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Dyeing and functional properties of polyester fabric dyed with prodigiosins nanomicelles produced by microbial fermentation

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ABSTRACT

Nanosuspension of prodigiosins micelles produced by the fermentation of *Serratia marcescens* was utilized as a novel kind of cleaner disperse dye for polyester fabric dyeing. The average particle size of the pigments dispersion was 184.3 nm (range of 101.1–378.0 nm). The effects of technical parameters including dyeing temperature, dyeing time and dye bath pH on dyeing effects, antibacterial and ultraviolet protective properties of dyed fabrics were explored. The results indicated that when the dyeing temperature was set at 110 °C with a holding time of 30 min, dyed polyester under dye bath pH of 1.9 and 7.9 possessed high color strength, outstanding bacteriostatic rate of above 89.0% against *Staphylococcus aureus* and very good UV-protection ability. In addition, the dyed fabrics exhibited excellent rubbing, washing and perspiration color fastness but poor light color fastness. This research developed a novel clean method of preparing prodigiosins disperse dye by microbial fermentation and dyed polyester fabric to endow it with functionalities.

1. Introduction

In recent years, people have paid more attention to natural dyes, on account of their better environmental compatibility and biodegradability, lower allergic reaction and toxicity to human body (Boonsong et al., 2012; Shen et al., 2014; Zhang et al., 2014). Among natural dyes, microbial pigments are the most potential choice for development and utilization because of their rich species, high productivity and short production cycle. Moreover, the production of microorganism pigments is not restricted by season, climate and geography (Tuli et al., 2015; Venil et al., 2013). During the exploration, prodigiosins have recently been suggested as a type of promising microbial pigments, which are the secondary metabolites of *Serratia marcescens*, *Serratia plymuthica*, *Vibrio gazogenes* and some actinomycetes (El-Bialy and Abou El-Nour, 2015). 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 (Zang et al., 2014; Zhou et al., 2016). The color of prodigiosins is pH-sensitive and it presents purplish red under acidic and neutral conditions, while orange-yellow under alkaline condition (Andreeva and Ogorodnikova, 2015; Drink et al., 2015).

Prodigiosins have been reported to have many health benefits and functionalities, such as antifungal, antibacterial, antimalarial, immunosuppressive, antineoplastic and UV-resistant properties (Alihosseini et al., 2008; Borić et al., 2011; Guryanov et al., 2013). Fabric can be endowed with added value when the pigments are used as dyestuff (Gulani et al., 2012). Prodigiosins are almost insoluble in water at room temperature, while they have certain solubility at high temperature because of the –NH groups in their molecules. This property indicates that prodigiosins can be used as disperse dye for polyester fabric (Shen and Yang, 2013). However, since the poor solubility in water, most of prodigiosins are within the thalli in traditional culture media. As a kind of intracellular pigment, prodigiosins must be extracted from the interior of thalli by organic solvent before preparing disperse dye, and the solvent will be discarded in the following concentration process (Alihosseini et al., 2008; Chauhan et al., 2015; Kim and Choi, 2015). Besides, large amounts of dispersants, wetting agents and other

