Sustainable Functional Finishing For Cotton Fabrics Using Chestnut Shell Extract

Kyung Hwa Hong (✉ hkh713@kongju.ac.kr)

Kongju National University <https://orcid.org/0000-0002-9155-4871>

Research Article

Keywords: cotton, chestnut shells, antibacterial activity, antioxidant activity, deodorant properties

Posted Date: July 20th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-684543/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Cellulose on October 26th, 2021. See the published version at <https://doi.org/10.1007/s10570-021-04273-z>.

Abstract

Owing to global environmental concerns, sustainable industrial processes have become a topic of significant importance in various fields. Chestnut shells are byproducts of agricultural and food industries; however, they include various health-beneficial compounds such as polyphenols and flavonoids. In this study, the feasibility of using chestnut shell extract as a natural functional agent for textile finishing processes was investigated. The chestnut shell extract was prepared by boiling the inner and outer shells of chestnut in distilled water for 4 h. Subsequently, the extract was filtered, centrifuged, concentrated, and finally dried into powder form using a freeze dryer. The extract was then dissolved in distilled water at different concentrations and applied to cotton fabrics through a pad-dry-cure process. The finished cotton fabrics were investigated by scanning electron microscope, Fourier-transform infrared spectroscopy, etc. In addition, the antibacterial and antioxidant properties of the finished cotton fabrics were examined as functional properties. The results showed that the cotton fabrics finished by chestnut shell extract exhibited significant antibacterial, antioxidant, and deodorant properties when the concentration of the chestnut shell extract was above 10 wt% in the finishing bath.

Introduction

Textiles are generally processed in multiple steps during manufacturing, including scouring, bleaching, dyeing, and finishing. Each process not only consumes a large volume of water and energy, but also generates a huge amount of wastewater containing various toxic chemicals (Haji and Naebe 2020). With growing environmental concerns, many conventional textile and apparel manufacturing processes with considerable ecological footprints are adapting environmentally friendly processes to become more sustainable. (Eid and Ibrahim 2021; Khan et al 2017). Such approaches include search for ecofriendly chemicals, development of biocompatible polymers, application of new technologies, and implementation of integrating processes (Eid and Ibrahim 2021). Bio-wastes and byproducts from agricultural and food industries have been used as dyeing and/or finishing agents in textile processes. Bio-wastes are generally discarded into landfills; however, they contain large amounts of health-promoting bioactive compounds and/or natural colorants in them. Thus, using bio-wastes in textile processes can be considered as an economical and sustainable approach.

Chestnut is an angiosperm of the *Fagaceae* family. It is one of the most commercially important nuts in the world, and is distributed in temperate regions of the Northern Hemisphere (Xiao et al. 2021). For centuries, chestnuts have been a primary nutritional resource for native communities in many areas of Asia, North America, and Europe. In particular, China and South Korea are the world's leading producers of chestnuts (Maurelli et al., 2013; He et al. 2016). The hard outer shells and thin inner shells are removed to obtain the edible starchy fruit. Thus, chestnut shells are considered as a bio-waste generated during the peeling process, which accounts for ca. 10% of the weight of whole chestnuts (Vázquez et al. 2008, 2009; Hwang et al. 2001). It is well-known that chestnut shells are rich in phenolic compounds, most of which belong to the group of hydrolysable tannins. Natural tannins exhibit antibacterial, anti-inflammatory, and detoxifying properties (Pizzi 2019; Fraga-Corral et al. 2021). In addition, chestnut shells have been

reported to contain flavonoids, which exhibit anti-tumoral, anti-allergic, anti-platelet, anti-ischemic, and anti-inflammatory properties. These properties are attributed to the antioxidant capacity of the compounds (Vázquez et al. 2008; Moure et al. 2001). Thus, chestnut shells have good potential as a functional agent for textile finishing, as has been demonstrated previously (Hong 2018). However, chestnut shells have been mostly applied to textiles as a source of colorant for craft dyeing. Very few studies have been conducted on textile finishing with chestnut shells, and scientific approach to the finishing is still insufficient. Therefore, in this study, chestnut shells compounds were extracted in a more sustainable manner than that in previous studies (Hong 2018), and an optimum finishing condition for a textile process with chestnut shell extract was determined based on controlled experiments. Then, the cotton fabrics treated with chestnut shell extract were investigated in terms of various functionalities, including antibacterial, antioxidant, and deodorant properties.

