Cellulose (2020) 27:4831–4846
https://doi.org/10.1007/s10570-020-03109-6

ORIGINAL RESEARCH

# Advantages of *Scutellaria baicalensis* extracts over just baicalin in the ultrasonically assisted multi-functional treatment of linen fabrics

**Huimin Li · Zhengrui Li · Yixin Liu · Minghua Li**

Received: 11 October 2019 / Accepted: 13 March 2020 / Published online: 18 March 2020


**Abstract** Recently plant extracts with intrinsic properties of green, safe and eco-friendly were more often integrated with textiles to endow the fabric with multi-functions such as anti-microbial, anti-oxidation and anti-ultraviolet. Therefore, it is worthwhile to study the role of active constituents in plant extracts on the functionalization of textiles. Herein, *Scutellaria baicalensis* (chinese skullcap) extracts (SBE) and its main active ingredient, baicalin, were effectively combined with linen fabric by means of impregnation and ultrasonic treatment respectively. The treated linen fabrics were characterized by SEM, FTIR, XRD, TGA, DTG analysis and the relevant functions such as anti-microbial activity, antioxidant activity and ultraviolet protection ability as well as durability of functionalities were also comparatively assessed. It was found that even with the same content of baicalin, the corresponding functions of the linen fabric treated by SBE are obviously better than treated by baicalin. The advantages of the SBE over just baicalin on the functionalization of linen fabric was analyzed and verified by experiments. The conclusion of this work will guide the quantitative addition of plant extracts on textile functional treatment.

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s10570-020-03109-6) contains supplementary material, which is available to authorized users.

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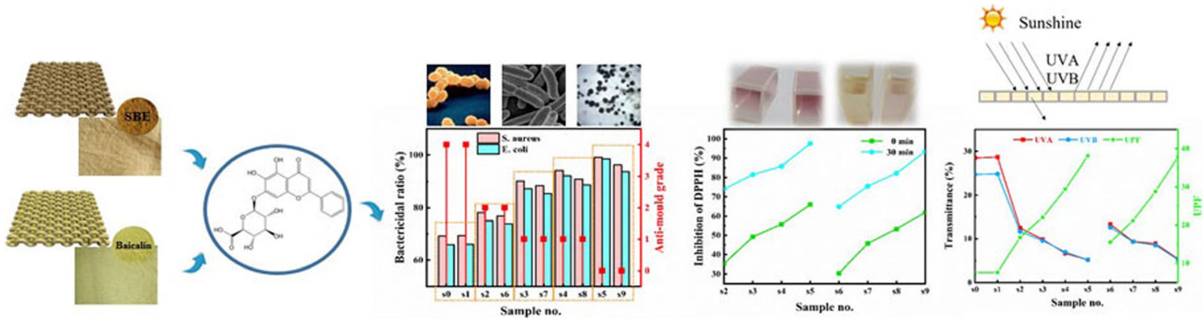
## Graphic abstract




**Keywords** Plant extracts · Baicalin · Linen fabric · Anti-microbial activity · Antioxidant activity · Ultraviolet protection ability

## Introduction

Plant extracts are never ending natural resources derived from plants which have a complex structure of small molecular organic compounds and change significantly according to plant species and separation processes (Islam and Mohammad 2015; Balandrin et al. 1985). The essence of functional properties of plant extracts is secondary metabolites in plant active ingredients. Compared with chemical synthesis reagents, the plant active ingredients are environmentally-friendly and renewable functional agents. A diverse range of plant extracts and live plants had been successfully ultilized in synthesis (Küp et al. 2020), medication (Sotomil et al. 2019), cosmetics (Hughes et al. 2019) and food industry (Li et al. 2020). Recently more studies were focused on the functionalization of textiles using multifunctional plant extracts (Adeel et al. 2019b; Ticha et al. 2017; Sheikh and Bramhecha 2019; Sheikh et al. 2019). Sheikh et al. (2019) demonstrated the linen fabric had a good antibacterial activity, antioxidant activity and UV protection ability treated by dyeing with plant extracts from *Kigelia Africana* flowers. Sheikh and Bramhecha (2019) indicated that the linen fabric with a chitosan-based formulation coating could be utilized as a backbone for in situ synthesis of silver nanoparticles using tamarind seed coat extract to help in getting functionalization of linen.

As one kind of plant extracts, *Scutellaria baicalensis* extracts (SBE) is derived from the dry root of *Scutellaria baicalensis* Georgi (Lamiaceae family). The main active ingredient of SBE is the baicalin ($C_{21}H_{18}O_{11}$, 5,6,7-trihydroxyflavone-7-*O*-glucuronide) (Guo et al. 2013; Zhang et al. 2014), which was proven to have antimicrobial (Wu et al. 2018; Luo et al. 2017), anti-inflammatory (Yang et al. 2016), antioxidant (Gao et al. 2001), anticancer (Li Weber 2009), antiviral (Nayak et al. 2014), anxiolytic (Liao et al. 2003) and other activities. Flavonoids as the major phytochemicals of baicalin existing in SBE (Zhang et al. 2019), are polyphenolic compounds which generally appear in the form of glycosylated derivatives. Flavonoids can inhibit the growth of microorganisms (Rauha et al. 2000; Cushnie and Lamb 2005) and they are also the major compounds in terms of radical scavenging activity (Miliauskas et al. 2004) and UV protection (Mota et al. 2019). Therefore, researches were concentrated on functional treatment of textiles with plant extracts rich in flavonoids such as *Scutellaria baicalensis* and cactus. Zhou et al. (2016) combined the baicalin with silk fabric through the electrostatic interactions between the ionized carboxyl groups in baicalin and the positively charged amino groups of protein macromolecule of silk, the treated silk fabric exhibited good UV protection. Xu et al. (2017) demonstrated that the silk fibroin grafted carboxylic cotton fabric treated by cactus flavonoid extracts can achieve a highly inhibitory effect against both *Staphylococcus aureus* and *Escherichia coli*.

Linen, made from the fiber from flax plants is inherently with good hygroscopicity, moisture conductivity and faint antibacterial properties. However, its vulnerability to damp-breeding moulds and lack of

UV protection against sunburn limit its further development as functional textiles (Sheikh and Bramhecha 2018). The integration of plant extracts with the linen fiber can be functionalized on the basis of their advantageous properties. However, most species of plant extracts were less applied to the linen fibers based fabric functionalization rather than to proteinaceous fibers-based fabric (wool, silk) (Adeel et al. 2019a, b; Ticha et al. 2017; Shabbir et al. 2018) because of its high degree of inter-molecular binding and dense structure (Arik 2020). Fabric treatment by ultrasound is an ecofriendly and energy-efficient method to improve the integration of plant extracts with the linen fabric (Ma et al. 2019; Abral et al. 2019; Ticha et al. 2017), because ultrasonic treatment destroys the inter-fiber bonds among the linen molecular layers, resulting in "cracking" or "erosion" on the surface of linen fibers (Wong et al. 2009). Moreover, ultrasound-assistance also accelerates the homogenization of SBE to reduce aggregation of bulky molecules which could increase more activated hydrophilic groups between molecules of SBE and linen fibers (Abou-Okeil et al. 2010). As a result the interaction between plant extracts and macromolecules of linen can be improved. Another challenge is the lack of criteria to assess the inter-relationship between plant extracts and their active ingredients in textile functional treatment due to the great difference of active ingredient in plant origin and taxa even in same species, which will affect the quantitative addition and waste of plant extracts on the functionalization of textiles. The mentioned problems also hinder the development of the plant extracts as a potential perspective in functional applications and energy conservation.

