A smart parcel locker system with parcel status and image notifications via LINE application

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ABSTRACT

During the COVID-19 pandemic, online shopping grew rapidly, leading to more parcel deliveries. However, recipients are not always home to receive them. Some existing systems send alerts via SMS or email, but these methods often incur additional costs. To address this issue, we developed a smart parcel box. It uses IoT and solar power to work efficiently and sustainably, and it sends free delivery alerts through the LINE notify app, which is popular in Thailand. The prototype was tested using four parcel sizes: CD-sized (15×15×15 cm), 0+4 (17×11×10 cm), 2A (14×20×12 cm), and M-sized (27×43×20 cm). Results showed that the 0+4 parcel size had the fastest average detection and notification time of 8.42 s, followed by CD-sized (9.81 s), 2A (9.9 s), and M-sized parcels (10.1 s). The M-sized parcel had the lowest standard deviation (SD) (0.42 s), while 0+4 was the least consistent (1.718 s). Differences in detection times were due to parcel size and placement but did not affect notifications. The system achieved 100% detection across all sizes, and the images allowed users to verify parcel details and sender information. These results demonstrate that the prototype is reliable, energy-efficient, and suitable for further development and adaptation in smart delivery systems.

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1. INTRODUCTION

The rapid expansion of e-commerce in recent years, significantly accelerated by the COVID-19 pandemic, has transformed consumer shopping habits worldwide. Lockdowns and public health concerns drove a massive shift from traditional retail stores to online platforms, emphasizing the importance of convenience, contactless service, and timely home deliveries [1]-[3]. This growing reliance on online shopping has placed new demands on the logistics sector, particularly in managing last-mile delivery the final step in the delivery process from a transportation hub to the customer's doorstep [4]-[6]. One of the most pressing challenges in last-mile logistics is the recipient's unavailability during delivery attempts. When customers are not present to receive their parcels, it often leads to missed deliveries, stolen packages, or weather-related damage. These issues contribute to increased operational costs for delivery companies and decreased customer satisfaction [7]-[9]. Repeated delivery attempts, customer complaints, and package losses place additional strain on logistics networks, highlighting the need for innovative solutions to make unattended deliveries safer and more efficient.