Materials And Methods

2.1 Sample material and chemicals

Bleached and desized cotton fabric (No. 400; plain woven 98 g/m²) was purchased from Testfabrics Inc. (West Pittston, PA). Chestnut-shells (*Castanea crenata*) containing inner and outer shells were provided by a chestnut processing company 'Albam Story' in Gongju, South Korea. Folin-Ciocalteu reagent, sodium carbonate, gallic acid ($\geq 97\%$), and (+)-catechin hydrate ($\geq 98\%$) were purchased from Sigma-Aldrich Korea (Seoul, South Korea). Free radical DPPH (1,1-diphenyl-2-picrylhydrazyl) was purchased from Alfa Aesar (MA, USA), and all reagents were used as received without further purification.

2.2 Extraction from chestnut shells

The nature of solvent may significantly affect the amount of extracted polyphenols, as demonstrated previously. In this study, distilled water was used as the solvent, since it is bio-renewable, nontoxic, and effective in extracting various natural compounds from chestnut shells due to its high polarity (Ham et al. 2015; Cacciola et al. 2020). The extraction process is described as follows. First, chestnut shells were chopped into flakes and dried completely immediately after peeling. Extraction was conducted by immersing 1.6 kg of chestnut shells in 12 L of distilled water, followed by boiling for 4 h at $100 \pm 3^\circ\text{C}$. Subsequently, the crude chestnut shell extract was filtered by filtering paper (185 mm ϕ) on a vacuum aspiration system, and then concentrated to approximately half the volume through a rotary evaporator. Next, the concentrated extract solution was centrifuged at 10,000 rpm for 30 min, and the gel-state sediments were removed. Lastly, the chestnut shell extract was completely dried into a powder using a freeze dryer (FDU-1200, Eyela, Japan). The extraction process is summarized in Fig. 1.

2.3 Fabric finishing process

The cotton fabric was cut into 30 cm · 30 cm pieces, and each piece was immersed for 30 min (bath ratio = 1:20, bath temperature: $20 \pm 5^\circ\text{C}$) in a container containing the finishing solution, with a designated concentration of the chestnut shell extract in distilled water (2 wt%, 5 wt%, 10 wt%, 15 wt% and 20 wt%).

Next, the fabrics dampened with the chestnut shell extract aqueous solution were squeezed using a laboratory padder (DL-2005, Daelim Starlet, Shiheung-si, Korea (pressure: 0.28 MPa)) till the wet pick-up rate reached approximately 100%. Then, the fabrics were completely dried in a convection oven at 85 °C. Subsequently, the fabrics were cured at 160°C for 3 min using a laboratory curing machine (DL-2015, Daelim Starlet, Shiheung-si, Korea), followed by intensive washing with distilled water and tumble drying.

2.4 Analysis of chestnut shell extract

Chestnut shell extract (50 mg) was dissolved in 80% methanol, and this mixture was sonicated for 60 min, followed by vigorous shaking for 60 min. The methanol phase was used to determine the total phenolic content, total flavonoid content, and antioxidant activity, using the spectrophotometric methods described below. All analyses were conducted using a UV–Vis spectrophotometer (Biomate 5, Thermo Fisher Scientific, MA, USA), and all samples were prepared and analyzed in triplicate.

Total phenolic content: The total phenolic content in the chestnut shell extract was measured by the colorimetric method of Singleton and Rossi (1965). 100 µL of the as-prepared sample solution was added to 0.5 mL of distilled water and mixed well. Subsequently, 100 µL of Folin-Ciocalteu reagent (diluted 1:10 in distilled water) was added to the mixture. The mixture was kept in the dark for 3 min. Then, 1 mL of sodium carbonate (7%) was added, and the mixture was incubated in the dark for 30 min, following which the solution absorbance was measured at 760 nm. The quantitative results were calculated using an analytical curve of gallic acid, and expressed as mg of gallic acid equivalents (GAE) per 1 g of sample (mg GAE/g).

Total flavonoid content: The total flavonoid content in the chestnut shell extract was determined based on the method proposed by Zhishen et al. (1999) with some modifications. The aliquots ranging from 100 to 300 µL of samples were topped-up with methanol to reach 200 µL volume. Then, 1 mL of distilled water and 50 µL of NaNO₂ (5 wt%/vol) were added to amber bottles and mixed well. After 6 min, 150 µL of AlCl₃·6H₂O (10 wt%/vol) was added, and after 5 min, 0.5 mL of NaOH (1 mol/L) was added. The solution absorbance was measured immediately at 510 nm. Catechin was used as the standard for the calibration curve, and the results were expressed as mg of catechin equivalent (CE) per 1 g of sample (mg CE/g).