Herein, the SBE and baicalin were effectively combined with the linen fabric by means of impregnation and ultrasonic treatment respectively. The treated linen fabrics were characterized by SEM, FTIR, XRD, TGA, DTG analysis, and their multi-functions as anti-bacterial, anti-mould, anti-oxidant and ultraviolet protection abilities were comparatively assessed to find out the inter-relationship between SBE and baicalin in textile functional treatment. Our work will develop a new production for regulating equivalence dosage of plant extracts and plant-derived chemicals for control of plant extracts additions on functionalization of textiles without contamination and toxicity. In the future, biologically active plant-derived chemicals with particular functions can be expected to play an increasingly significant role in the commercial development on textile functionalization to reduce unnecessary waste in mass production.

## Materials and methods

### Materials

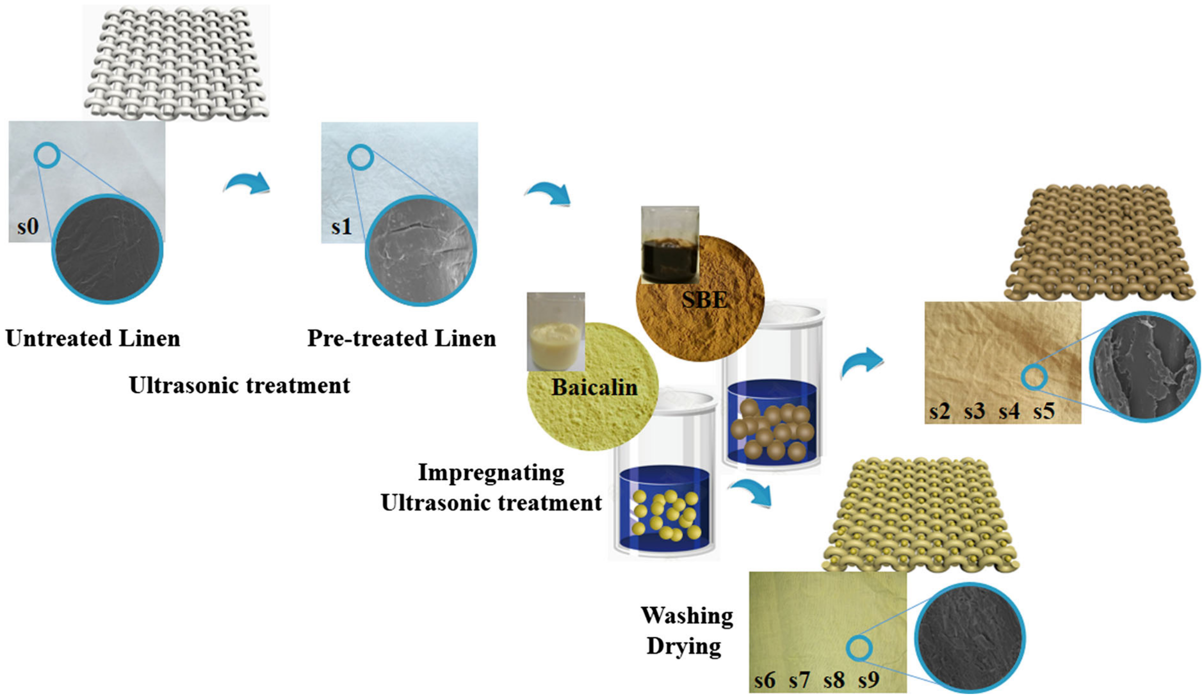
Ready-for-dyeing bleached linen fabric (EPI = 50, PPI = 48, GSM = 167) was obtained from Jin Tai Co. Ltd. CHN. Baicalin sample with the purity of 95 wt% was supplied by Shanghai Aladdin Biochemical Technology Co., Ltd. CHN, and the SBE was supplied by Lin Cao science Co., Ltd. CHN. The bacterial strains and fungal strains were obtained from Fu Chi science Co., Ltd. CHN. The DPPH (1,1-diphenyl-2-picrylhydrazyl, $C_{18}H_{12}N_5O_6$, $\geq$ 97.0 wt%) was supplied by Phygene Biotechnology Co., Ltd. CHN. All other auxiliary chemical reagents were supplied by National Pharmaceutical Group Chemical Testing Co., Ltd CHN and were used as received.

### Measurement for baicalin content of SBE

The baicalin content of SBE were measured by high-performance liquid chromatographic (HPLC) method using Agilent 1100 HPLC analyzer (USA). The baicalin content in SBE can be calculated by the ratio of the absorption peak area at 277 nm wavelength compared with baicalin sample with the purity of 95 wt%. The baicalin content of SBE used in this work was 5.32 wt% (Support Information S1).

### Treatment of linen fabrics

As shown in Scheme 1, firstly the bleached linen fabric as control sample (s0) was impregnated with deionized water for 30 min assisted by ultrasonic treatment and dried as the pre-treated sample (s1) for use. 300 g SBE and baicalin aqueous solution with same baicalin contents of 0.27 wt%, 0.53 wt%, 0.80 wt%, 1.06 wt% marked $B_2$ to $B_9$ were prepared using SBE and baicalin sample as solutes respectively. Then the pre-treated linen fabric (s1) was impregnated as prepared solution ($B_2$–$B_9$) respectively and followed by 60 min ultrasonic treatment (40 Hz, 240 W) at different temperatures from 40 to 100 °C with




**Scheme 1** Schematic of treatment of linen fabrics by SBE and baicalin solution

interval 10 °C to find the optimal treatment temperature using ultrasonic cleaner machine (Jie Meng Cleaning Equipment Co., Ltd. CHN, Support Information S2). At last treated linen fabrics marked s2 to s9 were rinsed repeatedly with deionized water to remove the unabsorbed SBE or baicalin and dried at 80 °C for 10 min. The un-treated bleached linen fabric marked control sample (s0) was used for comparison (Table 1, Support Information S3).