In response to these challenges, researchers and developers have explored various smart delivery systems based on internet of things (IoT) technologies [10]-[12]. Among the promising solutions is the use of smart parcel boxes secure, connected containers that allow packages to be delivered even when the recipient is not home [13]-[15]. Develop and clarify the specific contribution of each cited source. IoT and solar power for smart parcel box to work efficiently and sustainably can be also considered in relation to big data management algorithms, deep learning-based object detection technologies, and geospatial simulation and sensor fusion tools in the internet of robotic things [16], spectrum sensing, clustering algorithms, and energy-harvesting technology for cognitive-radio-based IoT networks [17], and energy-efficient industrial IoT in green 6G networks [18]. These systems typically integrate sensors, locking mechanisms, and communication modules to ensure the parcel's safety and provide users with real-time delivery updates. Relevant studies include the work of researchers such as Sa-ngiampak *et al.* [19] developed an IoT-based smart locker using a NodeMCU ESP32, micro switch, and electric door latch. The system uses a LINE bot for remote unlocking and allows users to share access. The locker swarm app enables locker control and sharing, while the backend lets admins monitor locker status and usage data. Nonthaputha *et al.* [20] presented an Arduino-based smart mailbox using two microcontrollers. The first, an Arduino, controls a magnetic lock and uses an ultrasonic sensor to detect parcels inside the box. Users unlock the mailbox using a keypad passcode. The second microcontroller, a NodeMCU, detects motion and sends delivery notifications via the LINE app. A buzzer also alerts users when a parcel is placed inside. Mokhsin *et al.* [21] designed an IoT-based parcel receiving box for smart city applications in Malaysia. The system uses an ESP8266 microcontroller and an infrared sensor to detect parcel deliveries. Upon detection, it sends real-time notifications to users through the Parcel Rest Box mobile application [22]. In a separate study, Tan developed a parcel locker system using a Raspberry Pi 3B+, a camera module, and an ultrasonic sensor. When a parcel is delivered, the ultrasonic sensor detects it, and the Raspberry Pi processes the event. A photo is taken by the camera and sent to the owner as a delivery notification. Tahyuddin *et al.* [23] developed a smart parcel receiver box using an ESP32 microcontroller. The system includes several input components such as a push button, servo motor, QR code scanner, and ultrasonic sensor. When a parcel is detected, the system sends an SMS notification to the user and allows them to monitor the delivery status through a web page. Kaewsrisuphawong *et al.* [24] developed a prototype smart mailbox using IoT and solar energy. The system uses an ESP8266 microcontroller that receives signals from an infrared sensor. It is powered by a battery charged through a solar panel. When the sensor detects a parcel, the microcontroller sends a notification message “Receiving Box: You got a parcel” to the owner's LINE application. Alghfeli *et al.* [25] developed a secure parcel delivery system that uses QR code or barcode scanning to unlock the smart box. The code, which contains the parcel's tracking number, is printed on the shipping label. While the system requires the customer to be present during delivery, it also allows shared access by using a shared QR code. Gurung *et al.* [26] developed a smart lock using IoT that replaces traditional locks. It sends alerts to the user’s phone and triggers a buzzer if someone tries to break in or damage the lock. Data is also stored on the Bolt Cloud. Umadi *et al.* [27] developed a smart e-locker system that uses radio frequency identification (RFID) technology to improve security and convenience. When an unregistered token is scanned, the system triggers a buzzer and automatically sends an email alert to the responsible person, warning of unauthorized access. Hadidi and Ikhsan [28] developed Smart Parcel, a smart monitoring system using IoT. It allows users to monitor their mailbox from anywhere. The system uses components like the ESP32-CAM for live video streaming through a web browser, and the ESP8266 as the main controller. The Blynk app is used to send package arrival notifications and to control the smart lock and built-in sanitizer in the mailbox. However, existing research on smart parcel boxes still presents several limitations. Most systems depend on local notification methods such as indicator LEDs or buzzers, which are ineffective when users are not nearby. Some studies have proposed solutions like sending SMS or email alerts to inform users remotely when a parcel is delivered. While these methods improve remote awareness, they can involve additional costs, such as SMS fees or email storage limitations. Moreover, such notifications typically provide only basic status updates and do not offer visual information about the delivered package’s appearance.

This paper presents a smart parcel locker system with status updates and image notifications via the LINE application, designed to enhance the security and convenience of unattended deliveries. The system includes a durable electronic locking mechanism, which is controlled by a keypad for secure access. An ESP32-CAM microcontroller is installed inside the locker, along with a proximity sensor that detects when a parcel is delivered. Upon detection, the system processes the signal and sends both a text and an image of the package through LINE, a widely used free communication app in the region, enabling real-time updates. The system is powered by solar panels, making it energy-efficient and suitable for outdoor use without the need for external electricity. Delivery personnel can securely deposit parcels using a simple authentication process, while users receive instant alerts and can monitor the parcel in locker. The rest of this paper is organized as follows. Section 2 describes the methodology used in developing the smart parcel locker system, along with the test scenarios designed to evaluate its performance. Section 3 presents the results and discusses the system's effectiveness. Section 4 discusses comparisons with related work. Finally, section 5 provides conclusions drawn from the study and suggests directions for future research to further improve the system's functionality and applications.

2. METHOD AND TEST SCENARIOS

2.1. Experimental system

Figure 1 presents the design of the parcel locker system used in the experiment, showing Figure 1(a) the side view, Figure 1(b) the 3D front view, and Figure 1(c) the 3D back view. The locker system has dimensions of 30×45×90 cm (width×length×height). Figure 2 presents the system is divided into five parts, A-E: part A is responsible for monitoring the occupancy status of the parcel locker. If a parcel is stored and its height reaches the sensor (E18-D80NK proximity sensor) detection point which processed by microcontroller board (Arduino UNO R3, board based on the ATmega328, and 14 digital input/output pins), the locker will activate a red signal light as an alert.

