Glucose and sucrose analysis in daucus carota extract using optical tapered fibre sensor with GOU-AuNP composite layer synthesization

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Abstract. Tapered single-mode fibre (SMF) immobilized with glucose oxidase enzyme (GOD) and gold nanoparticles (AuNP) for the recognition of glucose and sucrose elements have been proposed. A tapered fibre was fabricated using a flame heating technique to improve the sensitivity of the fibre-based sensor. By taking advantage of amine groups in 3-aminopropyl triethoxysilane (APTES), GOD and AuNP are functionalized onto the tapered region of SMF through covalent interaction. The developments of the immobilized tapered fibre sensor for the analysis of glucose and sucrose concentration in different concentrations of the solution and types of carrots extracts were discussed in this paper. The solution concentrations of 0.1, 0.2, and 0.3 g/ml of glucose and sucrose were used to analyze the sensitivity of the fibre sensor. The extracts of baby carrots, imported carrots, and organic carrots were used to determine the existence of glucose and sucrose in these carrots. We demonstrated the sensitivities of GOD-immobilized fibre for 0.00672, 0.00722, 0.00902, and 0.00921 a.u/nm in terms of their glucose solutions, baby carrots, imported carrots, and organic carrots, respectively. Meanwhile, the sensitivities of AuNP-immobilized fibre were found to be 0.000030, 0.000026, 0.000012, and 0.000024 a.u/nm, respectively.

1. Introduction

The total sugar content in *Daucus carota* or carrot (sucrose, glucose, and fructose) is between 3.5 to 10.7 %. The higher percentage consists of sucrose, which is 56.9 % of the total amount of sugar, followed by glucose (24.6 %), and fructose (18.5 %) [1]. Organic carrots generally have slightly low sugar contents compared to conventional carrots due to the practices in organic agricultural (no pesticides usage) in the farming systems [2].

The development of high precision and accurate devices with a low limit of detection sensor has recently become favorable due to its varied range of applications and sensing research studies. The fibre-optic sensor is an optical fibre-based device which uses optical fibre as the sensing element or employing carrying signals from a remote sensor to electronic devices that process the signals called extrinsic sensors. The optical fibre typically consists of a glass or plastic core surrounded by a transparent layer of cladding material, with a lower refractive index (RI) than the core RI.

The excellent features of optical fibres such as the finest light transmission, easy enhancement of the bio-reaction, long-distance signal delivery, economical, low attenuation, and their competence to capture both excited and transmitted light from the measured target with a single component, justify the wide use of fibre optic sensor their implementations in numerous application areas [3, 4]. These benefits have seen in different potential applications in the optical fibre-based sensor for the detection of temperature, mechanical strain, humidity, pressure, vibration, velocity, displacements, liquid level monitoring, acceleration calibration and also biochemical measurements such as sugar content, pH value and concentration component of other bio-molecules in various types of solutions [5, 6]. For insensitive circumstances such as noise, high vibration, extreme heat, wet and ambiguous conditions, fibre optic sensors are primary options. These sensors can easily fit in smaller regions and can be perfectly placed wherever flexible fibres are needed. Thus, fibre optic sensors can also be designed to tolerate diverse situations. The optical fibre-based sensor has fibre optic components that are connected to a light source to allow detection or sensing in tight spaces or small profiles.

Aside from various benefits of the optical fibre itself, tapered fibre is currently attracting ample attention in contemporary research studies for the implementation of a wide range of sensing applications based on optical fibres. Its particular optical guidance features include relatively low attenuation, strong evanescent fields, narrow optical confinement (due to its large refractive index), and controllable waveguide dispersion, making it very beneficial for current technologies.

Based on the total internal reflection (TIR) principle, the light propagation in optical fibre is kept in the core with near-zero propagation loss within the cladding. However, this limits the sensing applications due to the non-interaction of the light with its surroundings. Thus, surface modification of optical fibre, based on the implementation of polymeric coatings can be used as a tool in order to improve particular features for sensing properties and other functional characteristics, depending on the applications [7].

Generally, the fabrication of tapered fibre by the flame heating technique is achieved by heating a short and uncoated section of the fibre to its softening temperature while simultaneously stretching the two ends of the fibre to form a structure of reduced and uniform diameter [8, 9]. The fibre ends are fixed on the translation stages when pulling in opposite directions. The moving heat source provides uniform heat to the fibre therefore the tapered fibre is shaped uniformly along the heated region. Multiple parameters of tapered fibre such as taper waist diameter, length, and transition shape, are important for a specially required interference spectrum.