## Characteristics of treated linen fabrics

The surface morphologies of the treated linen fabric s2 (by SBE) and s6 (by baicalin) were studied by scanning electron microscope (SEM Vega3tescan, CZ). The molecular structures and crystallographic structures of s2 and s6 were analyzed by FT-IR spectrophotometer (Thermo Scientific Nicolet iS50, USA) using KBr disk method in the range from 4000 to 400 $cm^{-1}$ at a resolution of 2 $cm^{-1}$. The crystallographic structures of s2 and s6 were characterized by X-ray diffraction diffractometer (XRD Rigaku Smartlab Horiba Co. JPN) with a CuK$\alpha$ radiation ($\lambda$ = 0.15405 nm) with a scanning rate of 2° $min^{-1}$ at 40 kV and 40 mA. The un-treated linen fabric (s0) was also analyzed for comparison.

## Measurement for the physical properties of treated linen fabrics

The thermal stabilities of treated linen fabrics s2 and s6 were determined by thermo-gravimetric analyzer (TGA, TG209F3, GER) with a heating rate of 10 °C $min^{-1}$ under $N_2$ environment from 40 °C to 900 °C as the test temperature range. The mechanical properties of treated linen fabrics s2 to s9 were tested by using Tensile Testing Machine (Hd026pc-500 Hong Da Inc. CHN) according to China National Standard (GB/T 3923.1-2013) with loading speed of 20 mm $min^{-1}$ and each sample was tested three times to obtain the average value. The un-treated linen fabric (s0) was also measured for comparison.

## Measurement for the multifunction of treated linen fabrics

The antibacterial activities of the untreated linen fabric s0, the pre-treated linen fabric s1 and treated linen fabrics s2 to s9 as well as their after-washing samples were quantitatively evaluated by shake flask method according to China National Standard (GB/T 20944.3-2008). Qualitative analysis was measured by

**Table 1** Recipes for treatment of linen fabrics with SBE and baicalin aqueous solution (300 g)

| Sample no. | SBE mass (g) | SBE content (wt%) | Baicalin sample mass (g) | Baicalin content (wt%) | Remark | pH (25 °C) |
|---|---|---|---|---|---|---|
| s0 | – | – | – | | Control sample | – |
| s1 | – | – | – | | Pre-treated sample | – |
| s2 | 15 | 5 | – | 0.27 | SBE solution ($B_2$) | 5.5 |
| s3 | 30 | 10 | – | 0.53 | SBE solution ($B_3$) | 5.5 |
| s4 | 45 | 15 | – | 0.80 | SBE solution ($B_4$) | 5.5 |
| s5 | 60 | 20 | – | 1.06 | SBE solution ($B_5$) | 5.5 |
| s6 | – | – | 0.84 | 0.27 | Baicalin solution ($B_6$) | 6.8 |
| s7 | – | – | 1.68 | 0.53 | Baicalin solution ($B_7$) | 6.8 |
| s8 | – | – | 2.52 | 0.80 | Baicalin solution ($B_8$) | 6.8 |
| s9 | – | – | 3.36 | 1.06 | Baicalin solution ($B_9$) | 6.8 |

agar diffusion plate method according to China National Standard (GB/T 20944.1-2007) to determine the distinct bacterial inhibition zone of sample s0, s2 to s9 (Support Information S4).

The anti-mould activities of the pre-treated linen fabric (s1) and treated linen fabrics s2 to s9 were quantitatively evaluated by petri dish test method according to China national standard (GB/T 24346-2009), and the un-treated linen fabric (s0) was also measured for comparison (Support Information S5).

The DPPH radical scavenging activities of treated linen fabrics s2 to s9 were measured by testing its corresponding treatment solution $B_2$ to $B_9$ according to the method as described by Gao et al. (1999) and calculated the value according to the method described by Hong KH et al. (Hong et al. 2012) (Support Information S6).

The ultraviolet protection abilities of the pre-treated linen fabric s1, treated linen fabrics s2 to s9 as well as the after washing samples were evaluated according to China National Standard (GB/T 18830-2009), and the un-treated linen fabric (s0) was also measured for comparison (Support Information S7).

The durability of functionalities were evaluated by the antibacterial activity and the ultraviolet protection ability before and after washing according to Part 10.1 of China National Standard (GB/T 20944.3-2008) (Support Information S8).

## Results and discussion

### Characterization of treated linen fabrics

Compared with the untreated linen fabric, “cracking” or “erosion” can be clearly seen on the surface of fibers after ultrasonic treatment, which indicated ultrasonic treatment can destroy the dense surface structure of the linen fiber (Fig. 1a–d). After subsequent impregnation with SBE and baicalin aqueous solution, it can be clearly seen that the particulate SBE and baicalin were closely deposited on the surface of linen fibers (Fig. 1e–h), which demonstrated the existing interaction between SBE/baicalin and the linen fiber most likely by hydrogen bonding through their reactive groups (e.g. hydroxyl, carboxyl) (Chung et al. 2004; Li et al. 2017). Since the SBE contains other chemical components than baicalin (e.g. baicalein, wogonoside) which have a large particle size and interact with each other to cause agglomeration, so the particle size of SBE are bigger than baicalin sample (Fig. 1i, j) (Zhou et al. 2018; Chirikova et al. 2010).

FT-IR spectra of the untreated linen fabric (s0), baicalin sample and the treated linen fabric by baicalin

