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Color fastness and antimicrobial activity of *Gardenia jasminoides* extract against antimicrobial-resistant *Staphylococcus aureus*

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Abstract

This study investigated the antimicrobial efficacies of fabrics (100% cotton and 100% silk) dyed with an ethanol extract of *Gardenia jasminoides* (*G. jasminoides*). More specifically, these fabrics were dyed using a *G. jasminoides* extract with a dye bath ratio of 1:20 at 40–60 °C for 60 min, followed by post-mordanting. The concentrations of the aluminum sulfate, copper sulfate, and ferrous sulfate mordants were each set to 3% (o.w.f.). The samples were mordanted using a mordant bath ratio of 1:30 at 40 °C for 20 min. The iron mordant slightly increased the dye uptake (K/S) of the cotton fabric but did not increase the dye uptake (K/S) of the silk fabric. The antimicrobial efficacies of the dyed fabrics against methicillin-resistant *Staphylococcus aureus* (MRSA) ATCC 33591 were determined to be 99.8 and 87.8% for the cotton and silk fabrics, respectively. The inhibitory effects of the cotton and silk fabrics against MRSA were 30.5 × and 167.3 × the inoculum size, respectively, indicating the superior inhibitory effect of the dyed cotton fabric. These results suggest that the fabrics dyed with *G. jasminoides* extract may possess antibacterial activity against antimicrobial-resistant bacteria.

Keywords: Antimicrobial efficacy, Color fastness, *Gardenia jasminoides*, MRSA, Natural dye

Introduction

Naturally occurring compounds can be utilized as coloring and finishing agents to produce environmentally friendly textile products. For example, natural colorants have been used to dye various materials, including fibers, foods, and cosmetics. For such purposes, it is necessary to select natural colorants that possess the appropriate properties for maintaining and enhancing the product quality, including good resistances to heat, light, salts, and acidic and alkaline conditions (Hong, 2023; Shin, 2007; Yin et al., 2024). Due to the ability of natural dyes to circumvent the harmful effects of synthetic dyes on the human body and on wastewater, they are expected to play a significant role not only in dyeing applications

but also in natural colors and fragrances, pharmaceutical development, and environmental protection when combined with modern advanced technologies (Cha et al., 2006). Natural dyes have the advantage of creating unique and deep colors compared to chemical dyes, penetrating deep into textiles, and maintaining the desired color for long periods of time. They also tend to be biodegradable and are less harmful to the skin and scalp, thereby representing good alternatives for individuals suffering from sensitive skin or allergies. It has also been reported that some natural dyes exhibit excellent antibacterial properties (Kim & Lee, 2015), anti-inflammatory effects (Son & Kim, 2013), and antioxidant capabilities (Yang et al., 2011). However, the majority of natural pigments exhibit inferior fixation and fastness characteristics when applied to cellulosic fibers (Hong, 2023). It is therefore desirable to evaluate the washing fastness properties of different fabrics following dyeing by natural colorants such as that originating from *Gardenia jasminoides* Ellis (*G. jasminoides*).

G. jasminoides, which is known traditionally for its antimicrobial properties, is an ever-green shrub belonging to the Rubiaceae family, and is commonly grown in many temperate regions. The oval-shaped fruits of *G. jasminoides* ripen in the late fall and are reddish-yellow in color. Traditionally, these fruits have been widely used as a herbal medicine to treat several diseases (He et al., 2006), as a dye for cloths (Hong et al., 2015; Zhou et al., 2015), and for coloring foods (Spears, 1988). More specifically, in traditional Korean medicine, *G. jasminoides* has been used to treat diabetes, jaundice, gonorrhea, conjunctivitis, and inflammation. Previous studies into its bioactivity describe its wide-ranging antimicrobial (Choo, 2002; Kim et al., 2003; Yim et al., 1999), anticancer (Abdullaev, 1994; Lee et al., 2006), antioxidant (Kim et al., 2006, 2020; Pham et al., 2000), blood pressure-lowering (Choi et al., 2002), and lipid-lowering effects (Lee et al., 2005).

The yellow pigment of *G. jasminoides* has a long history of use as a food dye, wherein its key component is crocin, a glycosyl ester (Kim & Jang, 2005; Kim et al., 2020). It has also been reported to contain iridoid compounds, such as genipin, geniposide, geniposidic acid, gardenoside, shanzhiside, methyl deacetyl asperuloside, gardanin (a flavonoid) quinic acid and its derivatives (anti-inflammatory compounds), vanillic acid 4-O- β -D-(6'-sinapoyl) glucopyranoside, and caffeic acid (Kim et al., 2006; Shin et al., 2003). Previous studies have reported that *G. jasminoides* exhibits antimicrobial activity against *Salmonella Typhimurium* and *Escherichia coli*, among other bacteria (Oh, 2002). However, no studies have examined the antimicrobial activity of *G. jasminoides*-dyed fabrics against antimicrobial-resistant bacteria, also known as superbugs. Such investigations are of particular interest due to the ability of such bacteria to spread not only from patient to patient but also through medical fabrics, bedding, and various household items (Scott et al., 2008).

Therefore, this study aims to examine the color fastness of *G. jasminoides* in cotton and silk fabrics following natural dyeing and subsequent post-mordanting with aluminum, copper, and iron. The dyeing solution used herein is obtained by extracting *G. jasminoides* with ethanol. The antimicrobial properties of the resulting dyed cotton and silk fabrics are then tested for their effectiveness against methicillin-resistant *Staphylococcus aureus* (MRSA).

Methods

Test fabric materials

The test fabrics used for natural dyeing and antimicrobial activity measurements were commercially available cotton and silk fabrics (Taihan Textile Co., Seoul, Republic of

Table 1 Characteristics of the cotton and silk fabrics employed in the current study

Composition	Weaving structure	Count (Ne)	Density (thread/5 cm)		Mass (g/m ²)
			Warp	Weft	
Cotton 100%	Plain weave	21.8×22.1	129.8	127.8	161.1
Silk 100%	Plain weave	80.8×80.2	188.8	169.2	112.2