2. Glucose oxidase enzyme and gold nanoparticles coated tapered fibres

The validation and analysis of the sugar content especially for the presence of glucose and sucrose in food is considerably important. Sugar is soluble carbohydrates which might be in either monosaccharide or disaccharide groups. Glucose is a simple sugar or monosaccharide, the simplest form of carbohydrates with a molecular formula of $C_6H_{12}O_6$. Glucose has five hydroxyl groups ($-OH$) and a carbonyl group ($C = O$) and are cyclic when dissolved in water while sucrose consists of 12 atoms of carbon, 22 atoms of hydrogen, and 11 atoms of oxygen ($C_{12}H_{22}O_{11}$) [10, 11]. Sucrose is disaccharides or double sugars which originates from two simple sugars of fructose and glucose that are composed together.

GOD, is an extremely stable enzyme that provides high selectivity for glucose detection [12, 13]. For this purpose, the cleaned fibre is immersed into sodium hydroxide (NaOH) solution for 1 hour to activate the hydroxyl groups (OH) on the tapered fibre surface and drying for 10 minutes at room temperature. The fibre core surface is then left to soak in APTES solution for 24 hours to make sure the hydrogen bonding (O-H) is well bonded to the amine bonding (N-H). This allows the amino linkage aldehyde groups (NH) to serve as a bonding bridge between the fibre and GOD such that the immobilization of GOD can be utilized. It is then dipped in 10 µg/ml of the GOD solution prepared in pH3 buffer for 2 hours to bind carboxyl groups (COOH) from GOD with NH together on the fibre surface. The coating is continued by dipping the silanized fibre in 10 µg/ml of GOD solution to bind carboxyl groups (COOH) from GOD with NH together on the fibre surface followed by rinsing using ethanol and de-ionized water. The modified fibre is then left to dry in air.

The tapered fibre is immersed in a NaOH solution before depositing the AuNP onto the fibre surface. The tapered fibre is then hydrolyzed in base Piranha solution for 15 minutes to transform the OH on the tapered fibre surface [14, 15, 16]. A base Piranha solution is prepared using mixtures of ammonium hydroxide (NH4OH) and hydrogen peroxide (H2O2) with a volume ratio of 3:1 and this solution is kept in a hot water bath with a temperature of between 70 °C - 80 °C. The fibre is then rinsed using de-ionized water and dried at room temperature. The tapered fibre surface is then prepared to be functionalized with an APTES solution to obtain a layer containing amine functional groups (NH) over the surface of the tapered region [17, 18]. The amine-modified fibre is then undergoing a sputtering process of AuNP onto the fibre surface [19].

3. Scanning electron microscopy analysis on tapered fibre

Tapered fibres with waist diameters ranging from 15 to 20 µm were used to enhance the sensitivity of the sensing region of the testing samples. The surfaces of tapered fibres were coated with GOD and AuNP for the detection of glucose and sucrose, respectively. GOD and AuNP are bonded to the amino-silanized fibre surface using the immobilization process [20, 21].

Figures 1 (a) and (b) illustrate the images of GOD-immobilized fibre using SEM at 500 and 2000 times magnifications, respectively. The surfaces of the fibres covered with AuNP are shown in Figures 2 (a) and (b) based on the same magnifications. High magnification of SEM can display the images of the modified fibre surface more clearly.