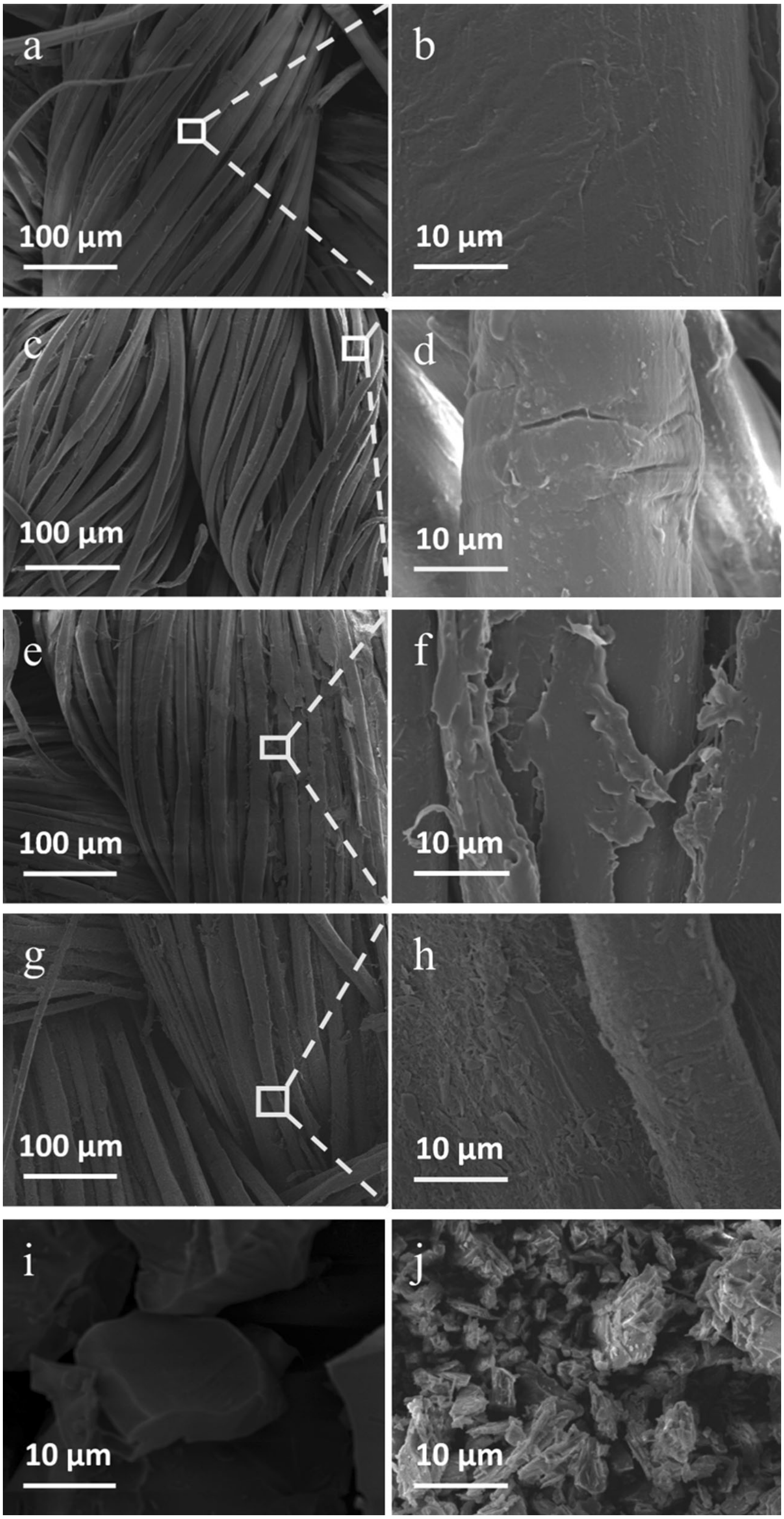



**Fig. 1** SEM images of **a**, **b** the twining fiber in the untreated linen fabric and its high magnification, **c**, **d** the twining fiber in the pre-treated linen fabric and its high magnification, **e**, **f** the twining fiber in the linen fabric treated by SBE and its high magnification, **g**, **h** the twining fiber in the treated linen fabric by baicalin and its high magnification, **i**, **j** the particle size of SBE and baicalin sample

(s6) were described in Fig. 2. A broad peak centered 3300 $cm^{-1}$ assigned to hydrogen-bonded (O–H) stretching and a broad peak around at 2800–3000 $cm^{-1}$ assigned to (C–H) stretching are related to characteristic peak of cellulose macromolecules for the untreated linen fabric (Chung et al. 2004). A peak at 3491 $cm^{-1}$ and 3552 $cm^{-1}$ assigned to phenolic (–OH), a peak at 1660 $cm^{-1}$ assigned to the carbonyl (C=O) stretching and a peak at 1726 $cm^{-1}$ assigned to carboxyl (–COOH) are related to characteristic peak of baicalin (Looker and Hanneman 1962). The diminished peaks at 3491 $cm^{-1}$ and 3552 $cm^{-1}$ and detectable peaks at 1660 $cm^{-1}$ and 1726 $cm^{-1}$ of s6, which indicated baicalin can combined with the linen fabric by formation of intermolecular hydrogen bonds between reactive groups in baicalin (e.g. hydroxy, carboxyl) and the hydroxyl groups in the macromolecule of linen fibers (Li et al. 2017). Moreover, in weakly acidic baicalin solution (pH 6.8–7.0, Table 1), baicalin can also combine with negative zeta potential of cellulose macromolecules through electrostatic interaction (Muderrisoglu and Yesil-Celiktas 2019; Rekaby et al. 2013).

The crystalline structures of the untreated linen fabric (s0) and treated linen fabrics (s2, s6) were determined by X-ray diffraction patterns. Figure 3 exhibited the peaks of (1-10), (110) and (200) that correspond to the characteristic diffraction peaks of cellulose I. The peaks appearing at the same position of s2 and s6 indicated that the crystallization characteristics of cellulose I were almost reserved whether

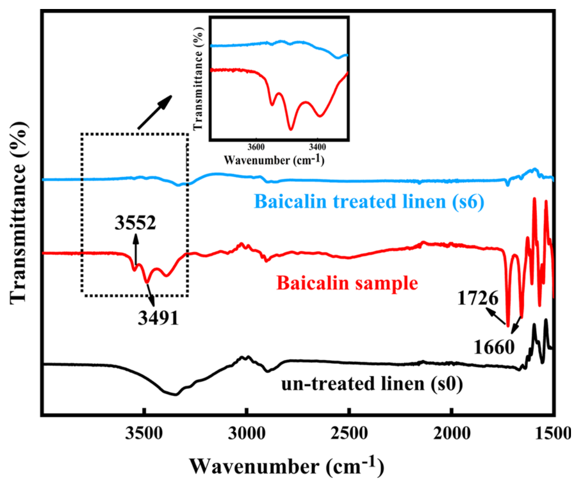



**Fig. 2** FT-IR spectra of the un-treated linen fabric (s0), baicalin sample and the baicalin treated linen fabric (s6)

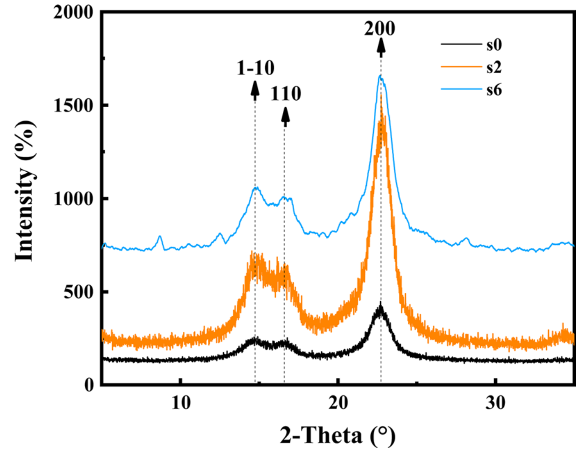



**Fig. 3** X-ray diffraction pattern of the un-treated linen fabric (s0), the SBE treated linen fabric (s2) and the baicalin treated linen fabric (s6)

treated by SBE or baicalin solution. Besides, the peak widths at half maximum height (pwhm) of s2 or s6 all slightly increased compared with the pwhm of s0, which meant the crystallinity index of s2 or s6 was slightly smaller than s0 according to Scherrer equation (Ling et al. 2019). The result of XRD demonstrated that short-time ultrasonic treatment played a positive effect on reducing crystallinity of cellulose fiber and improvement of combination between SBE/baicalin with the linen fabric (Cui et al. 2016; French and Cintrón 2013; Tang et al. 2014).