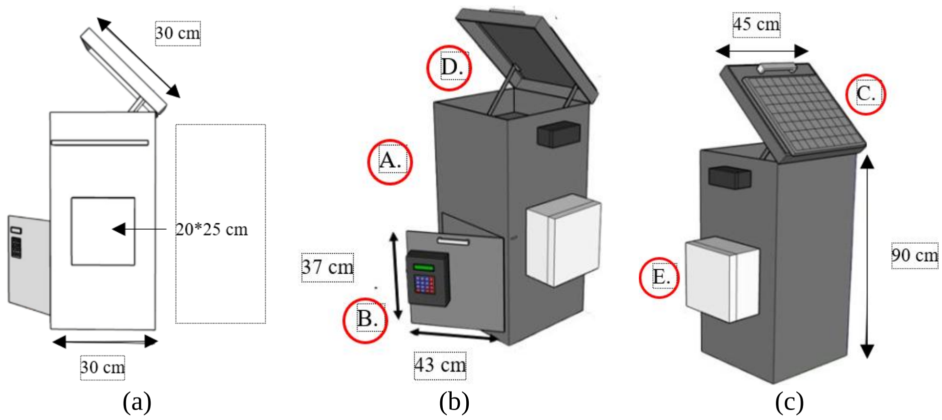


Figure 1. The parcel locker system used in the experiment: (a) side view of the parcel locker, (b) 3D view of the parcel locker, and (c) 3D back view of the parcel locker

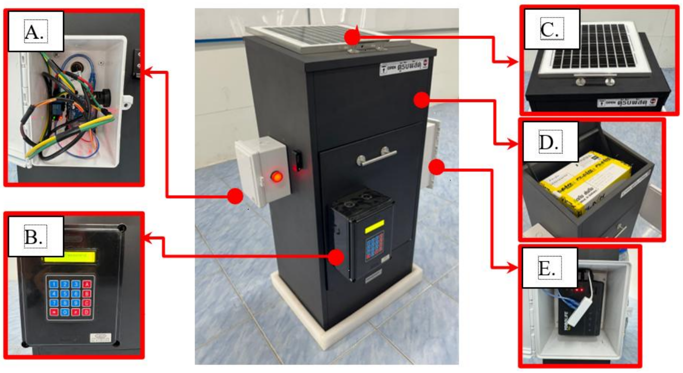
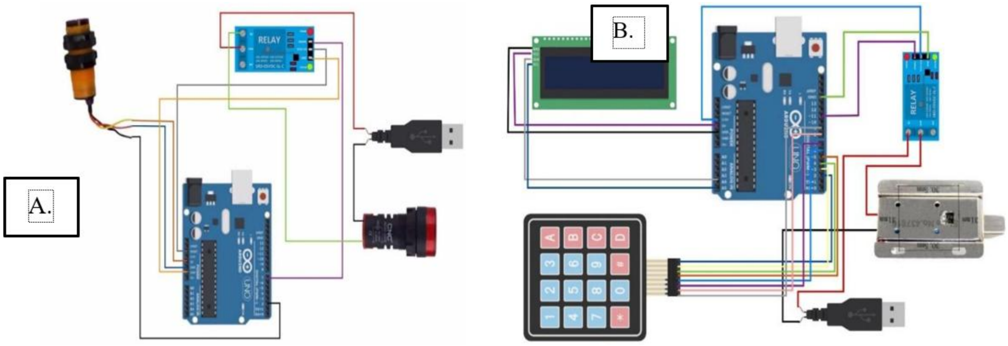


Figure 2. Five parts used for system: part A: detecting parcel; part B: keypad door lock; part C: solar cell; part D: serves as the parcel drop-off section; and part E: battery of system

Part B functions as the door lock mechanism for accessing the parcel locker and retrieving stored parcels. The system operates using a password-based access control, with an LCD screen (2 rows×16 character LCD, 80×36×13 mm) displaying the message "Enter Password" users can enter the password via the keypad (interface: 8-pin access to 4×4 matrix; dimensions: 6.9×7.6 cm). Part C consists of a solar cell (model: LM-15, 15 watt, 12 V_{oc}: 19.2 V, and I_{sc}: 0.91 A) that generates electrical power and stores energy in a battery, serving as the main power source for the smart parcel locker system. The stored energy in the battery (part B) is used to operate the mechanism that unlocks the locker cover, allowing recipients to retrieve parcels. Additionally, the system powers a red LED indicator in part A, which lights up to signal when a parcel has been fully delivered inside the smart parcel box.