Table 2 Measurement of the inhibitory effects of the dyed fabrics against MRSA

Sequence	Method	Remarks
1	Prepare the dyed fabrics (cotton and silk) by cutting into 5 cm × 5 cm squares and place them in a petri dish	Conduct the experiment on a clean bench (VS-1400LS-3N, Vision Scientific Co., Daejeon, Republic of Korea)
2	Incubate the MRSA (ATCC 33591) in BHI medium for 24 h	Incubator (SLI-400, EYELA)
3	Dilute the cultured strain to 1×10^5 and inoculate 250 μ L onto the prepared fabric sample	Petri dish (SPL, Pocheon, Republic of Korea)
4	Incubate in an incubator at 37 °C for 24 h	
5	Collect the bacteria from the dyed fabrics using phosphate buffered saline (PBS) buffer in a petri dish	
6	Inoculate the harvested bacteria on BHI Agar medium and incubate for 24 h	Incubator (SLI-400, EYELA)
7	Measure the colony-forming units (cfu) in the culture	

Korea). Table 1 shows the characteristics of these samples (Table 1). For the natural dye, 400 g of *G. jasminoides* was procured from the Korean Oriental Pharmacy, Republic of Korea. Extra pure reagents were used for the mordanting process. The mordants used were aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3$), iron sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$), and copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) (Daejung Chemical Co., Siheung, Republic of Korea). The strain used to investigate the antimicrobial properties of the dyed fabrics was MRSA ATCC 33591, which was cultured on brain heart infusion agar (BHA) and brain heart infusion broth (BHI; Becton, Dickinson and Co., Franklin Lakes, NJ, USA), containing oxacillin (2.0 μ g/mL; Sigma-Aldrich Co. St. Louis, MO, USA) and fungizone (2.5 μ g/mL; Life Technologies Co., Grand Island, NE, USA) (Table 2).

Extraction of the dyeing solution

The *G. jasminoides* sample (400 g) was placed in 70% ethanol (4 L), and the dye solution was extracted for two weeks at room temperature. After this time, the extract was filtered to yield 3.6 L of dye (Fig. 1).

Dyeing method

The cotton and silk fabrics were placed in a water bath with a dye bath ratio of 1:20. The temperature was raised from 40 to 60 °C and maintained at this temperature for 60 min. The mordanting process was based on the method reported by Oh (2002). The mordants contained 3% (o.w.f.) each of aluminum, copper, and iron, and the mordant bath ratio

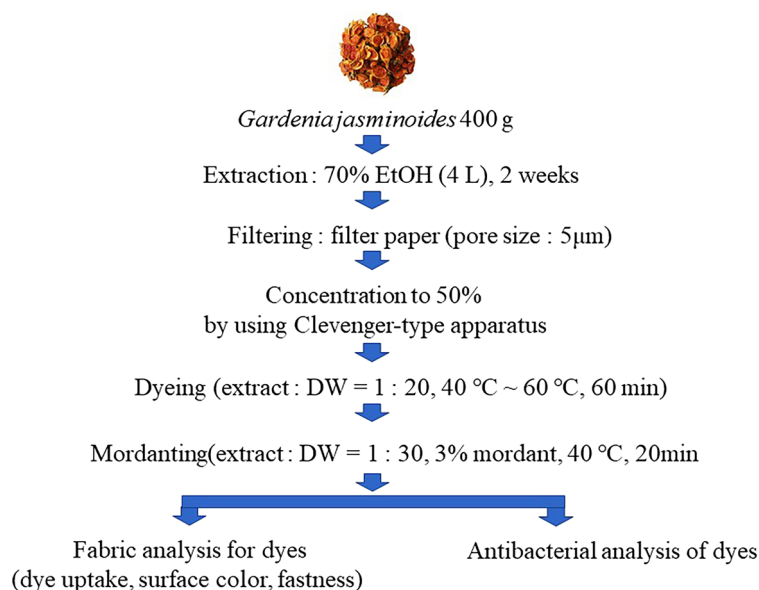


Fig. 1 Flow-chart outlining the process employed to dye cotton and silk fabrics using a *G. jasminoides* extract

was 1:30. The cotton and silk fabrics were placed in the water bath and subjected to mordanting at 40 °C for 20 min. After dyeing, the fabrics were washed and air dried (Fig. 1).

Measurement of the dye uptake

The dye uptake (K/S) values of the cotton and silk fabrics were measured using a spectrophotometer (CM-700d spectrophotometer, KONICA MINOLTA, Osaka, Japan). The surface reflectance of the dyed fabric was calculated at the maximum absorption wavelength using a D65 light source and a 10° field of view. The K/S value was calculated according to the Kubelka–Munk equation and evaluated as the dye uptake.

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

where K is the absorption coefficient of the dyed fabric, S is the scattering coefficient of the dyed fabric, and R is the surface reflectance of the dyed fabric.

Measurement of the surface color

L^* (The Lightness; 100 White to 0 Black), a^* (The Redness-Greenness; + Redness to - Greenness), and b^* (The Yellowness-Blueness; + Yellowness to - Blueness) values were measured using a GretagMacbeth Color Eye 7000A spectrophotometer (CCM; Grand Rapids, MI, USA) to determine the colors of the dyed cotton and silk fabrics (Choi et al., 2023; Park, 2023). The color difference (ΔE_{ab}) between the undyed and

dyed fabrics was measured using the differences in the L^* , a^* , and b^* values compared to the raw fabrics (KS S 0205:2018).

$$\Delta E_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2} \quad (2)$$

Fastness measurements

The washing fastness, rubbing fastness, perspiration fastness, and light fastness were measured and compared for the dyed fabrics. The washing fastness was measured according to KS K ISO 105-C06:2012 using a Launder-o-meter (Koa Shokai Ltd., Kyoto, Japan), while the rubbing fastness was measured according to KS K 0650:2017 using a Crockmeter (AATCC Atlas Electric Device Co., Chicago, IL, USA). In addition, the perspiration fastness was measured according to KS K 105-E04:2010 using a Perspiration Tester (AATCC, Atlas Electric Device Co.), and the light fastness was measured according to KS K 105-B02:2014 using a Color & Color Difference Meter. The color changes were evaluated according to KS K ISO 105-A05:1996 (Instrumental Assessment of Change in Color for Determination of Grey Scale Rating), while the stain ratings were evaluated according to KS K ISO 105-A04:1989 (Method for the Instrumental Assessment of the Degree of Staining of Adjacent Fabrics). The color change gray scales and color staining gray scales composed of achromatic color charts were used to determine color fastness. The color change and stain were evaluated by grading based on the color difference before and after treatment. A spectrophotometer was used to quantitatively set the color difference between the color tables. The color difference was calculated by measuring the reflectance at each stage with a spectrophotometer and determining the tristimulus value of the color.