## The thermal stability and mechanical property of treated linen fabrics

The thermo-stabilities of the untreated linen fabric (s0) and treated linen fabrics (s2, s6) were evaluated by the thermogravimetry analysis (TGA) and differential thermogravimetry (DTG). As shown in Fig. 4a, b, the initial decomposition temperature of s2 decreased from 230 °C of s0 to 200 °C, and the maximum decomposition temperature also decreased from 365 °C of s0 to 361 °C, which indicated that the thermal stability of linen fabric decreased due to the slight reduction in crystallinity of linen fiber after ultrasonic treatment (Liu et al. 2015). In addition, the destruction of the network structure between pectin and linen and the elimination of other non-cellulosic constituents like waxes in the ultrasonic treatment may determine the treated linen fabric will be more exposed to the thermal degradation than the untreated

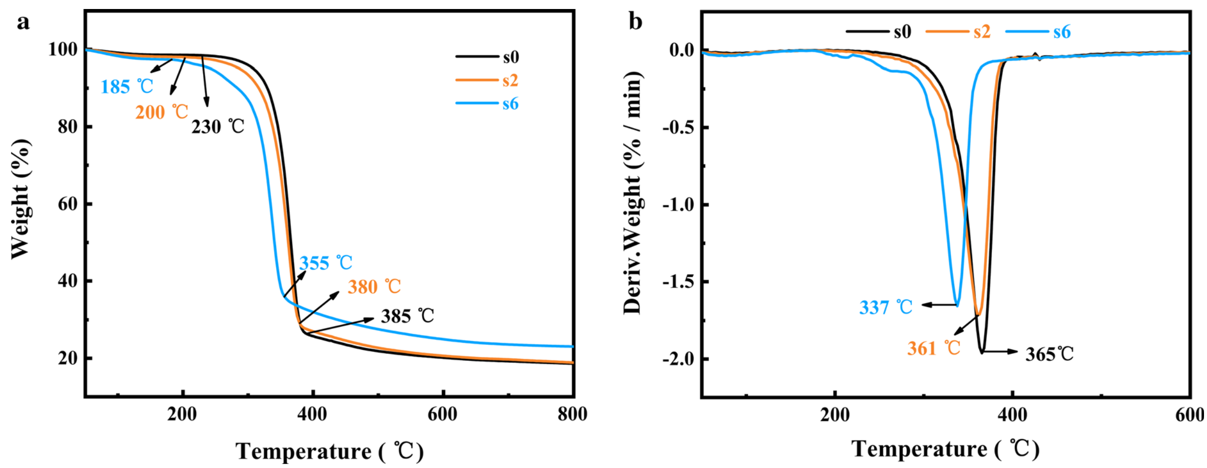



**Fig. 4** Thermogravimetric analysis of the un-treated linen fabric (s0), the SBE treated linen fabric (s2) and the baicalin treated linen fabric (s6) **a** TGA curves, **b** DTG curves

linen fabric, which can also lead to a decrease of the decomposition temperature (Dochia et al. 2018). While the decomposition temperature and the maximum decomposition temperature of s2 were higher than s6 maybe because other compounds (e.g. baicalein, tannins) in SBE tend to establish more hydrogen bonds with the linen fiber macromolecules resulting in higher thermostability (Chirikova et al. 2010; Teli and Pandit 2017).

The fracture strength and fracture elongation were used to evaluate the mechanical properties of treated linen fabrics (s2 to s9) and the untreated linen fabric (s0) for comparison. As shown in Fig. 5, the average of fracture strength and fracture elongation on dry state were smaller than on wet state, which was consistent with the basic mechanical feature of the linen fiber (Bourmaud et al. 2010). The fracture strength and fracture elongation of s2 to s9 were all smaller than s0 and further reduced with increase of SBE content (s2 to s5) or baicalin content (s6 to s9), which indicated that ultrasonic processing can destroy the dense structure of the linen fiber and more hydrogen bonds between the intra-molecules of the linen fiber were broken with increase of SBE or baicalin contents (Jarvis 2003). Despite of at the same baicalin content, the fracture strength and fracture elongation of linen fabrics treated by SBE (s2 to s5) were slightly lower than those of linen fabrics treated by baicalin (s6 to s9), because the other compounds (e.g. organic acids, phenolic acids, tannins) in SBE can exacerbate inter-molecular hydrogen bonds cleavage

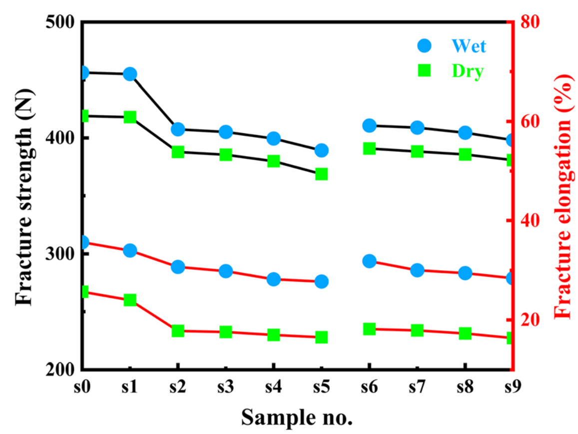



**Fig. 5** Mechanical properties of the untreated linen fabric (s0), the pre-treated linen fabric (s1), treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9)

between linen fibers and lead to more deterioration of the mechanical properties (Chirikova et al. 2010).

## Functionalities of treated linen fabrics

### *Antimicrobial activity*

The mechanism of antibacterial and anti-mould activity is that baicalin or other main phytochemicals as flavonoids contained in SBE can inhibit the activity of enzymes in bacteria and fungi and destroy protein genetic materials such as inhibit DNA or RNA synthesis in *Proteus vulgaris* and *Staphylococcus aureus* (Mori et al. 1987), so that further replication of genetic material does not occur to prevent the growth of bacteria and fungi (Yu et al. 2015; Daglia 2012). In addition, flavonoids also can reduce membrane fluidity of various bacteria to inhibit the cytoplasmic membrane function (Mori et al. 1987), and inhibit the energy metabolism to interfere with the life activities of bacteria and fungi (Cushnie and Lamb 2005). Antimicrobial activities were evaluated by two indexes as anti-mould level and antibacterial rate. As shown in Fig. 6 and Tables 2, 3, the antimicrobial activities of treated linen fabrics (s2 to s9) were better than the untreated linen fabric (s0), and due to the synergism of baicalin with other components in SBE the antimicrobial activities of treated linen fabrics by SBE (s2 to s5) were slightly better than treated linen fabrics by baicalin (s6 to s9) with the same baicalin content. Furthermore both SBE and baicalin had better inhibitory effect on *S. aureus* than on *E. coli*. The results demonstrated that baicalin was a highly effective antimicrobial agent and can achieve antibacterial rate above 73% and anti-mould level 2 with only 0.27 wt% content. As trends in the demand for antimicrobial textiles continue to rise, the effective control of antimicrobial effect with low dosage and harmless to human body becomes ever more important for the antimicrobial materials. These results may also

