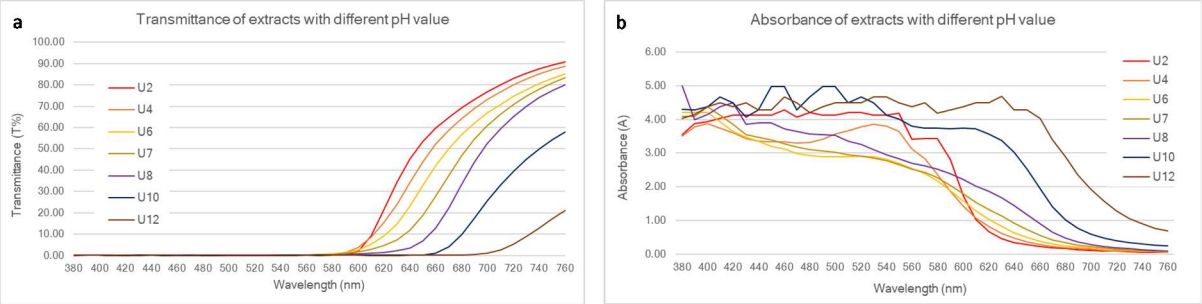

a
Transmittance of extracts with different pH value
Transmittance (T%)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
U2
U4
U6
U7
U8
U10
U12
380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760
Wavelength (nm)
b
Absorbance of extracts with different pH value
Absorbance (A)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
U2
U4
U6
U7
U8
U10
U12
380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760
Wavelength (nm)

Figure 3

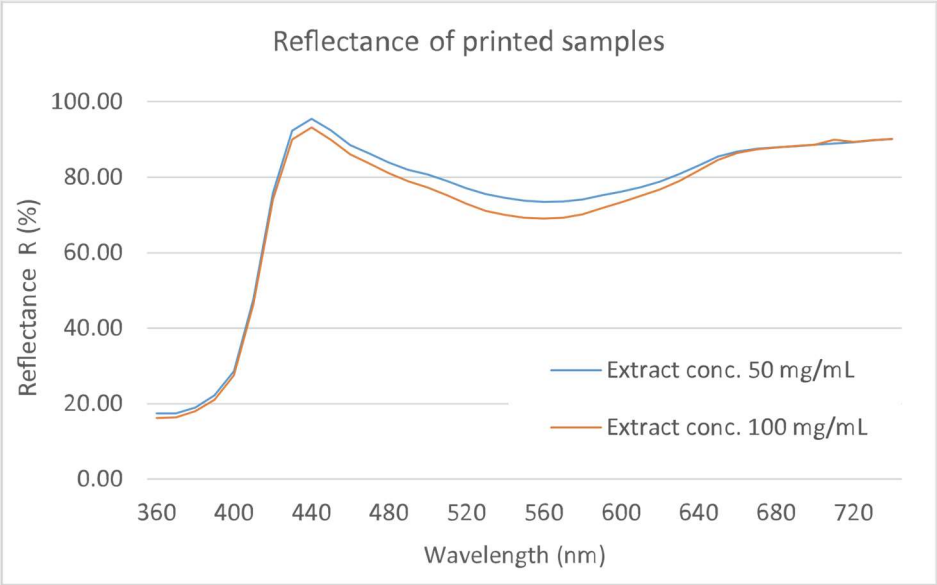

Reflectance of printed samples
100.00
80.00
60.00
40.00
20.00
0.00
Reflectance R (%)
360
400
440
480
520
560
600
640
680
720
Wavelength (nm)
Extract conc. 50 mg/mL
Extract conc. 100 mg/mL

Figure 4