MRSA inhibition measurements

The inhibition of MRSA by the dyed fabrics (see Table 2) was evaluated using the methodology described by Choi and Kang (2015). For this purpose, 1×10^5 cfu/mL of the MRSA strain (250 μ L) was inoculated on samples of the dyed fabrics (5 cm $\times$ 5 cm). After inoculation, the bacteria were cultured in a 37 °C incubator (SLI-400, EYELA, Tokyo, Japan) for 24 h. The cultures on the dyed fabrics were then harvested and inoculated on BHI Agar medium, incubated in phosphate buffered saline (PBS), and cultured in a 37 °C incubator (SLI-400, EYELA) for 24 h. The bacterial colonies (colony forming units, cfus) on the incubated BHI agar were measured, and the antimicrobial effect was calculated as follows:

$$\text{Antimicrobial effect (\%)} = (A - B)/A \times 100 \quad (3)$$

where A is the bacterial count of the raw fabric, and B is the bacterial count of the fabric dyed with *G. jasminoides*.

Statistical processing

The results of this study are presented as means $\pm$ standard deviations, as calculated using the statistical program SPSS (ver. 26.0). The mean values obtained for the experimental

and control groups were tested for significance using an independent sample t-test at the $\alpha=0.05$ level, and the results are presented as the means $\pm$ standard deviations.

Results and Discussion

Dye uptake of the dyed fabrics

Table 3 shows the K/S values of the cotton and silk fabrics dyed with the *G. jasminoides* extract. Overall, the K/S values were higher for the silk fabrics than for the cotton fabrics. In the case of the cotton fabric, treatment with the iron mordant increased the dye uptake only slightly, with no increased uptake being observed for the other fabric/mordant combinations. These results indicate that both the cotton and silk fabrics dyed with *G. jasminoides* extract can be dyed without using mordants. In addition, it was found that the dye uptake was greater for silk than for cotton. Notably, Oh (2002) found that the use of $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{K}_2\text{Cr}_2\text{O}_7$ mordants increased the dye uptake slightly on both cotton and silk fabrics, each producing different results (Table 3, Fig. 2).

Changes in the surface color

Table 4 shows the changes in the surface colors of cotton and silk fabrics dyed with the *G. jasminoides* extract. For the dyed cotton fabrics, the fabric treated with the copper mordant (83.1) exhibited the highest L^* value, whereas the fabric treated with the iron mordant (80.4) showed the lowest value. For the dyed silk fabrics, the fabric treated with the aluminum mordant (77.9) demonstrated the highest L^* value, whereas the fabric treated with the iron mordant (68.1) had the lowest value. These results indicate that the brightest dyed cotton and silk fabrics were obtained using copper and aluminum mordants, respectively. Both fabrics exhibited their lowest L^* values when the iron mordant was employed, resulting in the darkest colors. Moreover, when the same mordant was employed, the L^* values were lower for the dyed silk fabrics than for the dyed cotton fabrics. Consequently, the dyed cotton fabrics were lighter in color than the dyed silk fabrics.

The a^* and b^* values, which represent the degrees of red and green, respectively, were also examined. It was found that the cotton fabrics dyed with the *G. jasminoides* extract all possessed a reddish color with positive a^* values. The b^* values were all above +36, indicating a yellowish color. Similarly, the silk fabrics dyed with the *G. jasminoides* extract exhibited a reddish color with positive a^* values, and the b^* values were

Table 3 K/S and λ_{max} values of the dyed cotton and silk fabrics

Fabric	Mordant	λ_{max} (nm)	K/S
Cotton	No mordant	450	0.64 ± 0.020
	Aluminum	450	0.47 ± 0.018
	Copper	450	0.61 ± 0.012
	Iron	450	0.71 ± 0.011
Silk	No mordant	450	3.94 ± 0.013
	Aluminum	450	2.72 ± 0.011
	Copper	450	2.48 ± 0.018
	Iron	450	1.48 ± 0.013

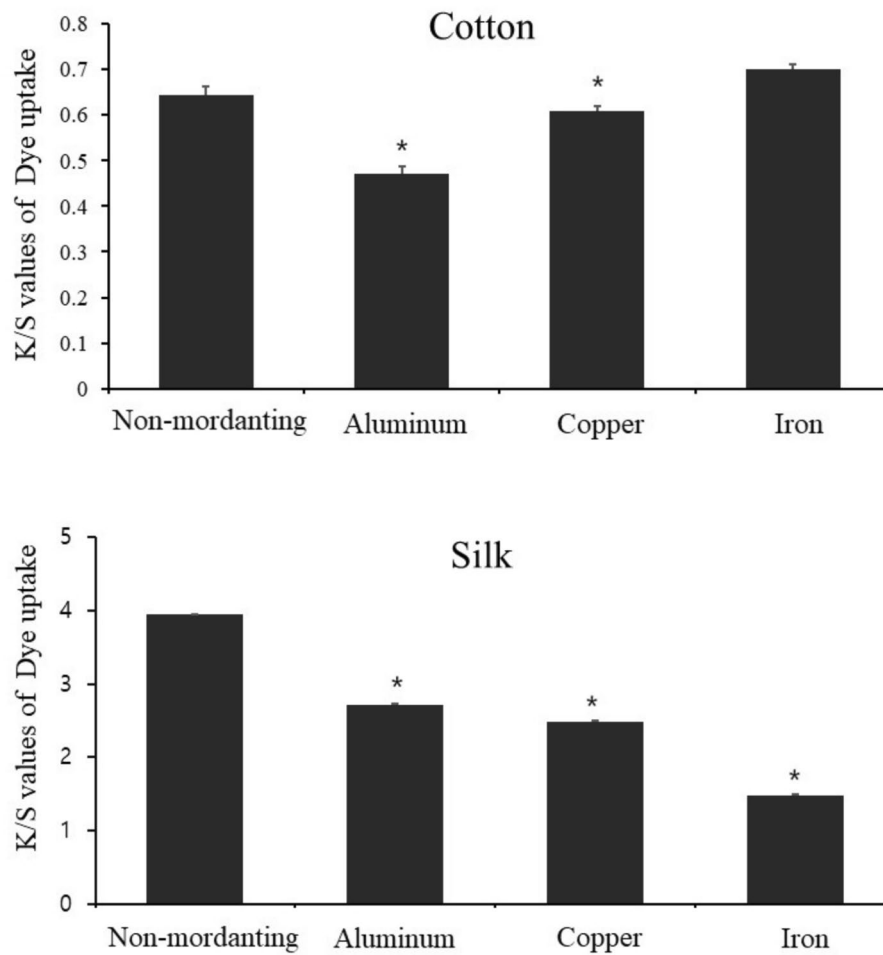
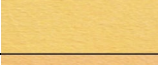
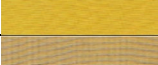