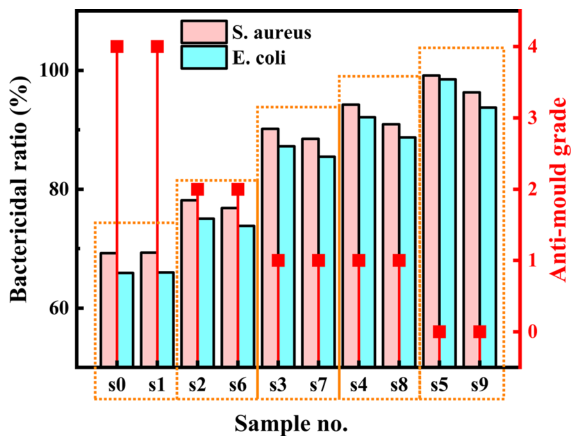
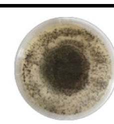
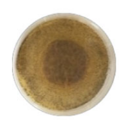
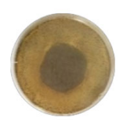
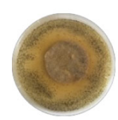
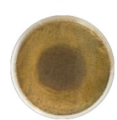
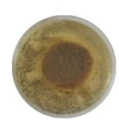
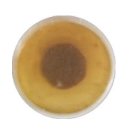



**Fig. 6** Antimicrobial activity of the untreated linen fabric (s0), the pre-treated linen fabric (s1) and treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9)

**Table 2** Anti-mould activity of the untreated linen fabric (s0), the pre-treated linen fabric (s1) and treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9)

| Sample no. | Anti-mould grade | Photo | |
|---|---|---|---|
| Control group (s0)/s1 | 4/4 |  |  |
| s2/s6 | 2/2 |  |  |
| s3/s7 | 1/1 |  |  |
| s4/s8 | 1/1 |  |  |
| s5/s9 | 0/0 |  |  |

Remark: All anti-mould grade of blank control group were 0

**Table 3** Antibacterial activity of the untreated linen fabric (s0), the pre-treated linen fabric (s1) and treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9)

| Sample no. | Agar diffusion plate method | | Bacterial reduction (%) | | | |
|---|---|---|---|---|---|---|
| | *S. aureus* | *E. coli* | *S. aureus* | | *E. coli* | |
| Control group |  | | | | | |
| s0/s1 |  | | | | | |
| | s0 | s0 | 69.23 ± 1.07 | 69.31 ± 0.86 | 65.89 ± 0.75 | 65.96 ± 0.92 |
| s2/s6 |  | | | | | |
| | s2/s6 | s2/s6 | 78.15 ± 0.43 | 76.85 ± 0.61 | 75.04 ± 0.65 | 73.83 ± 0.98 |
| s3/s7 |  | | | | | |
| | s3/s7 | s3/s7 | 90.15 ± 0.89 | 88.46 ± 0.19 | 87.21 ± 0.21 | 85.45 ± 0.25 |
| s4/s8 |  | | | | | |
| | s4/s8 | s4/s8 | 94.23 ± 0.21 | 90.92 ± 0.69 | 92.12 ± 0.11 | 88.71 ± 0.31 |
| s5/s9 |  | | | | | |
| | s5/s9 | s5/s9 | 99.15 ± 0.35 | 96.31 ± 0.32 | 98.51 ± 0.05 | 93.75 ± 0.89 |

Remark: Antibacterial activity rate represents average value of three determinations ± standard deviation %)

suggest that SBE and baicalin could be used as green, natural effective antimicrobial agents under low content on textiles functionalization.

### *Effects of SBE and baicalin on extinction of DPPH radical*

DPPH radical is a stable radical which could be quenched by antioxidant molecules causing the purple color to fade or disappear (Support Information S3), resulting in a decrease in absorbance peak at the 517 nm band. Phenolic hydroxyls in baicalin are considered to exhibit high antioxidant activity (Zhou et al. 2018). The flavonoids mainly containing in baicalin as active ingredients of SBE are responsible for the most prominent compound of radical-scavenging capacity due to its structural feature of a diortho-hydroxyl group in A-ring (Gao et al. 1999). Moreover

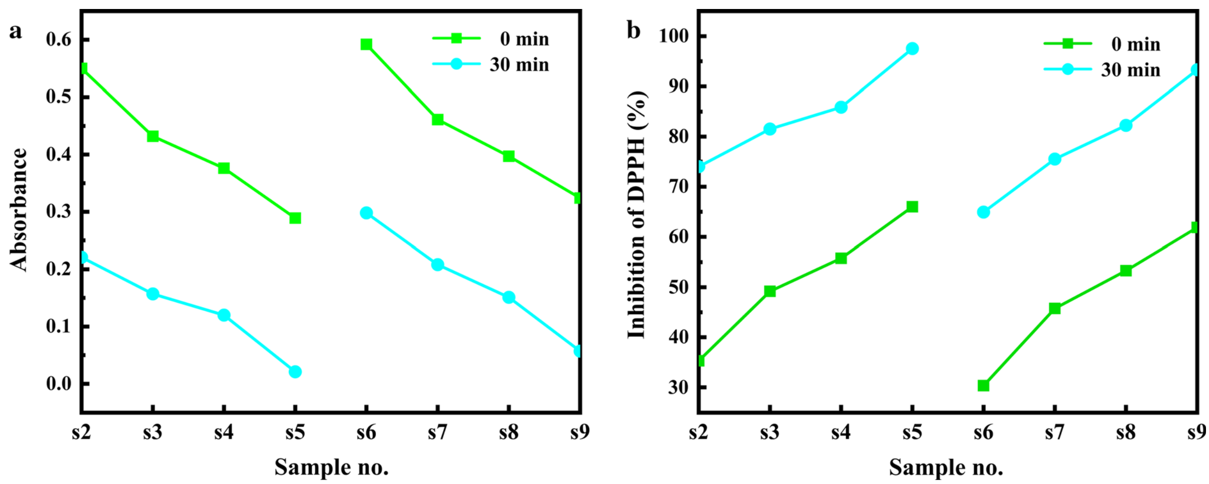



**Fig. 7** The effects on extinction of DPPH radical of treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9) on the DPPH **a** absorbance and **b** inhibition

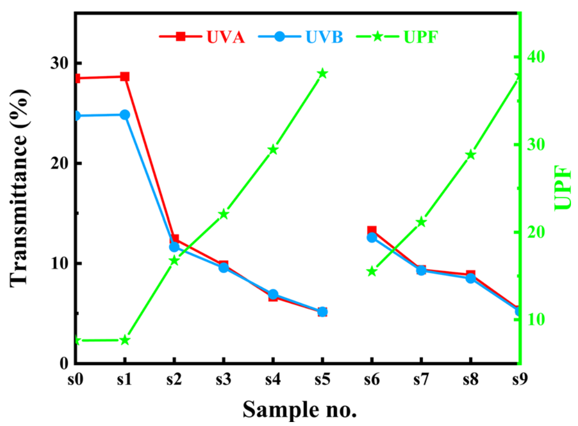



**Fig. 8** The ultraviolet protection ability of the untreated linen fabric (s0), the pre-treated linen fabric (s1), treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9)

