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Dyeing and antibacterial properties of cotton dyed with prodigiosins nanomicelles produced by microbial fermentation

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ABSTRACT

This study focused on dyeing of cotton fabric with nanosuspension of prodigiosins micelles which was produced by the fermentation of *Serratia marcescens*. The average diameter of the pigments micelles was 184.3 nm (rang of 101.1–378.0 nm). Various factors that affected the dyeing results were analyzed. Furthermore, the antibacterial property of dyed cotton was investigated. It was found that the ethanol concentration, dyeing temperature and dyeing time had great effects on color strength of fabric. When the ethanol concentration of dye bath was 25% (V/V) and the dyeing temperature was set at 90 °C for 90 min, dyed cotton fabric exhibited the maximum *K/S* value with good rubbing, washing and perspiration color fastness. In addition, due to the presence of prodigiosins, the dyed cotton showed bacteriostatic rate of 51.43% and 94.12% against *Escherichia coli* and *Staphylococcus aureus*, respectively. All the results indicated that prodigiosins were successfully dyed onto the cotton fabric via the nanomicelles dyeing method. This research developed a novel method of preparing dye liquid and dyeing cotton with intracellular prodigiosins.

1. Introduction

In recent years, people have more interests in natural dyes on account of their better biodegradability and compatibility with the environment as well as lower toxicity and allergic reaction. In order to meet the growing demand for natural dyes, new natural pigments are being sought, among which microbial pigments are the most potential choice for development and utilization because of their rich species, high productivity and short production cycle [1–3]. Moreover, the production of microorganism pigments is not restricted by season, climate and geography [4–6]. In this course, prodigiosins have recently been suggested as a type of promising microbial pigments, which are the secondary metabolites of *Serratia marcescens* (Fig. 1a), *Serratia plymuthica*, *Vibrio gazogenes* and some actinomycetes. As shown in Fig. 1, prodigiosins are a family of microbial pigments with the main structure of a tripyrrole, among which prodigiosin (pyrrole, 3-methoxypyrrole, 2-methyl-3-amylpyrrole) is the major and typical composition [7–9]. The color of prodigiosins is pH-sensitive and it presents purplish red under acidic and neutral conditions, while orange-yellow under alkaline condition [10,11].

Prodigiosins have been reported to have many health benefits and functionalities, such as antifungal, antibacterial, antimalarial, immunosuppressive, antineoplastic and UV-resistant properties [12,13]. Fabric can be endowed with added value when the pigments are used as dyestuff. However, there exists some shortages during their application in textile dyeing. First, prodigiosins are almost not soluble in water and most of them are within the thalli in traditional culture media as intracellular pigments. Before preparing dye liquor, the pigments must be extracted from the interior of thalli by organic solvent, such as methanol or ethanol. Besides, a large amount of organic solvent is utilized for preparation of dye liquor (organic solvent/water, 1/1, V/V) to dissolve the pigments [14]. Furthermore, although this kind of pigments has been utilized to dye wool, polyester and acrylic fabrics with relatively good color

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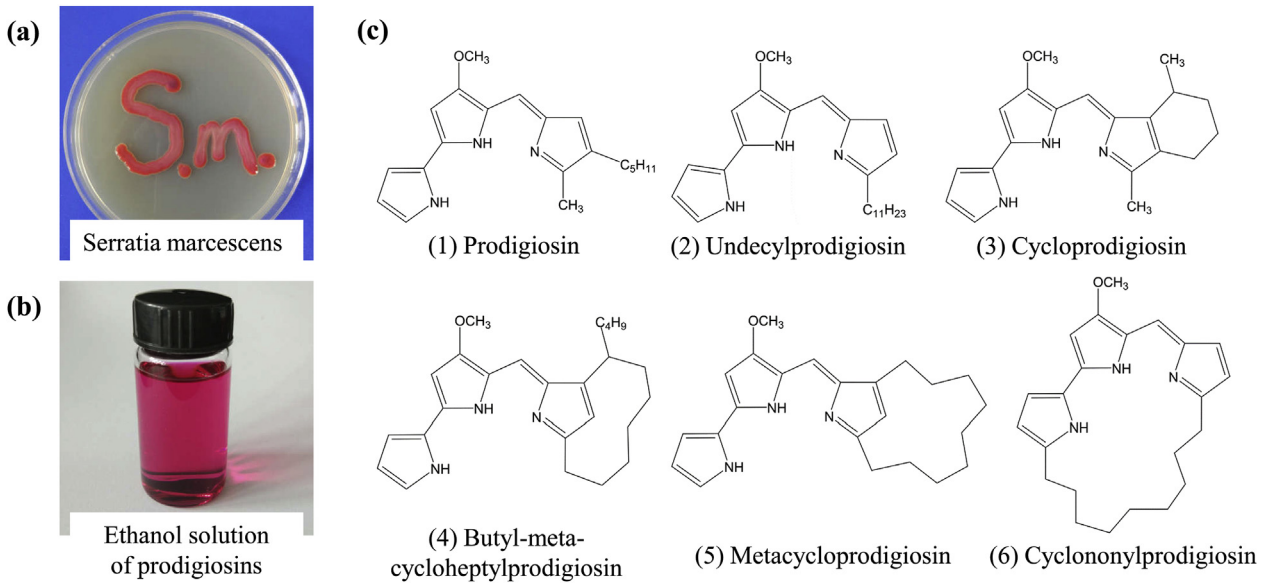

