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LOD based Fiber Optic Sensor for Glucose-Adulterated Honey Detection

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ABSTRACT

The adulteration of honey with glucose is a widespread issue that undermines consumer trust, compromises food quality, and poses health risks. To address this challenge, this study proposes a fiber optic sensor that exploits Lateral Offset Displacement (LOD) for the precise detection of glucose adulteration in honey. Using a single-mode fiber (SM-SM) configuration, the sensor leverages refractive index variations to achieve non-destructive and highly sensitive measurements. Systematic experiments were performed with controlled concentrations of honey and glucose, while varying the LOD from 0 µm to 16 µm. The results demonstrate excellent sensitivity and strong linearity, with the 16 µm LOD providing the highest performance. Specifically, honey solutions attained a peak sensitivity of -0.0496 dBm/%, glucose solutions recorded -0.02171 dBm/%, and honey–glucose mixtures exhibited 0.02821 dBm/%. These findings confirm the effectiveness of LOD as a robust tuning mechanism for enhancing sensing response and discrimination in complex mixtures. In order to safeguard consumers and ensure regulatory compliance, the suggested LOD-based fiber optic sensor is an effective tool for food quality monitoring and authenticity verification.

Keywords: fiber optic sensor, lateral offset displacement, single-mode fiber (SMF), adulterant analysis, food quality

INTRODUCTION

Honey's nutritional qualities and inherent health advantages make it a highly prized commodity. However, honey adulteration—especially with glucose—has grown to be a major problem, lowering product quality, undermining consumer trust, and increasing threats to food safety.

Conventional detection techniques such as high-performance liquid chromatography (HPLC) and stable carbon isotope ratio analysis offer high accuracy, but they require costly equipment, skilled personnel, and significant processing time. These constraints limit their applicability for routine, on-site quality control in the honey industry [1], [2].

Fiber optic sensors (FOS) have emerged as promising alternatives for food adulteration monitoring due to their high sensitivity, compact size, immunity to electromagnetic interference, and suitability for real-time measurements [3], [4]. Within this class of sensors, the Lateral Offset Displacement (LOD) technique in single-mode fiber (SMF) structures has shown particular potential for refractive index sensing in liquid samples. The LOD approach introduces a controlled misalignment between spliced fiber ends, creating a sensing region where optical power redistribution enhances interaction with the surrounding medium. This mechanism enables sensitive, non-destructive, and low-cost detection of adulterants [2], [5].

In this study, a fiber optic sensor based on LOD in SMF is designed and evaluated for the detection of glucose adulteration in honey [6], [7]. The sensor operates by correlating optical power loss with refractive index variations induced by different concentrations of honey and glucose solutions [8]. The performance is assessed in terms of sensitivity and linearity across multiple offset distances, highlighting the capability of the LOD technique to enhance measurement accuracy and reliability.

By leveraging LOD as a simple yet powerful displacement strategy, this research introduces a practical and affordable method for honey adulteration detection. This study advances beyond prior LOD-based sensor applications by demonstrating, for the first time, the direct and systematic detection of glucose adulteration in honey, thereby establishing LOD as a practical, high-sensitivity, and application-specific approach for food quality assurance [9].

METHODOLOGY

In this research, a fiber optic sensor based on lateral offset displacement techniques was designed and developed to detect glucose adulteration in honey. Single-mode fiber (SMF) was chosen as the main component due to its high sensitivity, precision, and capability to detect small refractive index changes. The fiber sensor probe was fabricated using a fusion splicing technique, a reliable method for creating precise fiber connections. Two possible fiber probe structures, waist expansion and lateral offset can be developed through this technique. For this study, the lateral offset method was selected for its simplicity, ease of implementation, and superior sensitivity in sensing applications as shown in Fig. 1.

In this method, the fiber ends are aligned adjacent or abutting each other, parallel to their longitudinal axes, with a deliberate lateral misalignment introduced during splicing. This misalignment, known as lateral offset, *x*, creates a sensing region where optical power loss occurs due to the distribution of light into the fiber's core and cladding [10]. The interaction between the cladding modes and the surrounding medium, such as honey or glucose solutions, causes changes in the refractive index, leading to variations in optical output power [11]. These variations were systematically measured and analyzed to evaluate the sensor's sensitivity and performance, demonstrating its effectiveness as a precise and reliable tool for detecting glucose adulteration in honey.