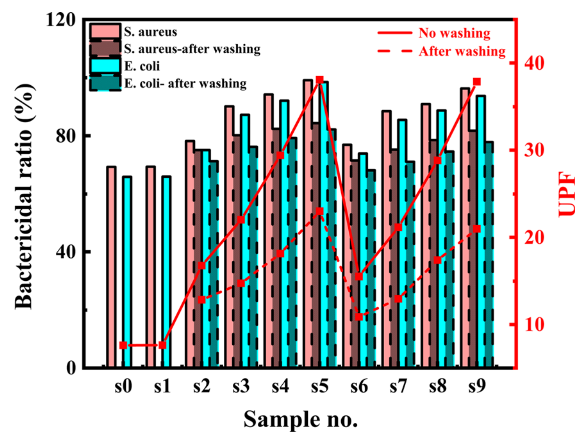



**Fig. 9** Durability of antibacterial activity and ultraviolet protection factor (UPF) of s0 to s9 after 10 times washing

tannins are also possible that both of above suggested mechanisms working in tandem as polyphenolic compounds in SBE because of its phenolic hydrogen structure in their molecules (Amarowicz et al. 2004). Figure 7a, b shown the effects of treated linen fabrics by SBE (s2 to s5) and baicalin (s6 to s9) with different absorbance and inhibition rate of DPPH radical. With increase of baicalin content, the extinction of DPPH radical activity increase whether it is treated by SBE or baicalin. While linen fabrics treated by SBE (s2 to s5) have better antioxidant activity than treated by baicalin (s6 to s9) after 30 min reaction because SBE contains other free radical scavengers (e.g. baicalein, wogonoside) than baicalin (Gao et al. 1999).

*UV Protection*

Flavonoids are known as UV-absorbing compounds and wavelength-selective for UV-B that may prevent the accumulation of UV-B-induced DNA damage, protecting cells against UV damage from UV radiation-induced peroxidation (Dias et al. 2019; Mota et al. 2019; Fernandes et al. 2017; Anouar et al. 2012). Flavonoids as main chemical constituents of baicalin containing in SBE can link to linen macromolecules to provide good UV protection (Chirikova et al. 2010; Teli and Pandit 2017). As shown in Fig. 8, compared with the untreated linen fabric (s0), treated linen fabrics (s2 to s9) exhibited remarkably decreased UV

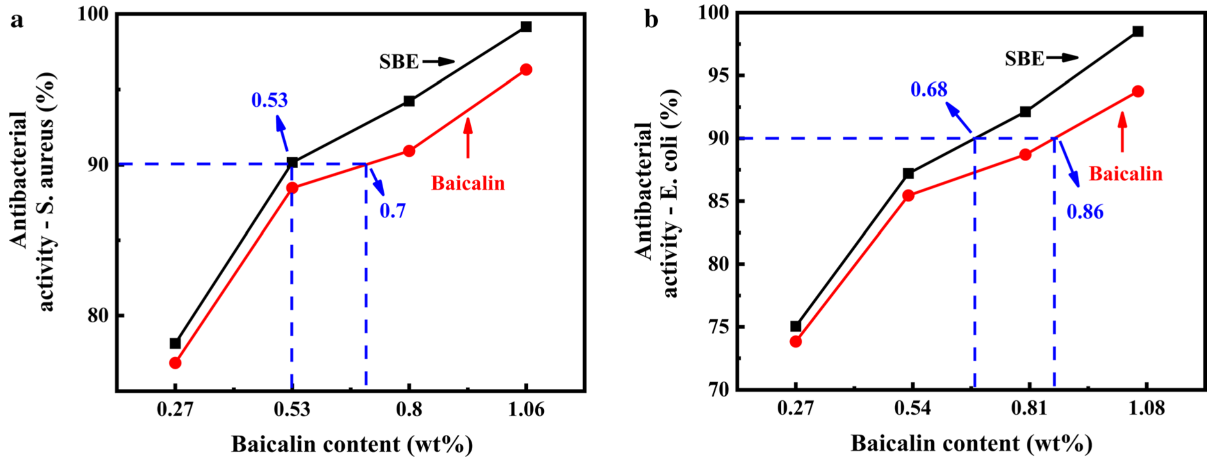



**Fig. 10** Comparison of baicalin content in SBE and baicalin aqueous solution under same antibacterial activity of treated linen fabrics **a** *S. aureus*, **b** *E. coli*

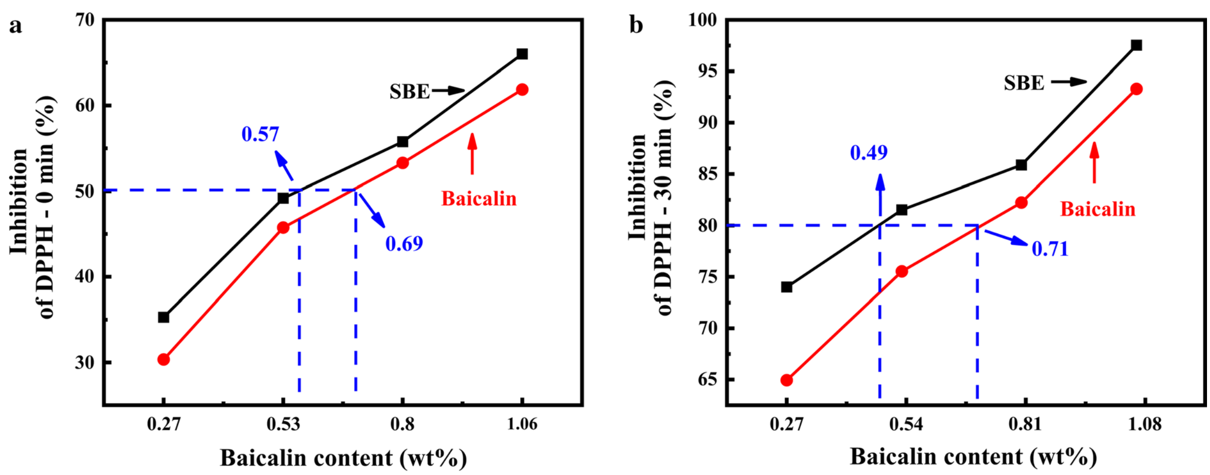



**Fig. 11** Comparison of baicalin content in SBE and baicalin aqueous solution under same inhibition rate of DPPH of treated linen fabrics **a** 0 min, **b** after 30 min

transmittance over the range of 280–400 nm (UVA, UVB), and remarkably increased Ultraviolet Protection Factor (UPF) with increases of SBE and baicalin content. Furthermore, the UPF of linen fabrics treated by SBE (s2 to s5) are better than treated by baicalin (s6 to s9) due to synergistic effect of other flavonoids in SBE (e.g. baicalin, baicalein, wogonoside) (Gao et al. 1999; Mota et al. 2019).

