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Analysis of Residual Soil Properties on Slope: A Study in Dusun, Universiti Teknologi Malaysia, Johor

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Abstract

This study investigates the physical index properties and engineering properties of residual soil from the slope at Dusun Universiti Teknologi Malaysia (UTM) in Johor, Malaysia. The research was conducted to understand the soil characteristics that influence slope stability, given the frequent slope failures in the region. Both disturbed and undisturbed soil samples were collected and subjected to various laboratory tests. For physical index properties, tests included moisture content determination, specific gravity, particle size distribution (via sieve analysis and hydrometer), and Atterberg limits. Results showed that the soil has a moisture content of 31.7%, a specific gravity of 2.5, and is classified as sandy silt with high plasticity, as indicated by a plasticity index of 27.0%. The soil composition was found to be 20.4% clay, 44.7% silt, 30.1% sand, and 4.8% gravel. Engineering properties were assessed using the Consolidated Isotropic Undrained (CIU) triaxial tests on undisturbed samples. The tests were performed under different cell pressures (30, 60, and 80 kPa) to evaluate shear strength parameters, specifically the effective cohesion (c') and effective friction angle (ϕ'). The results indicated that the soil has an effective cohesion of 13.0 kPa and an effective friction angle of 27.0° The study concludes that the residual soil in the study area exhibits significant plasticity and strength, which are critical factors for slope stability. These findings provide essential insights into the behavior of residual soils under varying conditions, contributing to safer geotechnical infrastructure development in slope-prone areas.

1. Introduction

Residual soils, which form through in-situ weathering processes, are a critical component of the geotechnical landscape in tropical regions, particularly in Malaysia [1]–[4]. These soils, which have not undergone significant transportation or alteration from their original formation site, exhibit unique physical and mechanical properties that vary significantly depending on local environmental conditions [5]–[8]. Understanding these properties is essential for developing safe and cost-effective geotechnical solutions, especially in areas prone to slope instability [9]–[12].

In Malaysia, sedimentary residual soils and granite are the most prevalent types. Prior to this, countries located in tropical regions, such as Malaysia, generally encounter considerable levels of chemical and physical weathering that happens on-site [13]–[17]. Various factors, including climate, the composition of the materials, topography, water movement, and the amount of rainfall received annually, affect the process of weathering [18]–[22]. These factors will have tremendous impacts on the residual soil's engineering properties [23], [24]. Soils' in-situ behaviors are complicated because they depend on a lot of different things [25]–[29]. To do that, the factors need to be studied using geotechnical engineering and related areas such as climatology, hydrogeology, and geomorphology, in addition to other pertinent fields within the geophysical and atmospheric disciplines [30]–[32].

Coherent to that, slope failures are a recurrent and devastating issue in Malaysia and globally, accounting for approximately 10% of all natural disasters in the country [33]–[36]. According to the Public Works Department of Malaysia, over 600 landslide incidents were reported between 2010 and 2020, with a significant proportion occurring in areas underlain by residual soils. These failures often lead to loss of life, property damage, and disruptions to transportation networks, with economic losses estimated to exceed RM 1 billion annually [37]–[39]. The frequency and severity of these incidents underscore the need for detailed studies of residual soils in regions where slope stability is a concern [40].

In the United States, landslides cause an estimated $3.5 billion in damage annually and are responsible for more than 25 to 50 deaths each year, according to the U.S. Geological Survey (USGS) [41]. In Japan, the frequency of landslides is even more severe, with more than 1,500 landslides reported annually, particularly in regions with highly weathered volcanic soils. Similarly, in Brazil, landslides triggered by heavy rainfall in tropical regions result in approximately 200 deaths per year on average [42]. These global statistics underscore the widespread nature of slope failure problems, particularly in regions where residual soils and intense weather conditions prevail [43].

Dusun Universiti Teknologi Malaysia (UTM) in Johor is one such area, where the interaction between the tropical climate, geological conditions, and soil properties presents unique challenges for infrastructure development [44]. The region's high rainfall, averaging 2,500 mm annually, exacerbates the risk of slope failure by increasing soil moisture content and reducing shear strength [45]. Despite the importance of these factors, there is a paucity of detailed geotechnical data specific to this region, which hampers the ability to predict and mitigate slope failures effectively [46].

The research conducted at Dusun UTM is novel and significant due to the unique and challenging geotechnical conditions of the region, which have a direct impact on infrastructure safety and slope stability. Unlike standard site investigation activities that are typically conducted before construction, this study provides a comprehensive analysis of the residual soil's physical and mechanical properties specific to Dusun UTM, a location that has experienced recurrent slope failures. The area's tropical climate, characterized by intense rainfall and varied weathering processes, contributes to complex soil behaviors that are not fully understood through conventional site assessments alone. By thoroughly characterizing the soil properties in this specific environment, the research offers valuable insights into mitigating slope failures, which are a common and costly issue in this region. This work not only addresses a critical gap in localized geotechnical data but also provides a foundation for developing more effective, site-specific solutions for slope stabilization, ultimately contributing to safer infrastructure development in areas prone to similar geotechnical challenges.