Antioxidant activity: The antioxidant activity was determined by the DPPH assay based on the method proposed by Kim et al. (2014). A 3.75 mL aliquot of 6×10^{-5} mol/L DPPH methanolic solution was mixed with 250 µL of the sample solution. The DPPH absorbance was monitored at 517 nm after keeping it for 30 min in the dark. Quantification was performed using an ascorbic acid analytical curve, and the results were expressed as mg of ascorbic acid equivalent antioxidant capacity (AAE) per 1 g of sample (mg AAE/g).

2.5 Analysis of finishing solution

The UV–Vis absorbance of the chestnut shell extract aqueous solution for textile finishing was measured with an S-3100 Spectrophotometer (Scinco Co., Ltd., Seoul, Korea) in the wavelength range 200–800 nm.

Rheological measurements for the finishing solution were performed in the steady rate sweep mode on an advanced rheometric expansion system (ARES, Rheometric Scientific, UK).

2.6 Characteristics of finished fabrics

Color changes in the cotton fabrics finished by the chestnut shell extract were investigated using a Datacolor spectrophotometer (Technical Color Solution, Karachi, Pakistan), and the values of the changes in colors (ΔE) were compared using the L^* , a^* , and b^* values.

The add-on (%) of the chestnut shell extract on the cotton fabrics was measured using a weighing method based on the weight changes of the fabric before and after finishing.

Changes in the molecular structures of the cotton fabrics finished by the chestnut shell extract were analyzed using Fourier-transform infrared spectroscopy (FTIR). The FTIR spectrum analysis device (100 FTIR spectrum, Perkin-Elmer, MA, US) was used at a resolution of 4 cm^{-1} , and attenuated total reflection (ATR) was used to obtain the results.

The surface morphologies of the cotton fabrics finished by the chestnut shell extract were observed using a high-resolution field emission scanning electron microscope (SEM, Tescan, Brno, Czech Republic).

The ability of the cotton fabrics finished by the chestnut shell extract to prevent bacterial growth and retention was tested using *Staphylococcus aureus* (*S. aureus*) (ATCC 6538; a Gram-positive bacterium) and *Klebsiella pneumoniae* (*K. pneumoniae*) (ATCC 4352; a Gram-negative bacterium) cultures according to an established protocol (KS K 0693) expressed by the following equation.

$$\text{Bacterial reduction(\%)} = \frac{(B - A)}{B} \times 100 \quad (1)$$

Here, A and B represent the surviving bacterial cells (colony-forming units in mL^{-1}) on the plates inoculated with a bacterial solution derived from the finished fabric and a control solution derived from untreated fabric, respectively. To identify the antimicrobial ability of the cotton fabrics finished by the chestnut shell extract against laundering, washing cycles were conducted based on KS K ISO 105 C06:2010, A2S (washing temperature: $40 \pm 2^\circ\text{C}$, washing time: 30 min, 0.4% ECE standard solution + 0.1% natrium used, 10 still balls).

The deodorant property of the cotton fabrics finished by the chestnut shell extract was determined against ammonia and acetic acid using a detector tube method. Fabric samples ($10 \cdot 10\text{ cm}$) were placed in a sealed and air-tight Tedlar bag (5 L). Subsequently, the target gas (100 ppm of ammonia or 50 ppm of acetic acid) was injected into a bag containing 3 L of air. The bags were placed under ambient conditions ($21 \pm 5^\circ\text{C}$) for 2 h, and the gas concentration in the bag was determined using a detector tube. The deodorization rate was calculated as

$$\text{Deodorization rate(\%)} = \frac{(C - A)}{C} \times 100, \quad (2)$$

where A and C represent the gas concentrations in the bag with and without fabric samples, respectively.

The antioxidant ability of the cotton fabrics finished by the chestnut shell extract was measured by the DPPH assay. DPPH is a free radical that can trap other radicals (scavenger radical). Therefore, the rate reduction of a chemical reaction upon the addition of DPPH is used as an indicator of the nature of the radical reaction (Alger 1997). The evaluation was conducted as follows. The fabric (500 mg) was immersed in a container containing 30 mL of 0.15 mM DPPH/methanol solution. The absorbance at 517 nm was measured using an UV–Vis spectrophotometer, after keeping the solutions in the dark for 1 h. Lower absorbance of the solution indicated higher DPPH scavenging ability. The DPPH scavenging ability was calculated as follows.

$$\text{DPPH scavenging activity (\%)} = \frac{C - S}{C} \times 100 \quad (3)$$

Here, S and C represent the absorbance of the sample solution from the finished fabric and untreated fabric, respectively.

Results And Discussion

3.1. Analytical properties of the chestnut shell extract

The total polyphenol and flavonoid content in the chestnut shell extract (whole shells including inner and outer shells) were 11.131 mg GAE/g and 4.574 mg CE/g, respectively, as presented in Table 1. The contents were significantly lower than those extracted only from the inner shells (Ham et al. 2015). However, the extract exhibited higher antioxidant capacity. This result can be interpreted from the UV–vis spectrum (Fig. 2) of the chestnut shell extract prepared in this study.