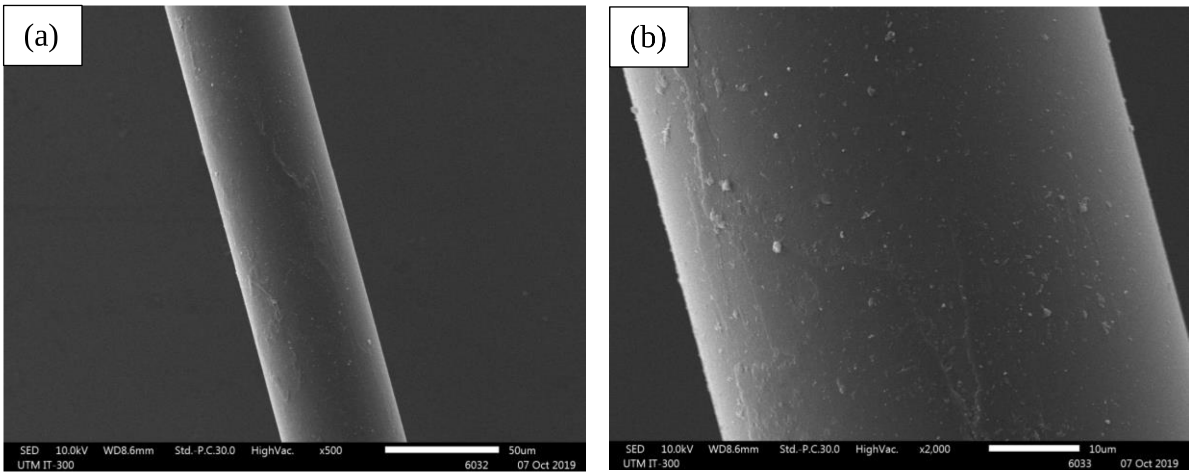

Figure 1. GOD-immobilize fibre using SEM at (a) 500; and (b) 2000 times magnification.

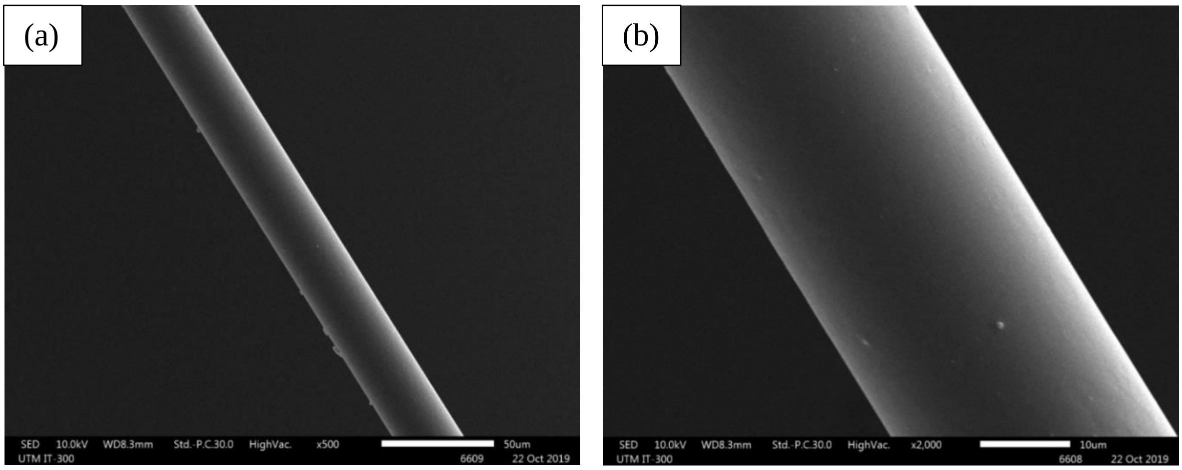

Figure 2. AuNP-immobilize fibre using SEM at (a) 500 and (b) 2000 times magnification.

4. GOD and AuNP-immobilized tapered fibre

Figure 3 represents the GOD-immobilized tapered fibre in carrot extracts. The intensity graphs of different types of carrot extracts are presented in Figure 4 where the sensitivity of the glucose sensor towards the carrot extracts has been calculated at 0.00902, 0.00921, and 0.00722 a.u/nm, respectively.