2. Methodology

The study takes place on the slope of Dusun UTM in Skudai, Johor Malaysia, at coordinate (N 1.5642°, E 103.6253°). Fig. 1 depicts the geographical region under study.

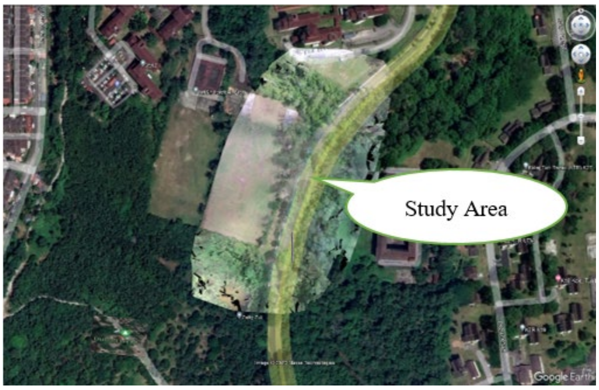


Fig. 1 *Study area at Dusun UTM*

Typically, site assessments involve digging trial pits to gather both disturbed and undisturbed samples. Fig. 2 shows a trial pit being excavated at the slope base to 1 meter below the surface of the ground. The trial pit and other field research activities are carried out in adherence to the guidelines specified in [47], the British Standard Code of Practice.

Fig. 2 *Excavation work (trial pit) at study area*

The primary objectives of data collection are to identify the characteristics and composition of soil materials through laboratory analysis. The laboratory tests are performed by categorizing them into groups based on the type of soil samples used: disturbed samples are used to determine physical indices, while undisturbed soil samples are used to determine engineering properties. Testing is carried out in a controlled laboratory setting to evaluate the soil's cohesion and friction angle, which are the saturated parameters. The soils in this research region undergo primary physical index property tests, consisting of Atterberg Limit, specific gravity, and moisture content tests. Utilizing a hydrometer and a sieve, we ascertain the particle size distribution. The utilization consolidation isotropic undrained (CIU) method is used to carry out the engineering properties test. The experimental procedures are conducted in accordance with BS 1377: Part 1-9 [48].

2.1 Physical Index Properties Tests

Following the completion of a physical index property test, the engineering characteristics of the soil are analyzed with the goal to ascertain the efficacy of those features. The index property analysis is executed in compliance with the guidelines specified in BS 1377: Part 1-9 [48]. The purpose of conducting this specific set of tests is to determine Atterberg limits, specific gravity, moisture content, and particle size distribution.

2.1.1 Moisture Content

Finding out how much moisture is in natural soil is crucial because it reveals the characteristics of the soil that depend on the amount of water present. This is particularly relevant in regions that contain a significant number of fine particles. Due to the water-absorbing properties of clay particles, the natural moisture content of the material rises proportionally with the increase in clay content. Moreover, studies show that the amount of moisture in the soil increases with increasing depth below the surface. This occurs due to an increased exposure of the ground surface to sunlight as one descends further into the ground. The moisture content acts as a control standard for recompacted soils and is essential for classifying natural soils. It is assessed on samples used for various field and laboratory experiments. The oven-drying process, as shown in Fig. 3, is the established procedure employed in conventional laboratory practice.

Fig. 3 *Oven drying process for determining moisture content*

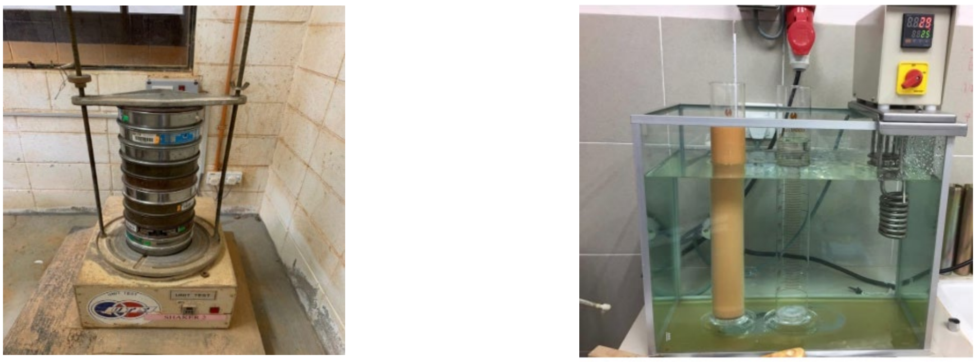
2.1.2 Specific Gravity

The correlation between the masses of water and soil at a temperature of 20°C forms the basis of soil-specific gravity. It is a crucial factor in determining the degree of soil saturation through calculation, its porosity, and the soil's void ratio. Furthermore, implementing the sedimentation method to test limits for shrinkage and particle size distribution is crucial for calculating compaction, consolidation, and permeability. Generally, the laboratory determination of soil solids' specific gravity employs the pycnometer or density bottle method, as shown in Fig. 4.