Fig. 2 Dye uptakes for the cotton and silk fabrics upon treatment with the *G. jasminoides* extract and subsequent mordanting

Table 4 The L^* , a^* , b^* , and ΔE_{ab} values for the dyed cotton and silk fabrics

Fabric	Mordant	L^*	a^*	b^*	ΔE_{ab}	Sample image
Cotton	No mordant	81.3±0.21	13.4±0.15	52.7±0.18	52.4±0.12	
	Aluminum	82.4±0.15	11.9±0.12	50.9±0.19	50.1±0.20	
	Copper	83.1±0.21	3.6±0.22	37.4±0.15	35.6±0.13	
	Iron	80.4±0.16	37.4±0.14	36.4±0.20	36.4±0.11	
Silk	No mordant	76.9±0.01	9.7±0.11	63.8±0.09	43.4±0.12	
	Aluminum	77.9±0.12	8.5±0.15	60.4±0.17	40.6±0.15	
	Copper	74.8±0.20	3.8±0.21	55.7±0.15	36.6±0.13	
	Iron	68.1±0.13	1.6±0.12	43.5±0.15	27.4±0.11	

all above +43, indicating an extremely deep yellowish color. The color difference (ΔE_{ab}) between the raw and dyed cotton fabrics was also compared, and the largest color difference values were found for the non-mordanted samples, followed by those treated with the aluminum, iron, and copper mordants. Furthermore, upon comparison of the color differences between the raw and dyed silk fabrics, the largest color difference values were found for the non-mordanted samples, followed by those treated with the aluminum, copper, and iron mordants. These results indicate that both the dyed cotton and silk fabrics exhibited the largest color difference values when no mordant was used. The dyed cotton fabrics showed a lower color difference when the copper mordant was used whereas the dyed silk fabrics showed a lower color difference when the iron mordant was used. According to Jeon et al. (2003), dyeing with *G. jasminoides* is not affected by mordants due to the ability of the dye to bond directly with the cellulose molecular chains. Thus, in the present study, it was confirmed that the dyeing of cotton and silk fabrics with *G. jasminoides* produces strong colors even without the use of mordants (Table 4).

Comparative analysis of the color fastness

The color fastness properties of the cotton and silk fabrics dyed with *G. jasminoides* extract were compared for the non-mordanted fabrics and those treated with the three different mordants, as detailed below.

Washing fastness

Table 5 shows a comparison of the washing fastness properties of the cotton and silk fabrics dyed with *G. jasminoides* extract, wherein it can be seen that under all conditions, the color change was poor to moderate (levels 2–3) for all cotton fabrics, while the silk fabrics gave greater color change levels of 4 and 4–5 for the non-mordanted and aluminum-treated samples, respectively. Notably, the color changes observed herein were greater than those reported by Oh (2002), who described very poor color change in cotton fabrics dyed with *G. jasminoides* (i.e., level 1), both with and without mordanting. Similarly, a poor to moderate degree of color change was observed for their silk specimens compared to the specimens examined herein (i.e., levels 2–3). These differences were attributed to the extraction methods employed in the two studies, suggesting that ethanol extraction leads to greater color changes. Moreover, the results indicate that cotton fabrics may be more susceptible to fading than silk fabrics when washed in water.

Table 5 Washing fastness characteristics of the dyed fabrics

Color fastness	Mordant	Cotton fabric			Silk fabric		
		Color change	Stain		Color change	Stain	
			Cotton	Wool		Silk	Cotton
Washing fastness	No mordant	2–3	4	4–5	4	4–5	4
	Aluminum	2–3	4	4–5	4–5	4–5	4
	Copper	3	4–5	4–5	3	4–5	4
	Iron	3	4–5	4–5	3–4	4–5	4

The washing fastness to stain was good to very good for the cotton fabrics (i.e., levels 4–5) when the accompanying fabric was wool, while good to very good results were obtained (level 4 for non-mordanted and aluminum mordanted; 4–5 for copper and iron mordanted) when the accompanying fabric was cotton. Similarly, the washing fastness to stain was good to very good for the silk fabrics (i.e., levels 4–5) when the accompanying fabric was silk, and good (i.e., level 4) when the accompanying fabric was cotton. In *Chamaecyparis obtusa* (*C. obtusa*) dyeing, the stain washing fastness of cotton fabric was reported to be good to very good (i.e., levels 4–5) for both cotton and silk (Choi & Park, 2023). However, in the current study, a lack of mordanting or aluminum mordanting gave a level 4 stain washing fastness, which is lower than the results obtained for *C. obtusa*, while copper and iron mordanting gave levels of 4–5. These results suggest that *G. jasminoides* dyeing can be recommended on cotton fabrics when copper or iron mordants are employed, resulting in a low stain washing fastness (Table 5).

Rubbing fastness

Table 6 shows the results of the rubbing fastness tests performed on the cotton and silk fabrics dyed with the *G. jasminoides* extract. After drying, the rubbing fastness was good to very good for both the dyed cotton and silk fabrics (levels 4–5). These results suggest that the dyed cotton and silk fabrics were resistant to rubbing, both in their dry and wet forms. These results are consistent with those reported by Kim et al. (2016), suggesting that these fabrics can be dyed with *G. jasminoides* extract without using mordants (Table 6).