Table 1
Active constituents and their concentrations (mg/g) in the chestnut shell extract

	Total polyphenol (Gallic acid equivalent)		Total flavonoid (Catechin equivalent)		Antioxidant capacity (Ascorbic acid equivalent)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Chestnut shell extract	11.131	0.090	4.574	0.046	199.374	10.202

Figure 2 shows UV–vis spectrum of the chestnut shell extract. It has been reported previously that chestnut shell extract exhibits a single absorption maximum at 270 nm, characteristic of proanthocyanidins (Vázquez et al. 2008). Proanthocyanidins, also called condensed tannins, are oligomers and polymers of monomeric flavans linked through specific single or double bonds. These secondary plant metabolites exhibit substantial antioxidant activity (Beecher 2004). However, the chestnut shell extract obtained in this study exhibited a broader band in the range 240 nm-370 nm. This

may be attributed to the presence of other antioxidant compounds in the extract, including ellagitannins that have an additional absorption maximum at approximately 365 nm (Cadahía et al 1997). Therefore, it can be inferred that a wide variety of tannins were extracted from the inner and outer chestnut shells.

3.2. Rheological properties of the finishing solution

Finishing solutions were prepared as a function of the concentration of chestnut shell extract in distilled water at 2, 5, 10, 15 and 20 wt%. The rheological properties of the finishing solutions (chestnut shell extract aqueous solutions) were measured by increasing the shear rate, as shown in Fig. 3. Although the sediments with high density were removed from the crude extract of chestnut shells using a centrifuge, the viscosity of the finishing solution increased with an increase in the concentration. In particular, the concentration at 20 wt% of chestnut shell extract exhibited a significantly high level of stress and viscosity, with shear rates comparable to other concentrations of the solutions. Moreover, it was observed that the finishing solutions exhibited pseudo-plastic fluid behavior. Pseudo-plastic fluids, also called shear-thinning fluids, exhibit non-Newtonian behavior where the viscosity decreases under shear strain. This can be attributed to the high molecular content in the chestnut shell extract, such as a variety of tannins, proanthocyanidins, etc. (Cacciola et al. 2020). Furthermore, since the viscosity of the finishing solution might have an influence on the performance of textile finishing, it can be inferred that the optimum concentration of the finishing solution would depend on the finishing method used.

3.3. Surface properties of cotton fabrics finished using the chestnut shell extract

Color. Although the brownish hue of chestnut shell extract might not be desirable for functional textile treatment, the pigments in chestnut shells have been historically used for textile dyeing in Asian countries (Jeong 1997, Yoo et al. 1998). Thus, the color of the cotton fabrics finished by the chestnut shell extract was investigated, as shown in Table 2. The cotton fabrics finished by the chestnut shell extract increased in the a^* and b^* values, but decreased in the L^* value, as the concentration of chestnut shell extract increased in the finishing solution. This means that the cotton fabrics turned more reddish and yellowish after finishing with the chestnut shell extract. Chestnut shells contain approximately 15% melanin, which act as the brown pigment (Yao et al. 2012, 2016). Melanin refers to a group of dark brown to black protein pigments abundant in many organisms. Their structures are complex, and vary with the combination of monomeric units and environmental conditions during synthesis (Yao and Qi 2016). Melanin has been previously investigated as a colorant or antioxidant for the food industry. However, the toxicity or safety of melanin has not been clearly demonstrated, and thus, it has not been practically applied in the food industry (Yao et al. 2016). However, application of melanin for textile finishing in terms of coloring and functionalizing is a feasible approach.

Table 2

Color of cotton fabrics finished by chestnut shell extract as a function of the concentration of the finishing solution

Concentration (wt %)	L*	a*	b*	Whiteness Index-CIE	Yellowness Index-D1925
Pristine cotton	94.75	-0.2	2.5	75.67	4.62
2	79.91	6.44	18.49	-38.45	42.78
5	76.26	7.51	21.06	-61.47	49.93
10	70.88	8.99	26.89	-107.31	64.32
15	70.34	8.58	25.57	-102.06	62
20	67.95	9.33	27.99	-122.15	68.43

Add-on (%): Figure 4 shows the add-on (%) of the chestnut shell extract on cotton fabrics after finishing. As expected, the add-on (%) of the chestnut shell extract on cotton fabrics increased with the concentration of chestnut shell extract in the finishing solution. Therefore, it was presumed that the functionality of cotton fabrics finished using the chestnut shell extract would be reinforced as the concentration of chestnut shell extract increases during textile treatment.