Fig. 4 *Pycnometer method for determining specific gravity*

2.1.3 Particle Size Distribution

Researchers discover that the amount of weathering, the mode of formation, the residual original material, and the depth and location of the samples at the site have an impact on the soil's characteristics. Zolkepli et al. [49] had conducted a study in which researchers determine the particle size distribution beginning at 20 millimeters and ending at 0.002 millimeters for the clay fraction using a combination of sieve analysis and hydrometer tests as shown in Fig. 5. The results from the dry sieving and hydrometer tests are added together to get full particle distribution curves.



(a) **(b)**

Fig. 5 *Particle size distribution; (a) dry sieving using sieve shaker machine; and (b) hydrometer test*

2.1.4 Atterberg Limit

The inclusion of water within the fine soil's voids can significantly influence its engineering characteristics. Accurate measurement of natural moisture is crucial; however, it is equally important to take into account the correlation between water content and specific engineering standards. Conducting the Atterberg limits test is an essential experiment for understanding the correlation and characteristics of soil in engineering. To figure out the plasticity of clay and silt, which are categorized as fine soils, a sample weighing one hundred grams is observed to be capable of being rolled into a diameter of three millimeters without sustaining any fractures. The term "Atterberg Limit" corresponds to the collective measurement of the Plasticity Index (PI), Liquid Limit (LL), and Plastic Limit (PL). The Atterberg limit test is shown in Fig. 6.

Fig. 6 *Atterberg limit test including Liquid limit (LL) and Plastic limit (PL)*

2.2 Engineering Properties Tests

The accurate determination of the undisturbed soil's initial density in a laboratory setting is of the utmost importance, given that the behaviour of soil permeability is substantially impacted by soil density and void ratio. The soil's samples are examined to ascertain their bulk density (ρb), dry density (ρd), and moisture content (ω) before a number of Consolidation Isotropic Undrained (CIU) tests are performed. The task is executed in compliance with the regulations. As per BS 1377: Part 1-9 [48], the goal is to figure out how moisture content and dry density are correlated.

To perform the CIU testing, three soil samples need to be prepared. Each sample should be sized at 38 mm in diameter and 76 mm in height. Fig. 7 displays undisturbed soil are specifically intended to be tested using the CIU method. A splitter for soil samples is utilized in the process of preparing the soil samples.

(a) **(b)** **(c)**

Fig. 7 *Three samples (a); (b); and (c) of undisturbed soil for CIU testing*

Under various cell pressures (30, 60, and 80 kPa), a number of CIU tests are performed to ascertain saturated (c' and ϕ') parameters related to shear strength. The triaxial machine model VJ Tech is utilized for the CIU tests that are carried out. The samples prepared using a triaxial machine is shown in Fig. 8.

Fig. 8 *Consolidated Isotropic undrained (CIU) testing with model VJ Tech*

3. Results and Discussions

3.1 Residual Soil Properties

Table 1 highlights the laboratory test results for the soil features of residual material from soils near the Dusun UTM. This table presented every important detail that classified and characterized the type of soil in the studied area. There were several important parameters included in Table 1 to present all the details of soil in the studied area, including natural moisture content, the soil's particle distribution, the soil's Atterberg Limit, specific gravity, the void ratio, the soil's porosity, and also the soil's density, which consisted of bulk and dry density. All of these parameters were important to identify and classify the index properties and engineering properties of soil. These parameters also helped researchers determine the type of soil that existed in the study area.

Table 1 *Soil material properties in nearby areas of Dusun UTM*

CONTENTS	Value
Natural moisture content (%)	31.7
Specific gravity (*Gs*)	2.5
Clay (%)	20.4
Silt (%)	44.7
Sand (%)	30.1
Gravel (%)	4.8
Liquid limit (%)	64.0
Plastic limit (%)	37.0
Plasticity index (%)	27.0
Void ratio (e)	1.0
Porosity (n)	0.5
Bulk density,ρ_b (kg/mm^3)	1.7
Dry density, ρ_d (kg/mm^3)	1.3
Soil classification BSCS	MHS

3.1.1 Soil Classifications (Index Properties of Soils)

The classification of soils was determined by various factors, such as the amount of moisture in the soil, specific gravity, the distribution of particle sizes, and Atterberg limits. Several comprehensive laboratory analyses on several disturbed samples of residual soil located near Dusun UTM were carried out to assess the physical index properties of the soil.