Fig. 1. (a) *Serratia marcescens*; (b) Ethanol solution of prodigiosins; (c) Chemical structures of the representative members of prodigiosin family.

fastness, cotton can only be stained by the pigments without chemical mordants because of low affinity between prodigiosins molecular and cellulose. Some papers report that cotton fabric dyed with prodigiosin doesn't have antibacterial activity to both *Escherichia coli* and *Staphylococcus aureus* due to the lower dye-uptake [14–16].

The preparation of nanomicelles mainly comprises three methods: dissolving directly, dialysing and self-assembled solvent evaporation. Nanomicelles of microbial pigments were primarily prepared by adding surfactant to the culture media at the beginning or during the process of the liquid fermentation under continuous oscillation. Because of their relatively lower cytotoxicity compared to ionic surfactants, nonionic surfactants were utilized more extensively [17,18].

This work produced prodigiosins nanomicelles by the fermentation of *Serratia marcescens* through adding nonionic surfactant to the culture media. For the first time, we dyed cotton fabric with the nanosuspension of prodigiosins micelles and discussed the optimum dyeing process. In addition, the antibacterial activity of dyed cotton against *Escherichia coli* and *Staphylococcus aureus* was investigated.

2. Materials and methods

2.1. Materials

2.1.1. Microorganism material

Serratia marcescens ATCC 8100 was bough from American type culture collection.

2.1.2. Textile material

The scoured and bleached cotton fabric (warp 106 dtex, weft 106 dtex; warp density 133 yarns per inch, weft density 72 yarns per inch; weight 106.6 g/m^2) was bought from Tianyi printing and dyeing company in Tianjin, China.

2.1.3. Chemical and reagents

Yeast powder, peptone were of biological reagent. Glycerol, Tween 80, $MgSO_4$, NaCl, KCl, sodium hydroxide, hydrochloric acid and ethanol were of analytical reagent grade and used as received.

2.2. Preparation of dye liquor

The *Serratia marcescens* was cultivated in seed culture media containing 5 g/L yeast powder, 10 g/L peptone, 3 g/L NaCl, 2 g/L KCl at 30 °C for 12 h. Then 8 mL above seed culture solution was added into a 500 mL Erlenmeyer flask containing 200 mL fermentation broth, whose composition contained 15 g/L peptone, 0.3% (V/V) glycerol, 1.8% (V/V) Tween 80, 2 g/L $MgSO_4$, 3 g/L NaCl and 2 g/L KCl. The fermentation culture media was cultivated in a shaking incubator at 28 °C and 200 rpm for 72 h.

The cultivated bacteria solution was centrifuged at 10000 rpm, 20 °C for 10 min to discard the thalli. The fermentation liquid obtained after centrifugation, namely nanosuspension of prodigiosins micelles (Fig. 1a) was applied for the dyeing experiment.

2.3. Dyeing procedure

Dyeing process was carried out in a 150 mL Erlenmeyer flask with a rubber plug and a reflux condenser of long glass tube in the shaking water bath. The liquor ratio was 1:50. The ethanol concentration of dye bath, dyeing temperature and dyeing time were investigated to determine the optimum dyeing condition. After dyeing process, the fabrics were washed twice with boiling soap liquid, followed by drying at 70 °C. All the experiments were performed in triplicate.

2.4. Measurements

2.4.1. Particle size analysis

The particle-size distribution of the prodigiosin nanomicelles was determined by DelsaNano C laser particle size analyzer (Beckman Coulter Inc, USA) with analysis method of CONTIN. The mean diameter, D_v (10%), D_v (50%), D_v (90%) of particle size and polydispersity index were tested.

2.4.2. Visible light scanning analysis

Prodigiosins were extracted from the thalli by 90% (V/V) ethanol-water solution (pH 4). The visible absorption spectrum of prodigiosins solution was measured by Lambda 750 UV/Vis/NIR spectrophotometer (PerkinElmer, USA).