Chemical property: Figure 5 shows the FTIR spectra of pristine cotton and the cotton fabrics finished by the chestnut shell extract. The C-O stretching of esters of hydrolysable tannins, particularly derivatives of gallic acid, was observed at approximately 1726 cm^{-1} in the spectra of the cotton fabrics finished by the chestnut shell extract, especially above 10 wt% concentration of chestnut shell extract in the finishing solution (Figure 5 (d),(e)). Moreover, the bands at approximately 1615 cm^{-1} and 1430 cm^{-1} attributed to the stretching absorption of aromatic C = C bonds also occurred in the spectra of the cotton fabrics (Coccia et al. 2019). Therefore, it was presumed that the compounds from the chestnut shell extract were imposed on cotton fabrics when the concentration of the finishing solution was above 10 wt%.

Surface morphology: Figure 6 displays the surface morphologies of cotton fabrics finished by the chestnut shell extract. As the concentration of the chestnut shell extract in the finishing bath increased, the coating, assumed to be the trace of the chestnut shell extract, was observed on the surface of the cotton fabrics. However, the coating was not dense enough to clog the interstices of the fabric structure, even at high concentrations of chestnut shell extract in the finishing bath (Figure 6(d)). Therefore, it was thought that the finishing by chestnut shell extract would not lead to any adverse effect on the mechanical properties or touch of natural cotton fabrics.

3.4. Functionalities of cotton fabrics finished by chestnut shell extract

Antibacterial activity: Table 3 presents the antimicrobial activities of the cotton fabrics finished by the chestnut shell extract as a function of the concentration in the finishing bath. It was observed that the cotton fabrics finished with the chestnut shell extract solution of > 10 wt% had excellent antibacterial

effects against *K. pneumoniae* and *S. aureus*, reducing > 99.9% of bacteria on the inoculated petri-dish (see Table 3 and Fig. 7). However, the cotton fabrics finished with lower concentrations of chestnut shell extract (2 wt% and 5 wt%) exhibited comparatively inferior antibacterial effects against *K. pneumoniae*. This result is consistent with the general tendency observed in many natural antibacterial substances, most of which exhibit excellent antibacterial properties toward gram-positive bacteria, with inferior antibacterial properties against gram-negative bacteria (Cisowska et al., 2011, Hong 2015^a). Bacteria are traditionally classified based on their gram-staining response against gram-positive and gram-negative bacteria. Gram-positive bacteria have a thick membrane (peptidoglycan layer), whereas gram-negative bacteria have a two outer-layer membranes (peptidoglycan layer and an outer membrane composed of lipopolysaccharide and protein). Owing to the differences in their outer membranes, gram-negative bacteria show higher minimal inhibitory concentration values than gram-positive bacteria (An et al. 2021, Farha et al. 2020). On the other hand, the antimicrobial activity of the cotton fabrics finished by the chestnut shell extract against *K. pneumoniae* was significantly reduced after laundering, as shown in Fig. 8. According to Farha's study (2020), "The minimum inhibitory concentrations (MIC) of various types of tannins are found in the range of 61.5–3200 µg/mL. Compared to Gram-negative bacteria, the MIC values of tannins are much lower for Gram-positive bacteria because of structural differences of the bacterial cell envelope". Therefore, it was presumed that the moiety of chestnut shell extract was washed off by laundering, and the remaining amount of chestnut shell extract compounds on the fabrics reached in the range of MIC values, which are effective to *S. aureus*, a Gram-positive bacterium, but not *K. pneumoniae*, a Gram-negative bacterium.

Table 3 Antibacterial activities of cotton fabrics finished by chestnut shell extract as a function of the concentration in the finishing bath

Concentration of chestnut shell extract (wt%)	<i>S. aureus</i>	<i>K. pneumoniae</i>
pristine	38.6	15.8
2	>99.9	98.3
5	>99.9	99.5
10	>99.9	>99.9
15	>99.9	>99.9
20	>99.9	>99.9

Antioxidant capacity: Figure 9 shows the antioxidant capacity of the cotton fabrics finished by the chestnut shell extract as a function of concentration in the finishing solution. It was observed that the antioxidant capacity increased significantly as the concentration of chestnut shell extract increased up to approximately 10 wt%, after which it reached equilibrium at approximately 96.5% antioxidant capacity. Chestnut shell extract is largely composed of phenolic compounds including gallic acid, ellagic acid, and other hydrolyzable tannins, which may explain the higher antioxidant capacity in comparison to phenolic

acid alone (Hong 2015^b). It has been reported that the extracts from natural substances present better functionalities than pure molecules, owing to the additive and/or synergetic effects of the components in the mixture (Squillaci et al. 2018, Coccia et al. 2019).