Perspiration fastness

Tables 7 show the results of the perspiration fastness tests performed for the cotton and silk fabrics dyed with the *G. jasminoides* extract. For acidic perspiration, the degree of color change for the dyed cotton fabrics was poor to morderate (i.e., levels 2–3), and the acidic perspiration fastness to stain was moderate to good (levels 3–4) when the accompanying fabric was cotton and good (level 4) when the accompanying fabric was wool. For alkaline perspiration, the degree of color change of the dyed cotton fabrics was also poor to morderate (i.e., levels 2–3), and the alkaline perspiration fastness to stain was moderate to good (levels 3–4) when the accompanying fabric was cotton and good (level 4) when the accompanying fabric was wool (Table 7a). Furthermore, for acidic perspiration, the degree of color change of the dyed silk fabrics was good to very good (i.e., levels 4–5), and the acidic perspiration fastness to stain was moderate to good (i.e., levels 3–4) when the accompanying fabric was

Table 6 Rubbing fastness properties of the dyed fabrics

Color fastness	Mordant	Cotton fabric		Silk fabric	
		Dry	Wet	Dry	Wet
Rubbing	No mordant	4–5	4	4–5	4
	Aluminum	4–5	4	4–5	4
	Copper	4–5	4–5	4–5	4
	Iron	4–5	4–5	4–5	4

Table 7 Perspiration fastness properties of the dyed cotton (a) and silk (b) fabrics

Color fastness	Mordant	Acidic			Alkaline		
		Color change	Stain		Color change	Stain	
			Cotton	Wool		Cotton	Wool
(a) Cotton fabric							
Perspiration fastness	No mordant	2–3	3	4	2–3	3	4
	Aluminum	2–3	3	4	2–3	3	4
	Copper	3	3–4	4	3	3–4	4
	Iron	3	3–4	4	3	3–4	4
(b) Silk fabric							
Perspiration fastness	No mordant	4	3–4	3	4	3–4	3
	Aluminum	4–5	3–4	3–4	4–5	3–4	3–4
	Copper	4	3–4	3–4	4	3–4	3–4
	Iron	3–4	3–4	3–4	3–4	3–4	3–4

Table 8 Light fastness properties of the dyed fabrics

Color fastness	Mordant	Cotton fabric	Silk fabric
Light fastness	No mordant	1	1–2
	Aluminum	1	1–2
	Copper	1	1–2
	Iron	1	1

cotton, whereas it was also moderate to good (i.e., levels 3–4) when the accompanying fabric was wool. For alkaline perspiration, the degree of color change was also good to very good (i.e., levels 4–5), with the exception of the dyed fabric treated with iron (Table 7b). The alkaline perspiration fastness to stain was moderate to good (levels 3–4) when the accompanying fabric was either cotton or wool. These results indicate that color change of silkfabrics is lower than that of cotton fabrics, although the dyed cotton fabrics were less likely to stain wool than the silk fabrics. Notably, Oh (2002) reported that the perspiration fastness of cotton fabric dyed with *G. jasminoides* extract reached levels 3–4, which is higher than the grading reported in the current study (i.e., levels 2–3). Similarly, they found that the perspiration fastness of dyed silk fabric reached levels 4–5 in both acidic and alkaline perspiration solutions, i.e., about ~ 1 level higher than in the present study. However, their findings that silk fabrics exhibited superior perspiration fastness properties than the cotton fabrics are in line with the results of present study. It seems to be because the crocin stain was able to adsorb more readily on the cellulose surface of the cotton fabric (Table 7).

Light fastness

Table 8 shows a comparison of the light fastness characteristics of the cotton and silk fabrics dyed with the *G. jasminoides* extract. It can be seen that the light fastness properties of both fabrics were extremely low (i.e., levels 1–2) both with and without mordanting. Overall, the dyed silk fabrics outperformed the cotton fabrics by ~ 1 level

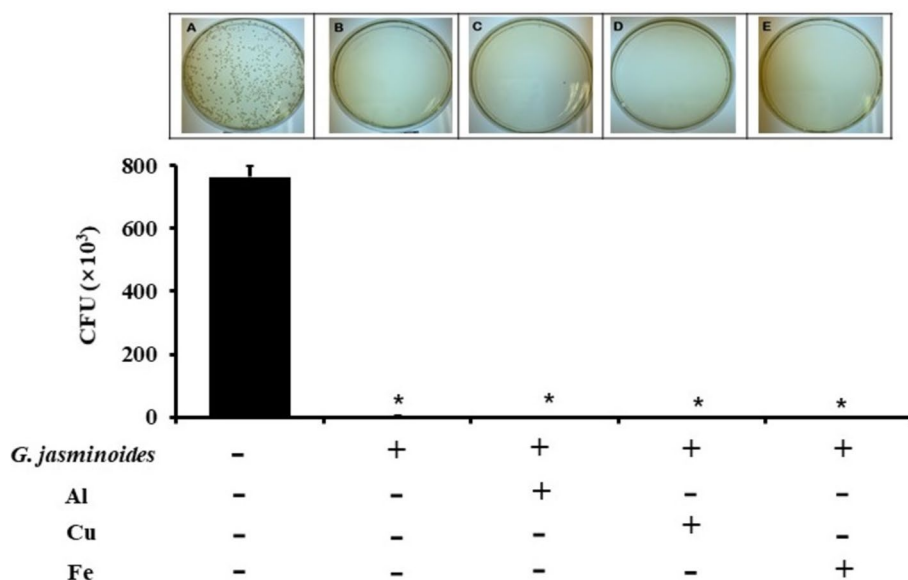


Fig. 3 Antibacterial abilities of the cotton fabrics dyed with the *G. jasminoides* extract. A: no dye + no mordant, B: *G. jasminoides* dye, C: *G. jasminoides* dye + $\text{Al}_2(\text{SO}_4)_3$ mordant, D: *G. jasminoides* dye + $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ mordant, E: *G. jasminoides* dye + $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ mordant. Three replicates were performed for each concentration of the test extract. * $p < 0.001$ was considered statistically significant, as determined by independent sample t-test for the mean values different from the control group

Table 9 Bacterial counts on cotton fabrics dyed with *G. jasminoides* extract

	No dye + no mordant	<i>G. jasminoides</i>	<i>G. jasminoides</i> + Al	<i>G. jasminoides</i> + Cu	<i>G. jasminoides</i> + Fe
cfu ($\times 10^3$)	762.9 $\pm$ 9.11	1.5 $\pm$ 0.23	0.0 $\pm$ 0.00	0.0 $\pm$ 0.00	0.2 $\pm$ 0.14
Reduction of the bacterial count (%)	0	99.8	100	100	99.9

in terms of the light fastness results. Notably, Park and Yoon (2010) also reported that the light fastness characteristics of dyed cotton and silk fabrics were extremely low (i.e., levels 2–3) both with and without mordanting. This can be accounted for by considering that natural carotenoids are unstable in solution and are particularly susceptible to decomposition in the presence of heat, light, and acids (Cho & Kang, 2000; Kim & Kim, 1997). Notably, in a study by Kim et al. (2016), the light fastness was improved through the use of an aluminum mordant and citric acid cross-linking. However, as the light fastness was extremely low, color change was a significant issue, and so it was recommended to dry the fabric in the shade after dyeing (Table 8).