Part D serves as the parcel drop-off section. When a delivery personnel places a parcel in the locker, they can open the top lid to drop it into the designated area. Once the lid is closed, the parcel is transferred to the storage area below, where a photo is taken and a notification, including the parcel's status and image, is sent via LINE notify to inform the recipient. Figure 3 shows the parcel locker circuits: part A monitors the occupancy status as show in Figure 3(a), while part B controls the door lock using a password-based system with an LCD screen as shown in Figure 3(b).



(a) (b)

Figure 3. Circuits used for; (a) part A of parcel locker system and (b) part B of parcel locker system

2.2. Experimental test scenarios

The parcel boxes used for testing the drop detection in the parcel locker system consisted of four types. Figure 4 shows four types of parcel boxes: Figure 4(a) CD-sized box (15×15×15 cm), Figure 4(b) 0+4 box (17×11×10 cm), Figure 4(c) 2A box (14×20×12 cm), and Figure 4(d) M-sized box (27×43×20 cm). The test scenarios were designed as follows:

- Measuring the average time taken to detect a parcel and send a notification via LINE notify.
- Calculating the standard deviation (SD) of the detection time and notification delivery via LINE notify.

(a) (b) (c) (d)

Figure 4. The parcels used in the experiment: (a) parcel CD size, (b) parcel 0+4 size, (c) parcel 2A size, and (d) parcel M-size

2.3. LINE notification

LINE notify is a notification service that lets users connect to a web service and receive notifications from the official account provided by LINE which allows Node MCU to send LINE notify message. In this system, each room is equipped with sensors calibrated to detect specified levels of LPG gas and smoke. When a sensor detects gas or smoke, adjust sensitivity of the sensor, the microcontroller processes this data and sends a message to the LINE application. Figure 5 illustrates the experimental setup: Figure 5(a) shows a parcel being dropped into the locker, Figure 5(b) shows the parcel stored after the locker is closed, and Figure 5(c) presents the circuit diagram of the LINE notify system activated when a parcel is detected.

(a) (b) (c)

Figure 5. Elements used for experiment: (a) the parcel was dropped in locker, (b) the parcel was kept after cover the locker, and (c) circuit diagram of LINE notify system when parcel was detected

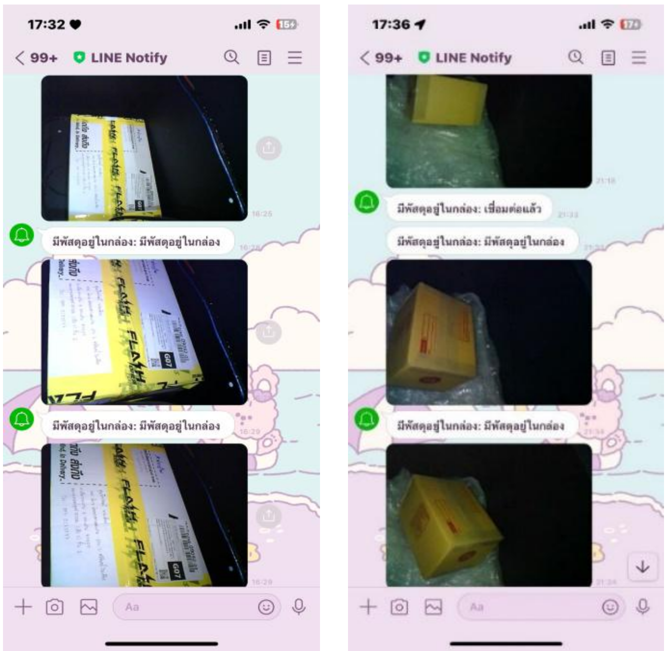
3. RESULTS

In this section, the results of the system testing are presented, focusing on the performance of message notifications delivered through the LINE application.

3.1. Result of message notifications to the LINE application

After developing a smart parcel locker system with status updates and image notifications via LINE application using IoT and solar energy, the system was tested to ensure all components worked correctly. The solar panel, charge controller, and battery were verified to function seamlessly together.