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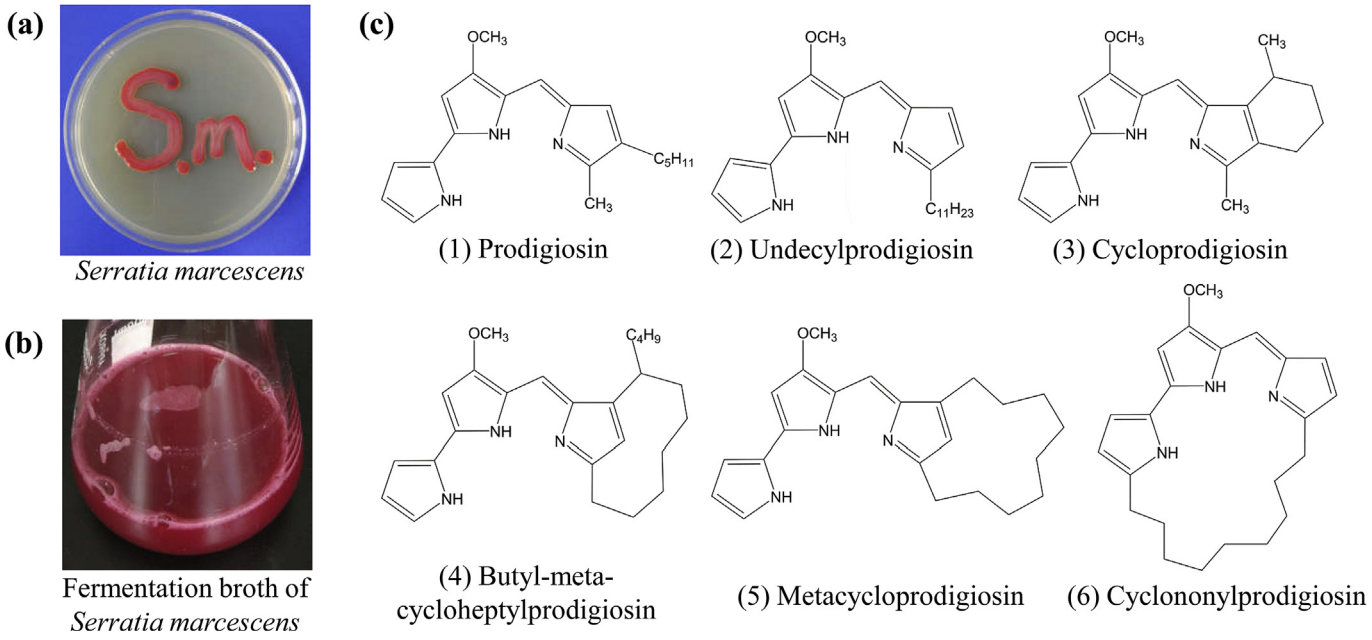

Fig. 1. (a) *Serratia marcescens*; (b) Fermentation broth of *Serratia marcescens*; (c) Chemical structures of the representative members of prodigiosin family.

auxiliaries are required in the conventional preparation of disperse dye. Moreover, the preparation process of disperse dye is complicated, which contains grinding, seasoning, spray drying and other process (Chang and Chao, 2007; Fu et al., 2013, 2011). When preparing prodigiosins disperse dye by the conventional preparation technology, these above complicated auxiliaries and ecologically unfriendly processes are necessary. These shortages limit the cleaner production of prodigiosins and other intracellular pigments when they are utilized as disperse dyestuffs.

Polyester is the most widely used synthetic fiber for apparel fabrics. The application of polyester fabric is becoming increasingly wider and deeper with the advent of polyester microfiber, on account of its more excellent performances. For example, the silk-like polyester fabrics possess the outstanding properties of comfort, beauty, thermal retention, air permeability, antifouling and other good performances (Kaynak and Babaarslan, 2016; Rajan et al., 2016; Sun et al., 2016b). However, the synthetic disperse dyestuffs applied to polyester dyeing are not clean, environmentally benign and healthy during the dyestuff preparation, dyeing process and long-term wearing.

Micelles of water-insoluble microbial pigments can be produced by adding surfactants to the fermentation broth (Hu et al., 2012; Kang et al., 2013; Wang et al., 2013). For the first time, we produced prodigiosins nanomicelles by the fermentation of *Serratia marcescens* through adding nonionic surfactant to the culture media. Polyester fabrics were dyed with the nanosuspension of prodigiosins micelles as a type of cleaner disperse dye and the optimum dyeing condition was obtained in terms of the dyeing result, antibacterial activity and UV-protection property of dyed polyester.

2. Materials and methods

2.1. Materials

2.1.1. Microorganism material

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

2.1.2. Textile material

The polyester fabric (weight 59.5 g/m^2; warp 86.4 yarns per inch, 2.5 dtex; weft 81.3 yarns per inch, 2.5 dtex) was bought from Toray Fibers Co., Ltd. in Nantong, China.

2.1.3. Chemical and reagents

Yeast powder, peptone were of biological reagent. Glycerol, Tween 80, $MgSO_4$, NaCl and KCl were of analytical reagent grade.

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 10,000 rpm, 20 °C for 10 min to discard the thalli. The fermentation liquid obtained after centrifugation, namely nanosuspension of prodigiosins micelles (Fig. 2) was applied for polyester fabric dyeing as disperse dye.

2.3. Dyeing procedure

An Ahiba Duance Eco dyeing machine (Datacolor company, USA) was utilized for fabrics dyeing. The dyeing process started from 40 °C with a raise velocity of 3 °C/min and liquor ratio 1:30. The dyeing temperature, dyeing time and dye bath pH were investigated to determine the optimum dyeing condition. After dyeing process, the fabrics were firstly washed with running water and then washed twice with boiling soap liquid for 10 min, followed by washing with running water and drying at 70 °C. The soap liquid contained 2 g/L soap flakes.