Antimicrobial efficacy against MRSA

Upon examining the antimicrobial activities of the various cotton fabrics (Fig. 3, Table 9), MRSA bacterial growth of $762.9 \pm 9.1 \times 10^3$ cfu/mL was observed on the raw fabric. In addition, for the cotton fabric dyed with the *G. jasminoides* extract in the absence of a mordant, bacterial growth of $1.5 \pm 0.2 \times 10^3$ cfu/mL was detected, indicating an antimicrobial activity of 99.8%. Following treatment with the aluminum, copper,

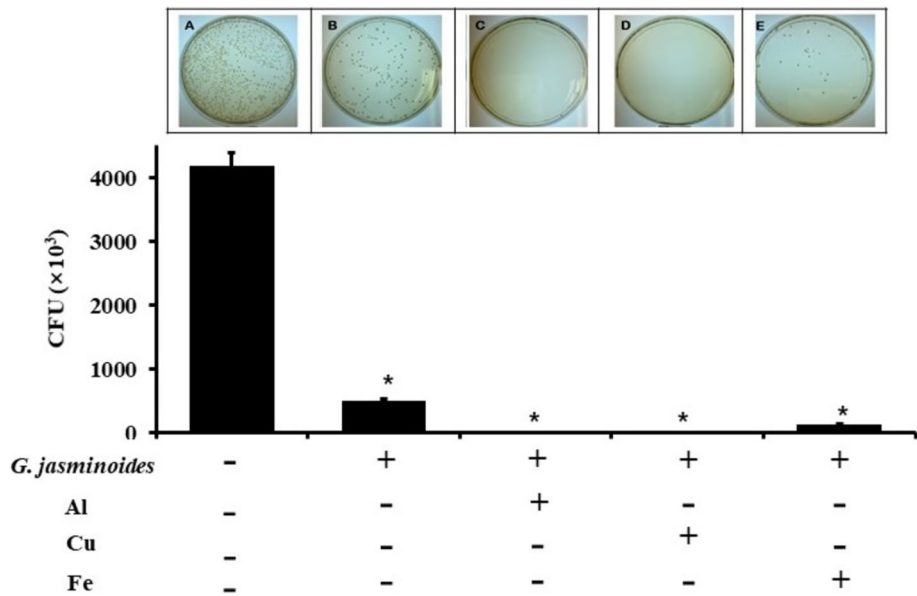


Fig. 4 Antibacterial abilities of the silk fabrics dyed with the *G. jasminoides* extract. **A:** no dye + no mordant, **B:** *G. jasminoides* dye, **C:** *G. jasminoides* dye + $\text{Al}_2(\text{SO}_4)_3$ mordant, **D:** *G. jasminoides* dye + $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ mordant, **E:** *G. jasminoides* dye + $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ mordant. Three replicates were performed for each concentration of the test extract. * $p < 0.001$ was considered statistically significant, as determined by independent sample t-test for the mean values different from the control group

Table 10 Bacterial counts on silk fabrics dyed with *G. jasminoides* extract

	No dye + no mordant	<i>G. jasminoides</i>	<i>G. jasminoides</i> + Al	<i>G. jasminoides</i> + Cu	<i>G. jasminoides</i> + Fe
cfu ($\times 10^3$)	4182 $\pm$ 359.2	510 $\pm$ 19.4	0.0 $\pm$ 0.00	0.0 $\pm$ 0.00	132 $\pm$ 3.7
Reduction of the bacterial count (%)	0	87.8	100	100	96.8

and iron mordants, the antimicrobial effects of the dyed cotton fabrics reached 100, 100, and 99.9%, respectively, with corresponding bacterial growths of $0.0 \pm 0.0 \times 10^3$, $0.0 \pm 0.0 \times 10^3$, and $0.2 \pm 0.1 \times 10^3$ cfu/mL. These results indicate significant bacterial growth inhibition against MRSA compared to the raw fabric ($p < 0.001$), wherein the effect of adding a mordant was insignificant (Fig. 3, Table 9).

The antimicrobial activities of the silk fabrics were also evaluated against MRSA, as outlined in Fig. 4 and Table 10. On the raw fabric, MRSA growth reached $4182 \pm 359.2 \times 10^3$ cfu/mL, and this value was significantly reduced in the dyed silk fabric without mordant treatment (bacterial growth = $510 \pm 19.4 \times 10^3$ cfu/mL), representing an antimicrobial activity of 87.8%. Following treatment with the aluminum, copper, and iron mordants, the antimicrobial effects of the dyed silk fabrics reached 100, 100, and 96.8%, respectively, compared to the raw fabric, with corresponding bacterial growths of $0.0 \pm 0.0 \times 10^3$, $0.0 \pm 0.0 \times 10^3$, and $132 \pm 3.7 \times 10^3$ cfu/mL. These results indicate significant bacterial growth inhibition against MRSA compared to the raw silk fabric ($p < 0.001$), although in this case, mordant treatment was found to enhance the antimicrobial effect (Fig. 4, Table 10).

In a previous study, Oh (2003) determined the antimicrobial activities of cotton and silk fabrics dyed with *G. jasminoides* extract against *Escherichia coli*. It was found that the bacterial reduction rate was higher in dyed fabrics than in undyed fabrics for both cotton and silk fabrics. In addition, mordanted fabrics demonstrated higher bacterial reduction rates than the untreated samples. Although these results did not indicate an antimicrobial effect against MRSA, they demonstrated an antimicrobial effect against *Escherichia coli*. This activity was attributed to the fact that the flavonoids present in *G. jasminoides* penetrate the bacterial cells and inhibit the enzymes involved in the synthesis of nucleic acids and proteins, thereby stopping bacterial growth and proliferation and ultimately leading to apoptosis (Kim & Song, 2001). Previous reports have showed the presence of various active compounds in *G. jasminoides*, including flavonoids (e.g., gordanin), iridoids (e.g., genipin, geniposide, geniposidic acid, gardenoside, shanzhiside, and methyl deacetyl asperuloside), and carotenoids (e.g., crocin, crocetin, quinic acid, caffeic acid, and vanillic acid 4-O- β -D-(6'-sinapoyl)glucopyranoside) (Kim & Jang, 2005; Kim et al., 2006, 2020; Shin et al., 2003).