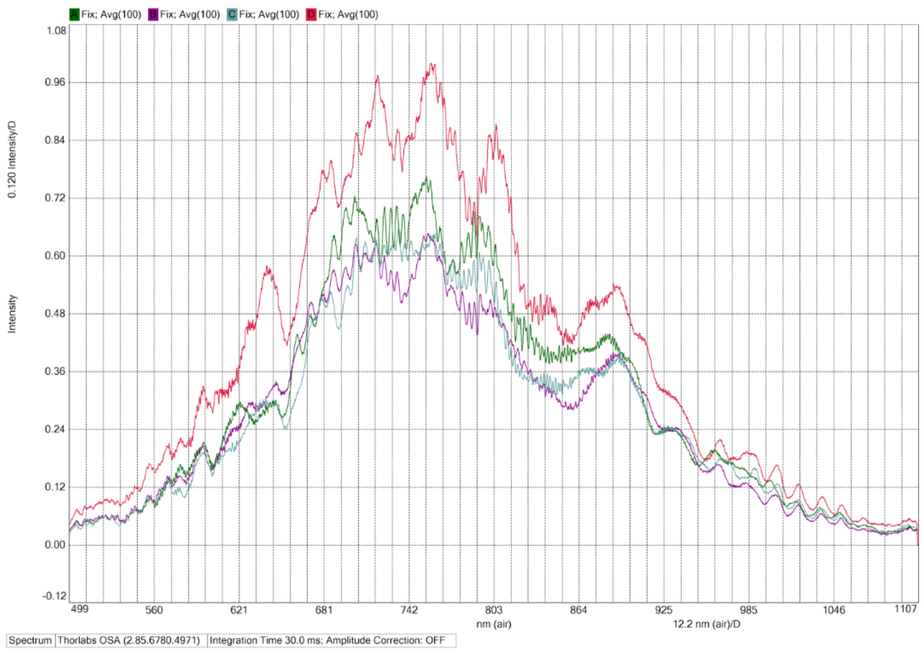

Figure 3. Graph of intensity vs. wavelength for GOD-immobilized fibre to carrot extracts.

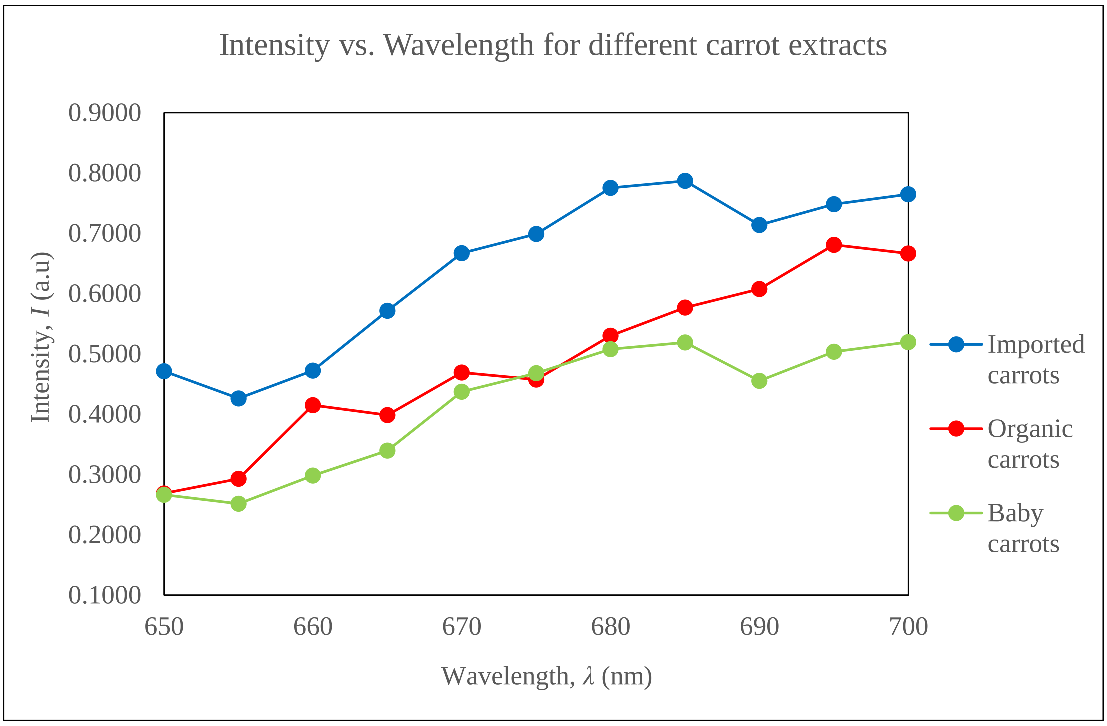

Figure 4. Intensity graphs of different types of carrot extracts for glucose detection.

The AuNP-immobilized tapered fibre shows a good response to these testing samples and the data obtained are shown in Figure 5. The sensitivity of the sucrose sensor to the carrot solutions has been calculated at 0.000024, 0.000026, and 0.000012 a.u/nm respectively as plotted in Figure 6.