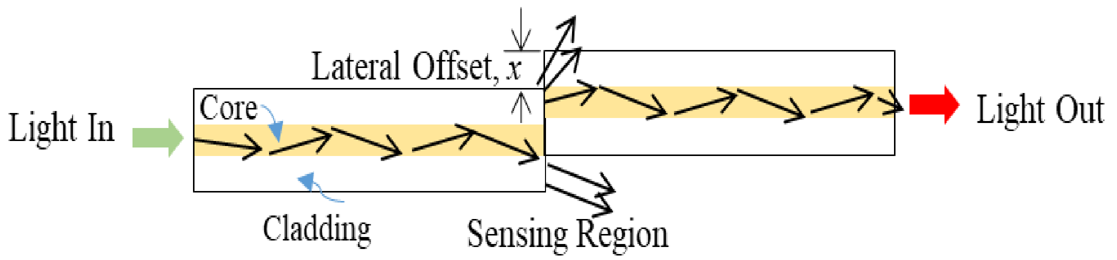

Fig. 1 Diagram of lateral offset displacement by splicing technique

The construction of the sensing probes in this research utilized two fusion splicing machines the SUMITOMO TYPE-36 and the Fujikura FSM-18R, both renowned for their precision and reliability in fiber optic splicing. The single-mode fiber (SMF) of the sensor is characterized by a cladding diameter of 125 µm and a core diameter of 9 µm and can hence be used for sensitive glucose adulteration detection in honey [12]. The sensing probe was fabricated by introducing deliberate misalignments at the junction of two fiber ends, a process known as lateral offset displacement. This mismatch results in a sensing layer in which the optical power reduction is observed in the light transmission, enabling refractive index alterations in the media surrounding it to be sensed. In this work, distances of 0 µm, 2.66 µm, 6 µm, 8.66 µm, 16 µm were explored in order to establish the optimal sensitivity of the sensor. The spliced offset regions were imaged with a high-resolution Zeiss Microscope Image Analyzer to confirm the structural integrity and accuracy of the offset constructs are shown in Fig. 2. The sensor works at wavelength 1550 nm, a common selection in view of its low attenuation and high sensitivity to refractive index changes. For consistency between experiments, fiber lengths were all set to 1 m [12]. This powerful approach demonstrates the applicability of the designed fiber optic sensor in accurately identifying glucose adulteration in honey and opens a new possibility in terms of food quality control.

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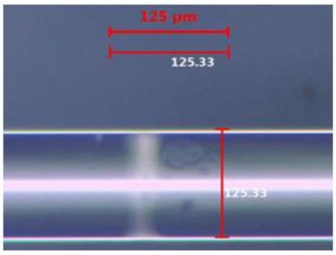

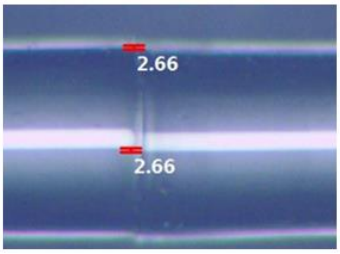

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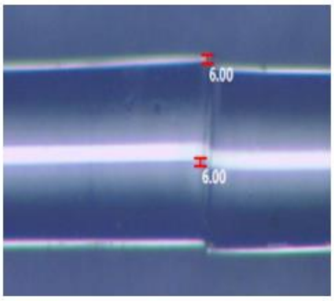

