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Digital Printing of Enzymes on Textile Substrates as Functional Materials

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Abstract

Recently, there have been significant developments in inkjet printing for applications in various fields such as medicine, biomaterials and sensors. In this research, enzymes like horseradish peroxidase (HRP) and glucose oxidase (GOx) were directly printed by inkjet printer onto flexible textile fabric in predefined patterns to produce a functional material. The functionality of the printed enzymes (bioink) was investigated by chemical reaction after printing fresh and stored bio-ink in a digital printer. The results indicated that these enzymes can be effectively printed individually or in combination, which retains their functionality after printing. Furthermore, HRP was coupled and printed with fluorescent group, the result confirmed that the printed enzyme was still active and retained its functionality despite the printing process. Hence, the digital printing technique can be used as a novel method for producing functional textiles for advanced applications in monitoring health and security.

Keywords: Horseradish Peroxidase; Glucose Oxidase; Inkjet Printing; Functionality; Enzymes; Biomaterials

1 Introduction

Inkjet printing is a versatile technique with the potential to produce multifunctional materials at low cost. In sensing applications the advantages include the ability to retain the activity of immobilized biomolecules [1-4]. This is an attractive technique for manufacturing processes due to its precision, speed and flexibility, eliminating the additional expenses associated with other printing methods such as screen printing [2, 5-8]. It is also an eco-friendly method due to lower consumption of materials during the printing of visual effects such as tonal gradients and infinite patterns that cannot be practically achieved with screen printing [2, 7, 9, 10]. This

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technique also allows for more than one biomolecule in a small quantity to be patterned on a substrate, offering sophisticated possibilities to fabricate devices for security, or low cost diagnostic applications [11-14].

Since there is no contact between printed samples and printer head, the risk of cross contamination between the printed biomolecules is minimized [5, 15]. However, the effect of printing procedures on the activity of printed biomolecules and precision of the printed pattern [3, 12] on flexible substrate requires more investigation. Khan et al [5], Risio and Yan [7] investigated the functionality of the printed horseradish peroxidase (HRP) using a piezoelectric inkjet printer. They showed that the printed enzyme retained its functionality, which could be due to the suitable low temperature printing for bio-printing.

Other applications of inkjet printing of biomolecules include fabricating low cost bioassays and diagnostic or security devices; and packaging [5, 14-16]. A few studies have been done to address the possibility of bioassays fabrication by inkjet printing on papers and membranes [8, 14, 15, 17-19]. However, there is a little information on the application of this technique for fabrication of textile based bioassays and diagnostic devices, which can give more benefit to the users, especially in the domestic sector.

This study investigated the possibility of printing biomolecules onto flexible textile fabric. The key issues addressed in this study include printing resolution, precision and activity of the printed biomolecules [5, 13, 15]. In this research HRP and GOx were used as biomolecules. HRP was selected due to its exceptional performance including good stability, high catalytic efficiency, low cost and biocompatibility [5, 13, 20]. When HRP is incubated with colourless substrate tetramethylbenzidine (TMB), it produces a colour and luminescent derivatives, allowing visual impressions which can be viewed with a spectrometer [10, 20-22]. This principle was used to confirm the activity of the enzyme after printing onto the textile fabric. GOx was used as it is widely used for determination of free glucose in body fluids [7, 23-25].

2 Materials and Methods

2.1 Materials

2.1.1 Fabric Samples

A plain woven (square set) mercerized cotton fabric with an area density of 140 g/m^2 (GSM) was selected for the study. The thread density of the fabric was 33 ends and picks per cm and the yarn linear density was 40 Tex (15 Ne) both for the warp and weft. The printing substrate was prepared from the fabric by cutting into square swatches of 40 cm × 40 cm dimension, hot-pressing them to remove the creases and then attaching to a backing paper for ease of printing in the digital printer.

2.1.2 Chemicals

Horseradish Peroxidase (HRP, Catalogue: 77332, lyophilized, powder, beige ∼150 μmol mg^{-1} min^{-1}); Glucose Oxide (GOx, G6125, Type II, ≥15,000 units/g solid) and phosphate buffer solution (PBS, with concentration of 50 mM phosphate (×10) and pH value of 7.4) were used in