Subsequently, one of the systems was tested using parcels of various sizes (CD, 0+4, 2A, and M). Each parcel size was tested 10 times. The results showed that the system successfully detected and sent notifications 100% of the time, regardless of parcel size. However, the detection and notification times varied depending on the size of the parcel. These notifications were delivered via the LINE notify application on mobile phones. Figure 6 shows the notifications sent when parcels are delivered via the LINE application. Figure 6(a) presents an example notification with a message and image for an M-sized parcel, while Figure 6(b) shows an example notification for a 2A-sized parcel. Figure 7 illustrates the delivered parcel. Figure 7(a) shows a photograph of the parcel captured by the ESP-CAM installed inside the locker. Figure 7(b) displays the keypad used for entering the password, and Figure 7(c) shows the locker with its door open, allowing access to retrieve the parcel.



(a) (b)

Figure 6. The notifications sent when parcels are delivered via the LINE application: (a) an example notification with a message and image for an M-sized parcel and (b) an example notification for a 2A-sized parcel

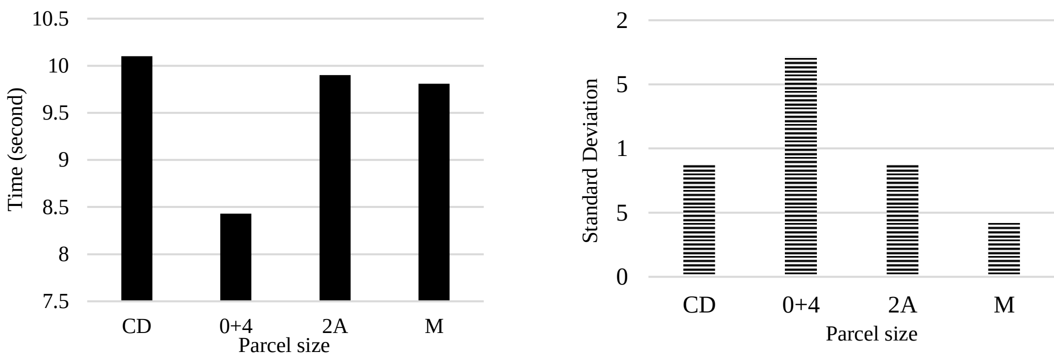
(a) (b) (c)

Figure 7. The delivered parcel: (a) a photograph of the parcel taken by the ESP-CAM installed inside the locker, (b) the keypad used for entering the password, and (c) the locker with its door open, allowing access to retrieve the parcel inside

The experiment involved sending parcels of four different sizes, with each size tested 10 times, as shown in Figure 8. The results showed that the 0+4 parcel had the fastest detection and notification time via LINE notify, averaging 8.42 s. This was followed by the M-size parcel, 2A parcel, and CD parcel, with average times of 9.81 s, 9.9 s, and 10.1 s, respectively as illustrated in Figure 8(a).

However, the statistical analysis of the SD revealed that the M-size parcel had the lowest SD at 0.42. The CD parcel and 2A parcel exhibited the same SD value of 0.875, while the 0+4 parcel had the highest SD at 1.718, as shown in Figure 8(b). Based on the experimental results and statistical analysis including the average detection and notification time via LINE notify and the SD, we can conclude that the M-size parcel demonstrated the most reliable performance. The M-size parcel demonstrated the most reliable performance. It was detected and notified efficiently while also having the lowest SD, indicating greater consistency compared to other parcel sizes.

The superior statistical performance of the M-size parcel can be attributed to its larger size, which makes it easier to detect. Additionally, the front-facing image of the parcel is clearer, allowing for easier identification of the sender's information. In contrast, other parcel sizes exhibited varying detection times due to inconsistent placement during delivery. When parcels dropped into the storage compartment, their positioning affected sensor detection speed, leading to variations in notification time. Furthermore, the front-facing images of smaller parcels were often unclear, making it hard to extract sender information.



(a) (b)

Figure 8. The statistical results of the experiment: (a) the average time and (b) the standard deviation for detection and notification sending

4. DISCUSSION

Table 1 presents a comparison of related research on parcel storage systems, focusing on comparisons with other research results, highlighting the sensors used for detection, types of microcontrollers, notification methods via mobile devices and other devices, and power supply configurations. This study is included in the comparison to highlight its differences from previous research.