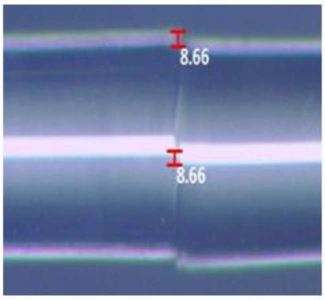

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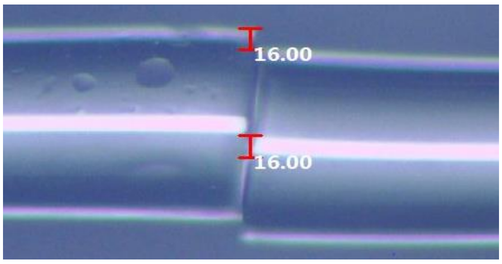

(e)

Fig.2. Recorded image from image analyser for (a) 0 µm lateral offset, (b) 2.66 µm lateral offset, (c) 6 µm lateral offset, (d) 8.66 µm lateral offset and (e) 16 µm lateral offset

The experimental setup utilised a fiber optic sensor to assess glucose adulteration levels in honey, employing single mode optical fiber (SMF) with a 1550 nm laser launched in the core of the sensing medium, as illustrated in Fig. 3. The lateral offset spliced region of the fiber served as the detecting unit, where honey samples with varied glucose contents were used to assess the sensor's response. These samples consisted aqueous honey, glucose solution, and honey-glucose solution mixtures prepared at certain concentrations to investigate refractive index changes and their effect on light transmission. The effects of such perturbations on optical signals, as measured by an optical power meter (OPM) and an optical spectrum analyser (OSA), were investigated for output power and spectral modifications such as wavelength shifts and intensity variations.

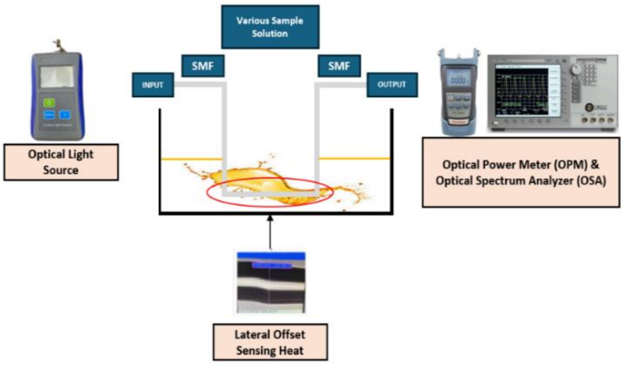

Fig.3 Experimental setup

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The setup demonstrated the relationship between variations in different sample concentrations, refractive index changes, and optical attenuation, as well as the sensor's potential for high accuracy and validity adulteration. Solution samples were prepared using a honey-gucose ratio as shown in Table I.

Table I. VARIOUS SAMPLE OF SOLUTION

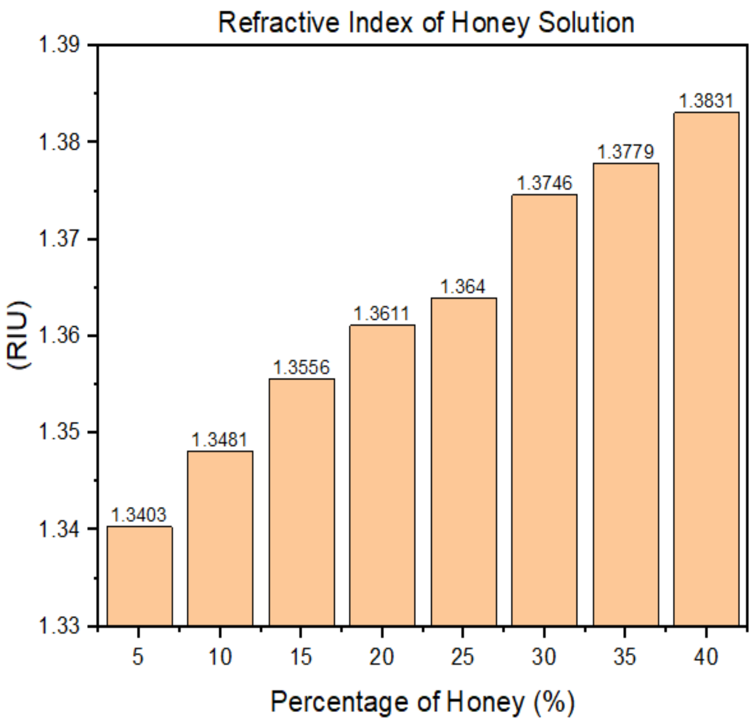
Various Sample Solution	Percentage (%)							
Honey	5	10	15	20	25	30	35	40
Glucose	5	10	15	20	25	30	35	40
Honey-Glucose	10	20	30	40	50	60	70	80