Deodorant property: The deodorant capacity of the cotton fabrics finished by 10 wt% chestnut shell extract solution was examined against ammonia and acetic acid, which are known as the main components of sweat and odor in the human body. As shown in Fig. 10, cotton fabrics finished by the chestnut shell extract revealed a significantly improved deodorant capacity against ammonia gas than pristine cotton fabrics. However, there is no significant difference between pristine cotton fabric and the cotton fabrics finished by the chestnut shell extract in the deodorization rate of acetic acid. It seems acetic acid molecules are effectively adsorbed onto the surface of cotton fabrics regardless of the finishing. Therefore, it was found that textile treatment with chestnut shell extract improved the deodorizing ability of cotton fabrics (> 99.8% deodorization rate of ammonia and 87.9% of deodorization rate of acetic acid). This result is in line with previous research conducted by Ham et al. (2015), where it was shown that the extract from chestnut inner shells demonstrated deodorant activity against trans-2-nonenal (a major odor component detected in the body of elderly people) and methyl mercaptan (a major chemical responsible for bad breath caused by oral cavity). The mechanism of deodorization of chestnut shell extract has not been established yet. However, it has been reported that flavonoids and tannins exhibit deodorizing properties (Sato et al. 1984; Wang et al. 2001).

Conclusion

In this study, chestnut shells were used as a functional agent for textile finishing. To extract the functional compounds from chestnut shells, the inner and outer shells were boiled in water for 4 h. Then, the crude extract was filtered and dried into powder state. It was found that the chestnut shell extract contained significant amount of polyphenols and flavonoids, exhibiting excellent antioxidant properties (199.374 mg AAE/g). In order to apply the extract to cotton fabrics, finishing solutions were prepared by dissolving the extract powder in distilled water at the following concentrations: 2, 5, 10, 15 and 20 wt%. The finishing solutions increased in viscosity with increasing concentration, and exhibited pseudo-plastic fluid behavior. Ultimately, the chestnut shell extract aqueous solutions were applied to cotton fabrics through a pad-dry-cure technique. After the process, the cotton fabrics finished by the chestnut shell extract turned yellowish in appearance, and the trace of chestnut shell extract was observed by SEM and FTIR. Moreover, the finished cotton fabrics revealed high antibacterial capacity (> 99.99) against *K. pneumoniae* and *S. aureus* after treatment with > 10 wt% chestnut shell extract solution. The cotton fabrics finished by the chestnut shell extract also showed excellent antioxidant capacity (> 96%) and deodorant ability (> 99.8% against ammonia, 87.9% against acetic acid). Therefore, the results show that chestnut shells could be a potential resource to obtain functional agents or colorants for textile finishing, without inducing any negative effect on the environment. However, the fabrics finished by natural compounds are known to show inferior durability in the functionality against laundry, oxidized aging, etc.

Therefore, in future research, it is necessary to improve the durability of the fabrics finished by chestnut shell extract and compensate for the lower antibacterial ability against gram-negative bacteria.

Declarations

Funding: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT). (NRF-2020R1A2C1006693).

Conflicts of interest/Competing interests: Not applicable

Availability of data and material: Not applicable

Code availability: Not applicable

Authors' contributions: Not applicable

Compliance with Ethical Standards

Animal studies or human participants involvement in the study: Not applicable

References

1. Alger MSM (1997) Polymer science dictionary (2nd ed.). London: Chapman and Hall (p152)
2. An JY, Wang LT, Lv MJ, Wang JD, Cai ZH, Wang YQ, Zhang S, Yang Q, Fu YJ (2021) An efficiency strategy for extraction and recovery of ellagic acid from waste chestnut shell and its biological activity evaluation. *Microchem J* 160:105616. <https://doi.org/10.1016/j.microc.2020.105616>
3. Beecher GR (2004) Proanthocyanidins: Biological Activities Associated with Human Health. *Pharm Biol* 42:2–20. <https://doi.org/10.1080=13880200490893474>
4. Cacciola NA, Cerrato A, Capriotti AL, Cavaliere C, D'Apolito M, Montone CM, Piovesana S, Squillaci G, Peluso G, Laganà A (2020) Untargeted Characterization of Chestnut (*Castanea sativa* Mill.) Shells Polyphenol Extract: A Valued Bioresource for Prostate Cancer Cell Growth Inhibition. *Molecules* 25:2730. <https://doi.org/10.3390/molecules25122730>
5. Cadahía E, Conde E, García-Vallejo MC, Fernandez de Simón B (1997) Tannin composition of *Eucalyptus camaldulensis*, *E. globulus* and *E. rudis*. Part I. Wood. *Holzforschung* 51:119–124. <https://doi.org/10.1515/hfsg.1997.51.2.119>
6. Cisowska A, Wojnicz D, Hendrich AB (2011) Anthocyanins as antimicrobial agents of natural plant origin. *Nat Prod Commun* 6(1):149–156
7. Coccia E, Siano F, Volpe MG, Varricchio E, Eroldogan OT, Paolucci M (2019) Chestnut shell extract modulates immune parameters in the trout *Oncorhynchus mykiss*. *Fishes* 4:18. <https://doi.org/10.3390/fishes4010018>