Table 1. Comparison table notification for parcel mailbox and notification mobile type and device

Ref.	Year	Microcontroller	Sensor	Notification via mobile phone	Output device	Power supply
[19]	2019	Node MCU ESP8266	Micro switch	LINE chat bot (UNLOCK Locker)	LCD	AC
[20]	2020	Arduino	Ultrasonic sensor	Line notify (text)	Buzzer	AC
	2020	Arduino UNO	Switch	SMS	LCD	AC
[21]	2021	ESP8266	Infrared sensor	Parcel rest box application	-	AC
[22]	2021	ESP8266	Ultrasonic sensor, push button	Web application	DC motor	Battery
[23]	2021	ESP32	Push button and ultrasonic sensor	SMS, web page	Servo	AC
[24]	2022	ESP8266	Infrared	LINE notify (text)	-	Solar cell
[25]	2022	Raspberry Pi 4	QR code	Drop parcel mobile application	LEDs and a buzzer	AC
[26]	2022	ESP8266	Different resistivity at the locker	Bolt cloud, notification to the user's mobile phone	LED and buzzer	Battery
[27]	2023	Node MCU ESP8266	RFID sensor and ultrasonic sensor	Adafruit cloud	Alarm buzzer	AC
[28]	2023	ESP32 ESP8266	Push button	Blynk	Pump (security)	AC
[29]	2023	Arduino Mega+GSM module	Infrared sensor and keypad	-	LCD and magnetic door	AC
[30]	2023		Light sensor, image sensor, and load sensor	SMS		AC
[31]	2023	ESP8266	Keypad		LCD, buzzer	AC
[32]	2023	ESP8266	Infrared sensor	Blynk	Solenoid valve	AC
[33]	2025	Arduino Mega 2560+GSM module	QR code	SMS	LCD	Solar cell
[34]	2025	ESP8266	Fingerprint sensor	-	Servo motor	AC
	This paper	ESP32	Proximity sensor and ESP camera	LINE notify (text+parcel picture)	Red light blub	Solar cell and battery

From the results presented in Table 1, the smart parcel locker system prototype demonstrated 100% accuracy in detecting parcels across all test cases. While the detection time varied slightly, the system consistently identified parcels and sent notifications via LINE notify. Compared to other studies, this system shares similarities in parcel detection and LINE notify alerts. However, existing systems typically send notifications as text-only messages, whereas this research enhances the functionality by providing both text notifications and parcel images. Additionally, in some test cases, the system successfully captured and sent clear images of the sender's information on the parcel, offering a distinct advantage over all related studies.

This study examined the effects of parcel delivery notifications for recipients. While previous research focused mainly on signal lights or text-based alerts, the influence of image-based notifications has not been explicitly addressed. We found that combining text and image notifications correlated with recipients' need to verify the appearance of delivered parcels and gain confidence in successful delivery. The proposed method was tested with four parcel sizes and consistently detected and notified users across all trials.

Our findings indicate that slight differences in notification times across parcel sizes did not reduce performance or user satisfaction. In addition, image notifications provided sender information directly from the parcel surface, further enhancing user trust without affecting the reliability of text and image alerts. This study implemented comprehensive notifications through LINE, a widely used free social application. However, further research is needed to optimize image clarity so that sender details and product labels can be clearly read across packages of varying sizes. Results show that text and image notifications are more resilient than signal light or sound alerts, which are ineffective when recipients are not physically near the delivery box. Future work may explore advanced image processing and practical techniques for improving visibility of printed parcel information.

Overall, this study demonstrates that integrating text and image notifications via LINE enhances convenience, reliability, and user confidence in parcel delivery systems, offering a clear advantage over traditional alert methods.

5. CONCLUSION

This study presents a smart parcel locker system that successfully combines IoT technology, solar energy, and real-time notifications to improve the reliability and security of parcel deliveries. The system demonstrated accurate parcel detection and prompt alerts, with a unique capability of sending parcel images in addition to text notifications. Unlike many existing systems that focus solely on text-based alerts, the inclusion of images enables recipients to visually confirm parcel details and sender information, adding an extra layer of security and confidence including images, ensuring both convenience and peace of mind for users. Its energy-efficient design allows for flexible placement, while the integration with LINE notify provides an accessible and user-friendly communication channel. Overall, the prototype demonstrates strong potential for further development, with opportunities for broader testing, enhanced features, and future application in smart home systems and modern logistics.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author. The data, which contain information that could compromise the privacy of research participants, are not publicly due to certain restrictions.

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