RESULTS AND DISCUSSION

This study examined the relationship between refractive index changes and glucose adulteration in honey by evaluating a range of sample solutions, including pure honey, glucose solutions, and honey-glucose mixtures at various concentrations. The refractive index unit (RIU) is critical in determining how light propagates through the single-mode fiber sensor since it is impacted by the refractive index ratios of the fiber's core and cladding.

As the glucose concentration increases, the density and optical properties of the solution change, resulting in higher refractive index values, as illustrated in Fig. 4. Measurements revealed a clear and consistent correlation between glucose concentration and RIU, with higher adulteration levels resulting in proportional increases in the refractive index [13].

The precise monitoring of these variations validated the sensor's high sensitivity for detecting adulteration. This relationship highlights the effectiveness of the fiber optic sensor in providing non-destructive, accurate, and reliable detection of glucose adulteration in honey, making a significant contribution to food quality assurance and safety.



(a)

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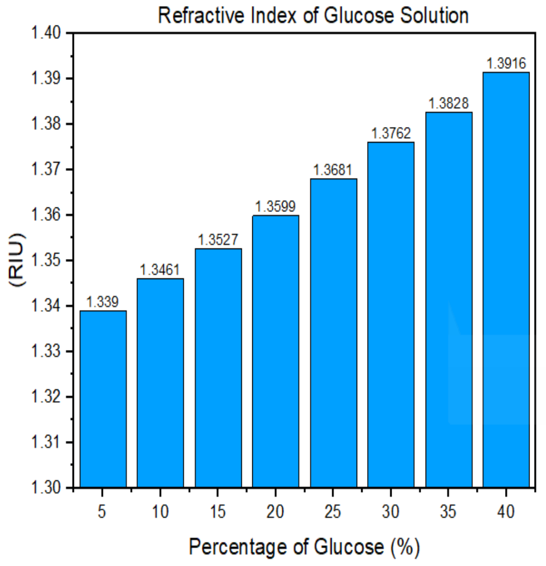

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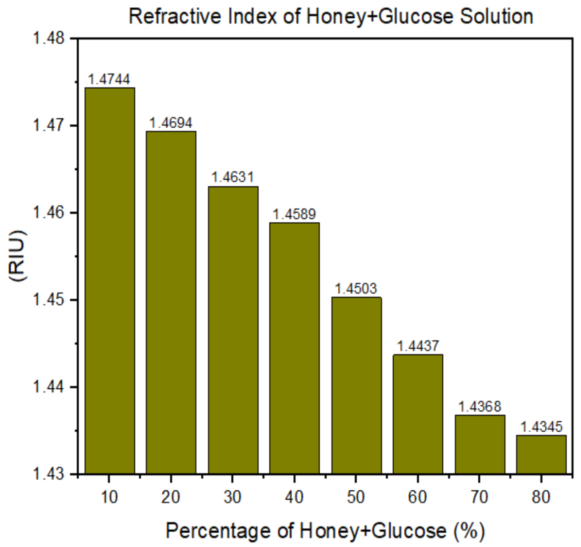

(c)

Fig. 4. Refractive Index of Various Sample Solution: (a) Honey Sample, (b) Glucose Sample, and (c) Honey + Glucose Sample

To evaluate the effect of lateral offset variations, *x*, on the sensor's performance, the offset distances of the fiber optic sensor (FOS) were systematically varied, and their impact on optical output power was analysed as shown in Fig. 5. The results clearly showed a relationship between the offset distance and the sensor's sensitivity, with greater offset distances leading to increased sensitivity.