8. Eid BM, Ibrahim NA (2021) Recent developments in sustainable finishing of cellulosic textiles employing biotechnology. *J Clean Prod* 284(15):124701. <https://doi.org/10.1016/j.jclepro.2020.124701>
9. Farha AK, Yang Q, Kim G, Li H, Zhu F, Liu H, Gan R, Corke H (2020) Tannis as an alternative to antibiotics. *Food Biosci* 38:100751. <https://doi.org/10.1016/j.fbio.2020.100751>
10. Fraga-Corral M, Otero P, Echave J, Garcia-Oliveira P, Carpena M, Jarboui A, Nuñez-Estevéz B, Simal-Gandara J, Prieto MA (2021) By-Products of Agri-Food Industry as Tannin-Rich Sources: A Review of Tannins' Biological Activities and Their Potential for Valorization. *Foods* 10(1):137. <https://doi.org/10.3390/foods10010137>
11. Haji A, Naebe M (2020) Cleaner dyeing of textiles using plasma treatment and natural dyes: A review. *J Clean Prod* 265:121866. <https://doi.org/10.1016/j.jclepro.2020.121866>
12. Ham JS, Kim HY, Lim ST (2015) Antioxidant and deodorizing activities of phenolic components in chestnut inner shells extracts. *Ind Crops Prod* 73:99–105. <http://dx.doi.org/10.1016/j.indcrop.2015.04.017>
13. He YC, Liu F, Di JH, Ding Y, Zhu ZZ, Wu YQ, Chen L, Wang C, Xue YF, Chong GG, Ma CL (2016) Effective enzymatic saccharification of dilute NaOH extraction of chestnut shell pretreated by acidified aqueous ethylene glycol media. *Ind Crops Prod* 81:129–138. <https://doi.org/10.1016/j.indcrop.2015.11.079>
14. Hong KH^a (2015) Preparation and properties of cotton and wool fabrics dyed by black rice extract. *Tex Res J* 85(18):1875–1883. <https://doi.org/10.1177/0040517515569520>
15. Hong KH^b (2015) Preparation and properties of phenolic compound/BTCA treated cotton fabrics for functional textile applications. *Cellulose* 22:2129–2136 <https://doi.org/10.1007/s10570-015-0604-4>
16. Hong KH (2018) Effects of a solvent system on the functionalities of wool and cotton fabrics finished in chestnut (*Castanea crenata*) shell extract. *Cellulose* 25(4):2745–2753. <https://doi.org/10.1007/s10570-018-1743-1>
17. Hwang JY, Hwang IK, Park JB (2001) Analysis of physicochemical factors related to the automatic pellicle removal in Korean chestnut (*Castanea crenata*). *J Agric Food Chem* 49:6045–6049. <https://doi.org/10.1021/jf010744b>
18. Jeong YO (1997) The dyeability of natural dye extracted from chestnut shells. *The Korean Society of Community Living Science* 8(2):83–91
19. Khan SAR, Dong Q, Zhang Y, Khan SS (2017) The impact of green supply chain on enterprise performance: in the perspective of China. *J Adv Manuf Syst* 16:263–273. <https://doi.org/10.1142/S0219686717500160>
20. Kim MJ, Kim YG, Kim HS, Cheong C, Jang KH, Kang SA (2014) Effects of Antioxidant Activities in Ethanol Extract of Apple Peel, Grape Peel, and Sweet Potato Peel as Natural Antioxidant. *J Korea Acad Industr Coop Soc* 15(6):3766–3773. <https://doi.org/10.5762/KAIS.2014.15.6.3766>
21. Maurelli L, Ionata E, La Cara F, Morana A (2013) Chestnut shell as unexploited source of fermentable sugars: effect of different pretreatment methods on enzymatic saccharification. *Appl Biochem*