Conclusions

This study investigated the color fastness and antimicrobial properties of cotton and silk fabrics dyed using *G. jasminoides* extract, a natural dye. The color fastness properties measured for the cotton and silk fabrics dyed with the *G. jasminoides* extract without a mordant were compared with those of the dyed fabrics treated with three different mordants. The results showed that the cotton fabrics were more susceptible to fading than the silk fabrics when washed in water, and that the dyed cotton and silk fabrics were less stained by washing. In addition, both the cotton and silk fabrics dyed with the *G. jasminoides* extract were found to be resistant to rubbing, whether in their wet or dry form. Furthermore, the perspiration fastness characteristics of the dyed silk fabrics were similar for acidic and alkaline perspiration and comparable to those observed for the dyed cotton fabrics. Overall, the silk fabrics were found to exhibit a higher color fastness than the cotton fabrics. Moreover, in the presence and absence of mordant treatment, the light fastness properties were low for both the cotton and silk fabrics. Overall, the dyed silk fabrics outperformed the cotton fabrics by approximately 1 level in terms of the light fastness properties, and the color fastness was not affected by the presence of mordants. Subsequently, the inhibitory effects of the cotton and silk fabrics dyed with the *G. jasminoides* extract were confirmed against MRSA, and indicating a significant antimicrobial effect. The antimicrobial effects of aluminum sulfate, copper sulfate, and ferrous sulfate mordants on the dyed cotton fabric were not significantly affected due to the strong antimicrobial activity of the dye itself, although these mordants exhibited significant antimicrobial effects in the dyed silk fabrics. These results indicated that the *G. jasminoides* extract increased the antimicrobial activities of the cotton and silk fabrics against MRSA, and the color fastness was not affected by mordants. Overall, the obtained results suggest that *G. jasminoides*, a natural dye demonstrating antibacterial effects against antimicrobial-resistant bacteria, has the potential for use in hospital bedding and clothing to significantly reduce the incidence of hospital-acquired infections.

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Author contributions

Conceptualization, N.-Y. C.; Formal analysis, N.-Y. C. and E.-S. K.; Investigation, N.-Y. C. & J.-H. L.; Methodology, N.-Y. C. and J. K.; Project administration, N.-Y. C.; Resources, N.-Y. C. & J.-H. L.; Supervision, N.-Y. C.; Writing – original draft, N.-Y. C. & E.-S. K.; Writing – review & editing, N.-Y. C.

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Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

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References

- Abdullaev, F. I. (1994). Inhibitory effect of crocetin on intracellular nucleic acid and protein synthesis in malignant cells. *Toxicology Letters*, 70(2), 243–251. [https://doi.org/10.1016/0378-4274\(94\)90168-6](https://doi.org/10.1016/0378-4274(94)90168-6)
- Cha, M.K., Lee, M.S., Park, J.H., & Kwon, Y.J. (2006). The Chemical Structure and the Dyeability of Yellow Natural Dyestuff. *Fashion & Textile Research Journal*, 8(2), 233–238. <https://www.researchgate.net/publication/263631302>
- Cho, K.R., & Kang, M.J. (2000). Studies on natural dyes (12) (Dyeing properties of Amur Cork Tree colors for silk). *Textile Coloration and Finishing*, 12(4), 239–247. <https://koreascience.kr/article/JAKO200011921152315.page>
- Choi, G.P., Chung, B.H., Lee, D.I., Lee, H.Y., & Kim, J.D. (2002). Screening of inhibitory activities on angiotensin converting enzyme from medicinal plants. *Korean Journal of Medicinal Crop Science*, 10(5), 399–402. https://www.researchgate.net/publication/263995521_
- Choi, N.Y., & Kang, S.Y. (2015). Effect of Ulmus Davidiana var. Japonica Nakai Extract on Antibiotic Resistant Bacteria in Dyed Cotton. *Journal of the Korean Society of Clothing and Textiles*, 39(2), 287–293. <https://kiss.kstudy.com/Detail/Ar?key=3322206>
- Choi, N. Y., & Park, B. I. (2023). Dyeing performance and anti-superbacterial activity of cotton fabrics dyed with *Chamaecyparis obtusa*. *Molecules*, 28(18), 6497. <https://doi.org/10.3390/molecules28186497>
- Choo, N.Y. (2002). Effect of Water Extract of *Gardenia jasminoides* on the Sensory Quality and Putrefactive Microorganism of Cooked Rice. *Korean journal of food and cookery science*, 18(5), 543–547. <https://koreascience.kr/article/JAKO200211921866672.page>
- He, M. L., Cheng, X. W., Chen, J. K., & Zhou, T. S. (2006). Simultaneous determination of five major biologically active ingredients in different parts of *Gardenia jasminoides* fruits by HPLC with diode-array detection. *Chromatographia*, 64, 713–717. <https://doi.org/10.1365/s10337-006-0099-0>
- Hong, I. K., Jeon, H., & Lee, S. B. (2015). Extraction of natural dye from Gardenia and chromaticity analysis according to chi parameter. *Journal of Industrial and Engineering Chemistry*, 24, 326–332. <https://doi.org/10.1016/j.jiec.2014.10.004>
- Hong, K. H. (2023). Preparation and properties of cotton fabrics dyed by Aronia (*Aronia melanocarpa*) extract and chitosan. *Fashion and Textiles*, 10, Article 14. <https://doi.org/10.1186/s40691-023-00334-y>
- Jeon, J.D., Kim, J.J., Lee, J.M., & Shin, H.S. (2003). A Study on the Dyeing of Chitosan treated Cotton and Nylon Fabrics- Caesalpinia sappan, Cochineal, *Gardenia jasminoides*. *Journal of Fashion Business*, 7, 156–164. <https://koreascience.kr/article/JAKO200331559975256.pdf>
- Kim, K.S., & Kim, Y.J. (1997). A Study on the Extraction of Soluble Colorants of the *Gardenia jasminoides* Ellis. *Journal of the Korean Society of Dyers and Finishers*, 9(3), 10–17. <https://koreascience.kr/article/JAKO199711920177062.page>
- Kim, B.H., & Song, W.S. (2001). The Dyeability and Antimicrobial Properties of *Dryopteris crassirhizoma*. *Journal of the Korean Society of Clothing and Textiles*, 25(1), 3–12. <https://koreascience.kr/article/JAKO200111920712316.page>
- Kim, J.G., Kang, Y.M., Eom, G.S., Go, Y.M., & Kim, T.Y. (2003). Antioxidative Activity and Antimicrobial Activity of Extracts from medicinal plants (*Akebia quinata* Decaisn, *Scirpus fluvialis* A. Gray, *Gardenia jasminoides* for. *grandiflora* Makino). *Journal of Agriculture & Life Sciences*, 37(4), 69–75. <https://db.koreascholar.com/Article/Detail/331631>
- Kim, I.S., & Lee, Y.S. (2015). Antimicrobial Activity of Hwangryunheadok-tang and Extracts of *Scutellariae Radix*, *Phellodendri Cortex*, *Coptis Rhizome*, and *Gardenia Jasminoides* against *Salmonella Typhimurium*. *The Journal of Internal Korean Medicine* 36, 165–179. <https://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE08910522>
- Kim, H. J., Kim, E. J., Seo, S. H., Shin, C. G., Jin, C., & Lee, Y. S. (2006). Vanillic acid glycoside and quinic acid derivatives from *Gardeniae Fructus*. *Journal of Natural Products*, 69(4), 600–603. <https://doi.org/10.1021/np050447r>
- Kim, S. J., & Jang, H. G. (2005). Characterization and Stability of *Gardenia Jasminoides* Biotransformed Pigment Produced in Jar Fermentor. *Journal of the Korean Society of Food Science and Nutrition*, 34(6), 880–884. <https://doi.org/10.3746/jkfn.2005.34.6.880>
- Kim, S. J., Lee, S. W., Jeon, H. J., Kim, S. H., Joo, H. G., Jang, D. H., & Jang, J. H. (2016). Dyeability of chitosan-pretreated cotton fabrics with gardenia-based colorant mixtures. *Textile Science and Engineering*, 53, 158–164. <https://doi.org/10.12772/TSE.2016.53.158>
- Kim, S. H., Shin, M. R., Lee, A. R., Seo, B. I., Park, H. J., & Roh, S. S. (2020). Improvement of Inflammation through Antioxidant Pathway of *Gardeniae Fructus* 50% EtOH Extract (GE) from Acute Reflux Esophagitis Rats. *BioMed Research International*, 24, 4826176. <https://doi.org/10.1155/2020/4826176>