The sensor's sensitivity was evaluated at several offsets, such as 0 µm, 2.66 µm, 6 µm, 8.66 µm, and 16 µm. The slope of the graph's linear fit indicates the sensor's sensitivity. For honey solutions, the corresponding sensitivities were -0.01431 dBm/%, -0.01912 dBm/%, -0.02988 dBm/%, -0.04679 dBm/%, and -0.0496 dBm/%. This pattern, which emphasises the proportionate relationship between offset distance and detection performance, is consistent with previous findings.

The output power steadily dropped as the concentration of honey increased, demonstrating the sensor's remarkable precision in detecting changes in refractive index. Additionally, better sensitivity is highlighted by the steeper slope seen at higher offsets, indicating that lateral offset optimisation is essential to obtaining superior sensor performance. These results validate the fiber optic sensor's precision as well as reliability in measuring honey content [14].

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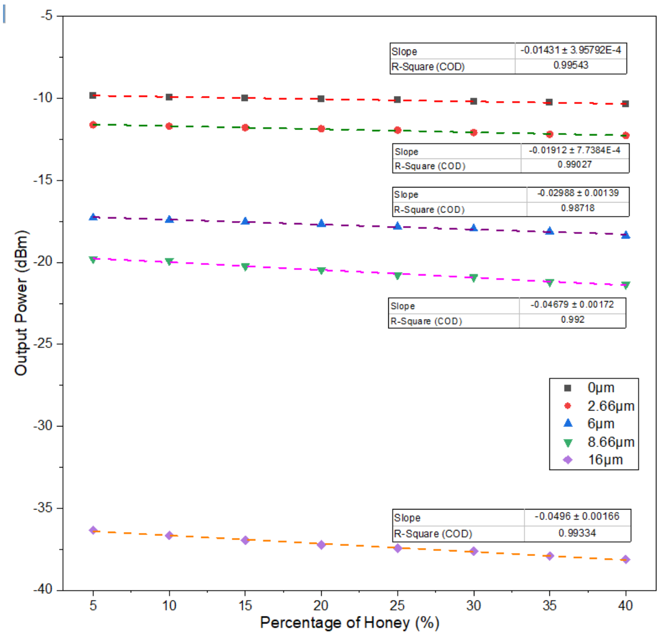

Fig.5. The Relationship between Output Power (dBm) and Honey for SM-SM Fiber

The sensor's sensitivity was measured throughout a range of lateral offset distances, as shown in Fig. 6, in order to assess the sensor's efficacy in detecting glucose solutions. Theoretically, optical power and refractive index are directly correlated. The larger the lateral offset distance, the more power will leak to the surroundings, causing the output power received at the end of the fiber to decrease.

Due to the negligible power loss in the perfectly aligned fiber ends, the sensitivity at a 0 µm offset was recorded as -0.00593 dBm/%, the lowest of all the offsets examined. Sensitivities increased to -0.00755 dBm/% and -0.01038 dBm/%, respectively, as the offset grew to 2.66 µm and 6 µm, indicating a better interaction between light and the glucose solution's refractive index.

Sensitivities of -0.01448 dBm/% and -0.02171 dBm/% were obtained with further increases to 8.66 µm and 16 µm, respectively, demonstrating that greater offsets greatly improve the sensor's ability to detect variations in refractive index. With increased sensitivity at higher offsets, these results show the sensor's reliable and accurate performance in monitoring glucose concentrations [15].

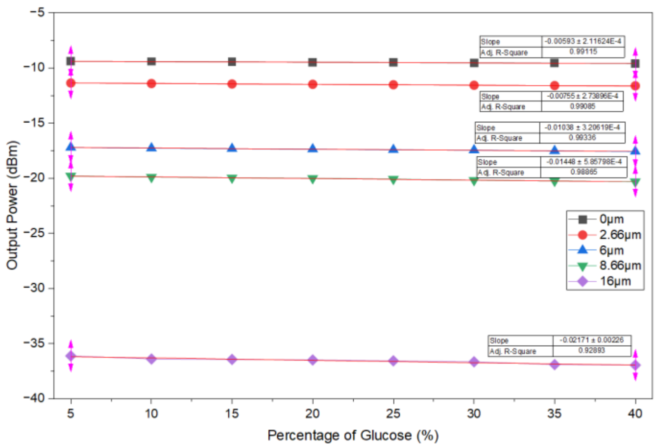

Fig. 6. The Relationship between Output Power (dBm) and Glucose for SM-SM Fiber

Fig. 7 illustrates the sensor's sensitivity enhancement for honey-glucose mixtures as lateral offsets increased, demonstrating its flexibility in handling diverse conditions. It can be seen that as the amount of adulterant increases, which in this study is glucose, the RIU value decreases, and the optical output power inhances.