## Durability of functionalities

The durability of functionalized textiles was evaluated by comparing functionalities before and after washing. The antibacterial activities and ultraviolet protection factor (UPF) of treated linen fabrics (s2 to s9) after 10 washing cycles according to China National Standard (GB/T 20944.3-2008) were measured. Compared with the untreated linen fabric (s0), the pre-treated linen fabric (s1), and treated linen fabrics before washing (s2 to s9), although antibacterial activities and ultraviolet protection factor (UPF) of treated linen fabrics (e.g. s3) after 10 washing cycles were visibly reduced from 90.15% to 80.15% (*S. aureus*), from 87.21% to 76.16% (*E. coli*), from 22.03 to 14.75 (UPF), it was still 10% higher than the untreated and pre-treated linen fabric (Fig. 9). These results further confirmed the SBE and baicalin can be used to functionalize textiles assisted by ultrasonic treatment because of the considerable durability of functions.

## The equivalence relationship between SBE and baicalin on functionalization of textiles

Comparative analysis of the functions of linen fabrics treated by SBE and baicalin with at the corresponding equivalent baicalin contents (0.27 wt%, 0.53 wt%, 0.80 wt%, 1.06 wt%), it was found that under the same baicalin content, the functions of linen fabrics treated by SBE were generally better than by baicalin due to synergistic effects of other components in SBE (e.g. baicalein, wogonoside) on textiles functionalization (Lu et al. 2011; Gao et al. 1999). The equivalent relationship between SBE and baicalin for a certain function can be determined by quantifiable functional indicators such as antibacterial activity rate, DPPH radical inhibition rate and UPF. As shown in Figs. 10, 11 and 12, if at same antibacterial activity rate (*S. aureus*, E. coli) of 90%, baicalin content 0.7 wt%, 0.86 wt% and SBE content 9.94 wt%, 12.8 wt% (baicalin content 0.53 wt%, 0.68 wt%) are functionally equivalent. If at same DPPH radical inhibition rate of 50% (0 min), 80% (30 min), baicalin content 0.69 wt%, 0.71 wt% and SBE content 10.7 wt%, 9.23 wt% (baicalin content 0.57 wt%, 0.49 wt%) are functionally equivalent. If at same UPF of 30, baicalin content 0.85 wt% and SBE content 15.42 wt% (baicalin content 0.82 wt%) are functionally equivalent. The equivalent relationship between these SBE and baicalin can guide the quantitative addition and waste reduction when functionalizing textiles with SBE.

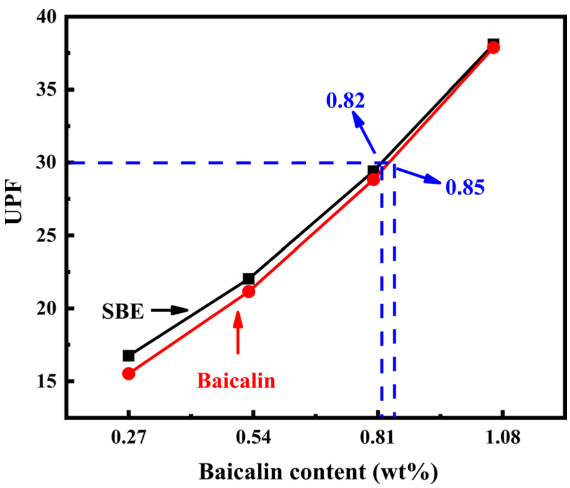



**Fig. 12** Comparison of baicalin content in SBE and baicalin aqueous solution under same UPF value of treated linen fabrics

## Experimental verification

In order to further verify the equivalent relationship between SBE and baicalin on the functionalization of textiles. The SBE and baicalin aqueous solution with different baicalin content according to same functions were prepared to treat linen fabrics respectively and

**Table 4** Comparison of multi-functions of treated linen fabrics by SBE and baicalin with equivalent baicalin content

| Baicalin content (wt%) | Antibacterial activity (%) | | Inhibition of DPPH (%) | | UPF |
|---|---|---|---|---|---|
| | *S. aureus* | *E. coli* | 0 min | 30 min | |
| 0.69 | – | – | 49.01 | – | – |
| 0.71 | 89.92 | – | – | 80.23 | – |
| 0.86 | – | 90.67 | – | – | 29.13 |

| SBE content (wt%) | Baicalin content (wt%) | Antibacterial activity (%) | | Inhibition of DPPH (%) | | UPF |
|---|---|---|---|---|---|---|
| | | *S. aureus* | *E. coli* | 0 min | 30 min | |
| 9.23 | 0.49 | – | – | – | 80.01 | – |
| 9.94 | 0.53 | 90.29 | – | – | – | – |
| 10.7 | 0.57 | – | – | 50.12 | – | – |
| 12.8 | 0.68 | 92.98 | 90.21 | – | 83.64 | – |
| 15.42 | 0.82 | – | – | – | – | 30.57 |

the corresponding functions were measured subsequently (Support Information S9). As shown in Table 4, the bacteriostatic rates (*S. aureus*) of linen fabrics treated by baicalin with baicalin content of 0.71 wt% and by SBE with baicalin content of 0.53 wt% were very close (89.92%, 90.29%), and the inhibition of DPPH (30 min) of linen fabrics treated by baicalin with baicalin content of 0.71wt % and by SBE with baicalin content of 0.49 wt% were very close (80.23%, 80.01%). Meanwhile linen fabrics were treated by baicalin and SBE with almost the same baicalin content (0.71 wt%, 0.68 wt%), the bacteriostatic rates of treated linen fabrics by SBE were significantly better than by baicalin. The same result was obtained by other functional evaluations, which confirmed the credibility of the previously conclusions of equivalent relationship between SBE and baicalin on functionalization of textiles.

## Conclusion

Hence, the SBE and its the active ingredients baicalin were effectively combined with linen fabrics by means of impregnation and ultrasonic treatment respectively. Through the comparative analysis of the functions of above-treated linen fabrics, it was also found that linen fabrics treated by SBE exhibited better antimicrobial activity, antioxidant activity and ultraviolet protection ability than treated by just baicalin. Subsequently, the equivalent relationship between SBE and baicalin on functionalization of textiles was further studied and verified experimentally. The conclusion of this work has very practical guiding significance for the quantitative addition and waste reduction of plant extracts on the functionalization of textiles.

**Acknowledgments** The work were kindly supported by No. 215 Research Institute of China Aerospace Science and Industry Nanjing Chenguang Groups, State Key Laboratory of Bio-Fibers and Eco-textiles of Qingdao University.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

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