- Biotechnol 170:1104–1118. <https://doi.org/10.1007/s12010-013-0264-5>
22. Moure A, Cruz M, Franco D, Dominguez JM, Sineiro J, Dominguez H, Nunez MJ, Parajo JC (2001) Natural antioxidants from residual sources. Food Chem 72(2):145–171. [https://doi.org/10.1016/S0308-8146\(00\)00223-5](https://doi.org/10.1016/S0308-8146(00)00223-5)
23. Pizzi A (2019) Tannins: Prospectives and Actual Industrial Applications. Biomolecules 9:344. <https://doi.org/10.3390/biom9080344>
24. Sato Y, Terazawa M, Uchida Y (1984) Green tea flavonoids. Shokuhin kogyo 26:57–65
25. Singleton VL, Rossi JA (1965) Colorimetry of total phenolics with hosphomolybdc-phosphotungstic acid reagents. Am J Enol Vitic 16:144–158
26. Squillaci G, Apone F, Sena LM, Carola A, Tito A, Bimonte M, Lucia AD, Colucci G, Cara FL, Morana A (2018) Chestnut (*Castanea sativa* Mill.) industrial wastes as a valued bioresource for the production of active ingredients. Process Biochem 64:228–236. <https://doi.org/10.1016/j.procbio.2017.09.017>
27. Vázquez G, Fontenla E, Santos J, Freire MS, González-Álvarez, Antorrena G (2008) Antioxidant activity and phenolic content of chestnut(*Castanea sativa*) shells and eucalyptus (*Eucalyptus globulus*)bark extracts. Ind Crops Prod 28:279–285. <http://doi:10.1016/j.indcrop.2008.03.003>
28. Vázquez G, González-Alvarez J, Santos J, Freire MS, Antorrena G (2009) Evaluation of potential applications for chestnut (*Castanea sativa*) shell and eucalyptus (*Eucalyptus globulus*) bark extracts. Ind Crops Prod 29:364–370. <https://doi.org/10.1016/j.indcrop.2008.07.004>
29. Wang CK, Chen SL, Wu MG (2001) Inhibitory effect of betel quid on the volatility of methyl mercaptan. J Agric Food Chem 49(4):1979–1983. <http://doi:10.1021/jf000433l>
30. Xiao J, Gu C, He S, Zhu D, Huang Y, Zhou Q (2021) Widely targeted metabolomics analysis reveals new biomarkers and mechanistic insights on chestnut (*Castanea mollissima* Bl.) calcification process. Food Res Int 141:110128. <https://doi.org/10.1016/j.foodres.2021.110128>
31. Yao Z, Qi J, Wang L (2012) Isolation, fractionation and characterization of melanin-like pigments from chestnut (*Castanea mollissima*) shells. J Food Sci 77(6):C671–C676. <https://doi.org/10.1111/j.1750-3841.2012.02714.x>
32. Yao ZY, Qi JH, Hu Y, Wang Y (2016) Insolubilization of Chestnut shellChestnut shells Pigment for Cu(II) Adsorption from Water. Molecules 21:405. <https://doi:10.3390/molecules21040405>
33. Yoo HJ, Lee HJ, Lim JH (1998) Fabrics Dyeing using natural dyestuff manufactured from chestnut hulls. J Korean Soc Cloth Tex 22(4):469–476
34. Zhishen J, Mengcheng T, Jianming W (1999) The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chem 64:555–559. [https://doi.org/10.1016/S0308-8146\(98\)00102-2](https://doi.org/10.1016/S0308-8146(98)00102-2)

Figures

Figure 1

Extraction process of chestnut shell compounds

Figure 2

(a) UV-vis spectrum of distilled water and (b) chestnut shell extract aqueous solution

Figure 3

Rheological properties of the finishing solution as a function of the concentration of the chestnut shell extract

Figure 4

Add-on (%) of the chestnut shell extract on cotton fabrics as a function of the concentration of the finishing solution

Figure 5

FTIR-ATR spectra of cotton fabrics finished by the chestnut shell extract as a function of the concentration in the finishing solution: (a) pristine, (b) 2 wt%, (c) 5 wt%, (d) 10 wt%, and (e) 20 wt%

Figure 6

SEM images of cotton fabrics finished by chestnut shell extract as a function of the concentration in the finishing bath (magnification: 5000x): (a) pristine, (b) 2 wt%, (c) 5 wt%, and (d) 20 wt%

Figure 7

Bacterial inhibition ability of cotton fabrics finished by chestnut shell extract

Figure 8

Antimicrobial capacity of the cotton fabrics finished by 10 wt% chestnut shell extract solution with increasing laundering cycles: (a) against *S. aureus*, (b) against *K. pneumonia*

Figure 9

Antioxidant capacity of cotton fabrics finished by chestnut shell extract as a function of the concentration in the finishing bath

Figure 10

Deodorization rate of pristine cotton and chestnut shell extract finished cotton fabrics