The sensitivity was measured at 0.00737 dBm/% at a 0 µm offset, which is comparatively low. The

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sensitivities increased to 0.00948 dBm/% and 0.01255 dBm/%, respectively, as the offset distance increased to 2.66 µm and 6 µm. Further increases to 8.66 µm and 16 µm resulted in sensitivities of 0.01649 dBm/% and 0.02821 dBm/%, respectively, indicating that the sensor can perform better at bigger offsets [16].

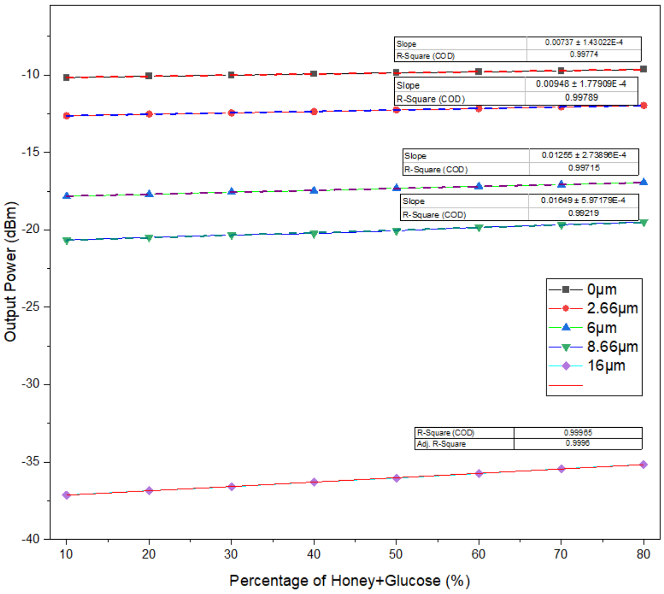

Fig. 7. The Relationship between Output Power (dBm) and Honey+Glucose for SM-SM Fiber

By employing a wavelength of 1550 nm to measure the output intensity (dBm) for glucose and honey solutions at different lateral offset distances, the fiber optic sensor's performance was assessed. As illustrated in Fig. 8, the output intensity increased consistently across all offset distances as the quantity of glucose and honey increased. The sensitivity was more apparent for wider offsets, such as 16 µm.

Despite higher scattering and misalignment losses at bigger offsets, the trend is explained by greater interaction between the light and the surrounding medium.

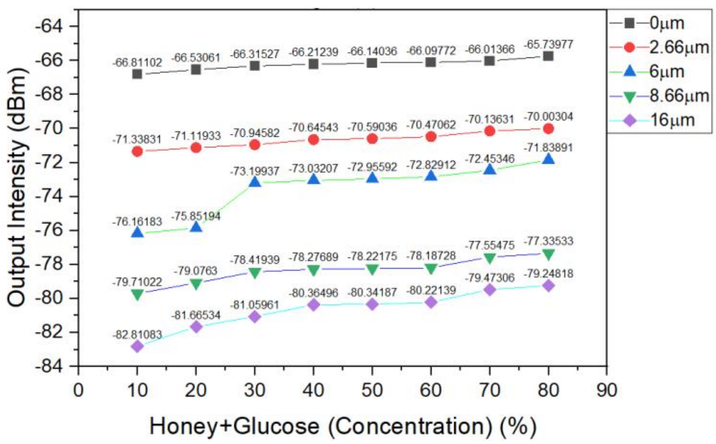

Fig. 8. Output Intensity (dBm) with Different Offset Distance of Fiber Sensor in Optical Spectrum Analyzer at λ=1550nm

The mathematical model for the sensor's performance particularly for the 16 µm offset, were summarized in Table II, where *y* represents the output power (dBm), *x* denotes the percentage concentration of the solution, and *c* is the intercept of the graph. The slope (*m*) reflects the sensor's sensitivity to refractive index changes induced by the varying composition of the samples. This model demonstrates consistent trends across all sample types, providing a reliable reference for predicting sensor behavior. Furthermore, it highlights the sensor's versatility and its potential for broader applications in food quality assurance and detection of adulteration in various liquid compositions.