- Lee, I. A., Lee, J. H., Baek, N. I., & Kim, D. H. (2005). Antihyperlipidemic effect of crocin isolated from the fructus of *Gardenia jasminoides* and its metabolite crocetin. *Biological and Pharmaceutical Bulletin*, 28(11), 2106–2110. <https://doi.org/10.1248/bpb.28.2106>
- Lee, P., Lee, J., Choi, S. Y., Lee, S. E., Lee, S., & Son, D. (2006). Geniposide from *Gardenia jasminoides* attenuates neuronal cell death in oxygen and glucose deprivation-exposed rat hippocampal slice culture. *Biological and Pharmaceutical Bulletin*, 29(1), 174–176. <https://doi.org/10.1248/bpb.29.174>
- Oh, H.J. (2002). The Dyeability, Antibacterial Activity and Deodorization of Gardenia. *Journal of the Korean Home Economics Association*, 40(11), 131–140. <https://koreascience.kr/article/JAKO200211922010910.page>
- Park, M.O., & Yoon, S.L. (2010). Properties of Natural Dyeing of Bast Fiber(Part 2)Pre mordanting dyeing of sappan wood, gardenia and gallnut. *Journal of Korea TAPPI*, 42, 1–14. <https://koreascience.kr/article/JAKO201015037854937.page>
- Park, Y. M. (2023). Characteristics of cotton fabric dyed with *Euphorbia* extract at different concentrations of cellulosic nanoparticles (CNP). *Fashion and Textiles*, 10, 3. <https://doi.org/10.1186/s40691-022-00319-3>
- Pham, T. Q., Cormier, F., Farnworth, E., Tong, V. H., & Van Calsteren, M. R. (2000). Antioxidant properties of crocin from *Gardenia jasminoides* Ellis and study of the reactions of crocin with linoleic acid and crocin with oxygen. *Journal of Agricultural and Food Chemistry*, 48(5), 1455–1461. <https://doi.org/10.1021/jf991263j>
- Scott, E., Duty, S., & Callahan, M. (2008). A pilot study to isolate *Staphylococcus aureus* and methicillin-resistant *S aureus* from environmental surfaces in the home. *American Journal of Infection Control*, 36(6), 458–460. <https://doi.org/10.1016/j.ajic.2007.10.012>
- Shin, H.J. (2007). A Trend in Research and Development of Natural Gardenia Pigments. *Korean Journal of Biotechnology and Bioengineering*, 22(5), 271–277. <https://koreascience.kr/article/JAKO200718259606882.page>
- Shin, Y. W., Kim, D. W., & Kim, N. J. (2003). Studies on the processing of crude drugs (VII)- on the constituents and biological activities of *Gardenia* fructus by processing. *Korean Journal of Pharmacognosy*, 34(1), 45–54. <https://doi.org/10.5555/20033079089>
- Son, J. H., & Kim, D. C. (2013). In vitro anti-bacterial and anti-inflammatory effects of *Trichosanthes* semen, *Gardenia* fructus, and *Angelica dahurica* radix aqueous extracts. *The Journal of Oriental Obstetrics & Gynecology*, 26, 41–58. <https://doi.org/10.15204/jkobgy.2013.26.1.041>
- Spears, K. (1988). Developments in food colourings: The natural alternatives. *Trends in Biotechnology*, 6(11), 283–288. [https://doi.org/10.1016/0167-7799\(88\)90126-6](https://doi.org/10.1016/0167-7799(88)90126-6)
- Yang, H. J., Park, M. J., & Lee, H. S. (2011). Antioxidative activities and components of *Gardenia jasminoides*. *Korean Journal of Food Science and Technology*, 43, 51–57. <https://doi.org/10.9721/KJFST.2011.43.1.051>
- Yim, C.K., Moon, J.H., & Park, K.H. (1999). Isolation of 3,4-dihydroxybenzoic acid, which exhibits antimicrobial activity, from fruits of *Gardenia jasminoides* Ellis. *Korean journal of food science and technology*, 31(5), 1386–1391. <https://accesson.kisti.re.kr/main/search/articleDetail.do?artid=ATN0027821608>
- Yin, S., Niu, L., Zhang, J., & Liu, Y. (2024). Gardenia yellow pigment: Extraction methods, biological activities, current trends, and future prospects. *Food Research International*, 179, 113981. <https://doi.org/10.1016/j.foodres.2024.113981>
- Zhou, Y., Zhang, J., Tang, R., & Zhang, J. (2015). Simultaneous dyeing and functionalization of silk with three natural yellow dyes. *Industrial Crops and Products*, 64, 224–232. <https://doi.org/10.1016/j.indcrop.2014.09.041>

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