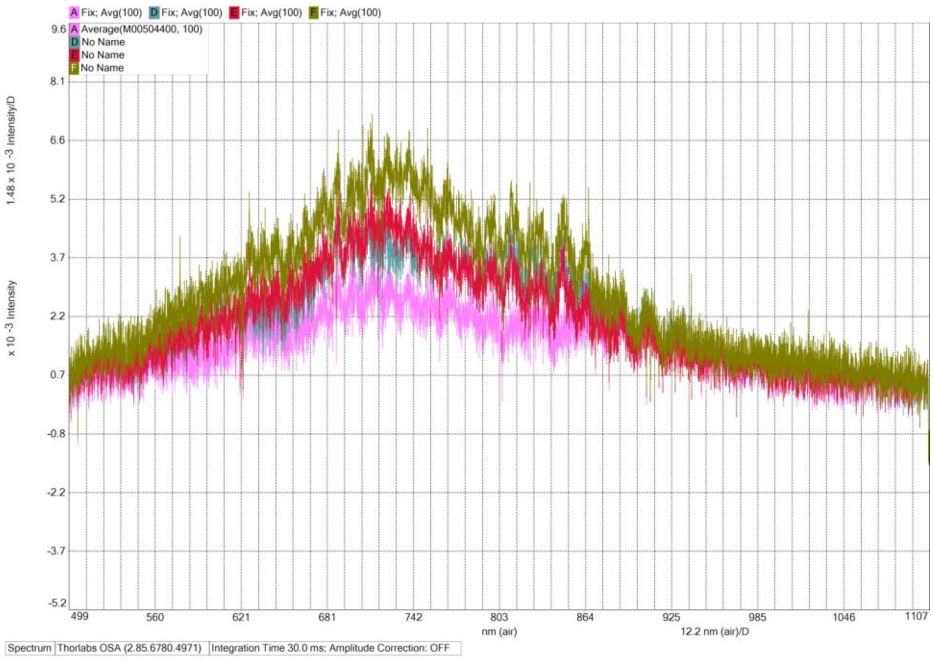

Figure 5. Graph of intensity vs. wavelength for AuNP-immobilized fibre to carrot extracts.

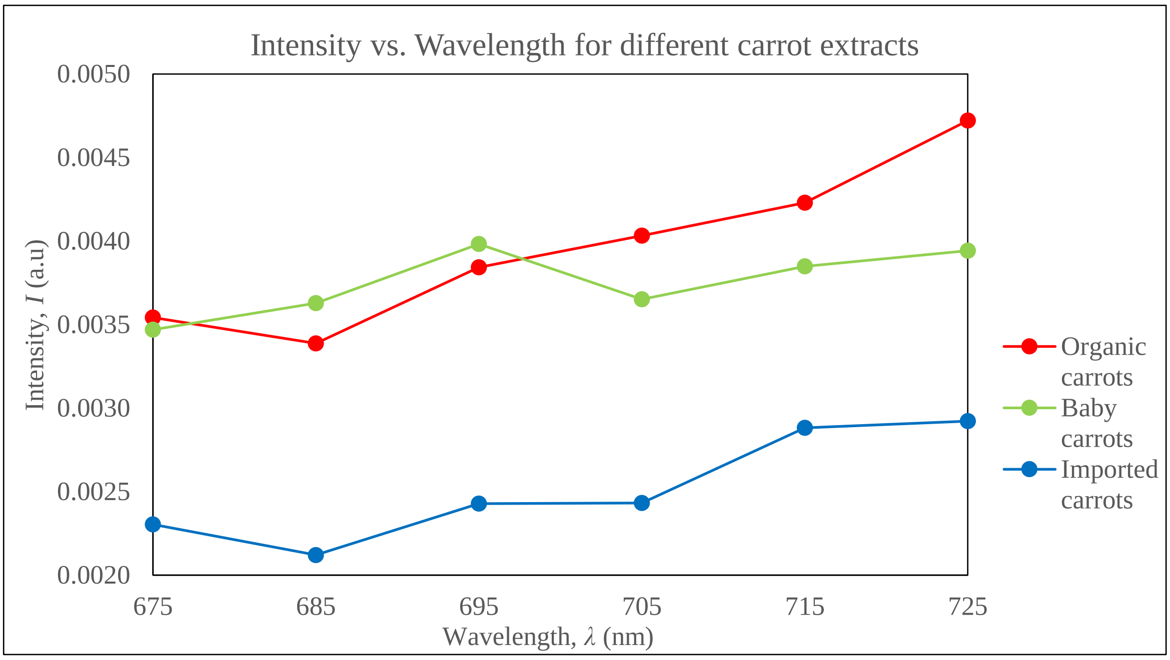

Figure 6. Intensity graphs of different types of carrot extracts for sucrose detection.

5. Conclusion

In summary, the GOD and AuNP-immobilized tapered fibre was performed with the glucose and sucrose solutions, as well as carrot extracts. The modified tapered fibre of SMF using the flame brushing technique for the selectivity and sensitivity of glucose and sucrose samples shows a good response to the different concentrations of samples and carrot extracts. The functionalization of GOD and AuNP on the tapered optical fibre for the detections of glucose and sucrose respectively was done by taking advantage of the amine groups in APTES.

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