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Table II. SENSOR'S MATHEMATICAL MODEL

Various Sample of Solution	Mathematical Expression
Honey	$y = -0.0496x + 0.99334$
Glucose	$y = -0.02171x + 0.93909$
Honey+Glucose	$y = 0.02821x + 0.99965$

The sensor's sensitivity assessments, which were initially expressed in dBm/%, were transformed using the standard limit of detection (*LoD*) formula into the more widely used unit of weight-to-weight percentage (% w/w) in order to allow for an equitable comparison with other honey adulteration detection approaches. $LoD=3\sigma/S$, where σ represents the noise level and S the sensitivity slope. Assuming a conservative optical noise floor of approximately 0.1 dBm, the calculated detection limits were ~2.0% for pure honey, ~4.6% for glucose solutions, and ~3.6% for honey–glucose mixtures at the optimal 16 µm offset. These values establish the sensor's ability to detect adulteration at the low single-digit percentage level. As summarised in Table III, the proposed sensor's performance outperforms HPLC-UV fingerprinting techniques, which typically only detect adulteration at ~15% w/w [17], and is competitive with advanced spectroscopic techniques like Raman and NIR spectroscopy, which normally report LODs of ~5–10% w/w [18]. Although isotope ratio analysis (EA/LC-IRMS) remains the most sensitive technique with detection limits as low as 1% w/w [19], it requires specialised instrumentation and laboratory facilities. In contrast, the proposed LOD-based fiber optic sensor offers a practical balance of sensitivity, simplicity, and cost-effectiveness, making it particularly well-suited for on-site food quality monitoring and extending its potential to broader applications in detecting other food adulterants or biomedical analytes.

Table III. COMPARISON OF HONEY ADULTERATION DETECTION TECHNIQUES

Method	LOD (% w/w adulterant)	Findings	Reference
LOD-based fiber optic sensor	~2–5% (depending on sample type)	Non-destructive, real-time, low cost	This work
HPLC-UV + chemometrics	~15% detection limit	High accuracy, but costly & time-intensive	[17]
NIR / Raman spectroscopy	~10% detection limit (some <5%)	Rapid, portable, but requires chemometric modeling	[18]
Isotope ratio (EA/LC-IRMS)	~1–7% depending on adulterant type	Gold standard, highly sensitive, expensive instrumentation	[19]

CONCLUSIONS

This study successfully developed a fiber optic sensor utilizing lateral offset displacement techniques to detect glucose adulteration in honey. The sensor's performance was evaluated across three sample solutions: pure honey, glucose solutions, and honey-glucose mixtures, at five lateral offset distances: 0 µm, 2.66 µm, 6 µm, 8.66 µm, and 16 µm. Among these, the 16 µm offset consistently demonstrated the highest sensitivity, with values of -0.0496 dBm/% for pure honey, -0.02171 dBm/% for glucose solutions, and 0.02821 dBm/% for honey-glucose mixtures. These findings confirm the sensor's ability to reliably detect refractive index changes caused by adulteration, with the 16 µm offset proving to be the optimal configuration. This work highlights the potential of the developed sensor as a precise, non-destructive, and cost-effective tool for food quality assurance and broader optical sensing applications. Importantly, this study extends the scope of LOD-based fiber optic sensors beyond generic refractive index monitoring by demonstrating their direct applicability for detecting glucose adulteration in honey, while also underscoring their broader potential for monitoring other food adulterants and biomedical analytes where high sensitivity and non-destructive detection are critical.

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