Fig. 9 shows sieve analysis results near Dusun UTM. The tropical residual soil, as classified by the BSCS (British Soil Classification System), was a sandy SILT characterized by a significant degree of plasticity (MHS). The particle size distribution analysis of a 200 g soil sample revealed that 4.8% of the particles were larger than 2 mm (classified as gravel), 30.1% were between 2 mm and 0.063 mm (classified as sand), 44.7% were between 0.063 mm and 0.002 mm (classified as silt), and 20.4% were smaller than 0.002 mm (classified as clay).

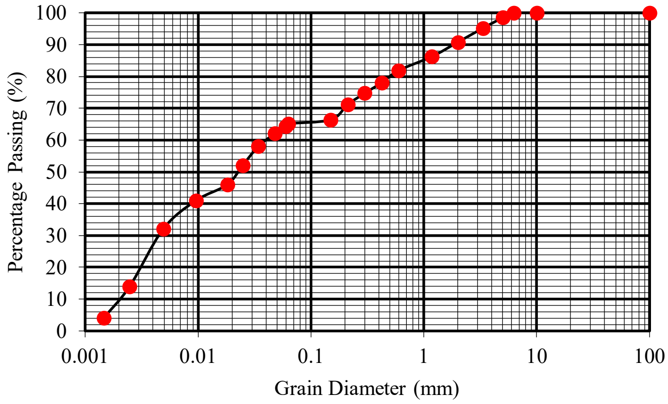


Fig. 9 *Distribution of soil particle sizes near Dusun UTM (sandy SILT)*

Table 1 indicated that the residual soil in the area of Dusun UTM had a liquid limit (LL) of 64.0% and a plastic limit (PL) of 37.0%. The numerical difference between the liquid limit and the plastic limit was used to calculate the Plasticity Index (PI), which was LL-PL = 27.0%. In accordance with the British Soil Classification System (BSCS), the soil that was present in the area under research could be classified as soil with high plasticity, also known as MHS on the SILT scale. Specifically, the specific gravity was 2.5 on average.

3.1.2 Moisture Content & Specific Gravity

The findings of previous studies were showcased in Table 2, which exhibited the inherent moisture content and specific gravity. The results of the study indicated that the inherent level of moisture in the residual soil in this country ranged from 6.0% to 51.0%, depending on the geographical location. From Table 2, the value of the moisture content conducted by the author (2024) was 31.7%. The value of moisture content at Dusun UTM, Johor, was almost identical to the location at Kuala Lumpur, founded by Zolkepli et al. [49] and Zaini and Hasan [50].

According to numerous studies, specific gravity values differed based on the location of the soil sample, as indicated in Table 2. In a study conducted by Zolkepli et al. [49], a sample was analyzed and found to have a specific gravity of 2.4, which was relatively small. Zolkepli [26], Salih et al. [28], Ishak et al. [42], Duraisamy [43], and Taha et al. [51] found that the specific gravity of the soil to be in the range of 2.6 to 2.7. The largest value of specific gravity, 2.8, was conducted at Kg. Awah, Pahang by Tan and Yew [52]. It is shown that the value of specific gravity in the present study is in the range of 2.5.

Table 2 *Malaysia's residual moisture content and specific gravity of the soil*

Researcher & Year	Location	Moisture content (%)	Specific Gravity, *Gs*
Present Study	Dusun UTM, JB	31.7	2.5
Zolkepli [26]	Pahang Matriculation College, Gambang	17.9	2.7
Ishak, et al. [42]	UTM, JB	43.9	2.7
Salih [28]	UTM, JB	26.5	2.6
Duraisamy [43]	Gambang	23.4-28.7	2.7
Tan and Yew [52]	Kg. Awah, Pahang	16.0-51.0	2.8
Taha, et al. [51]	Kuala Lumpur	31.0	2.5-2.6

3.1.3 Particle Size Distribution

Table 3 present the residual soil particle size distribution as examined in previous studies, which displayed the results of those researchers. It was clear, after conducting an analysis of the samples that were collected at a number of different levels, that the proportions of clay, silt, sand, and gravel that were present in each sample were not consistent and differed from one sample to another.

Table 3 *Malaysia's residual soil particle size distribution percentage*

Researcher & Year	Location	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
Present Study	Dusun UTM, JB	20.4	44.7	30.1	4.8
Zolkepli [26]	Pahang Matriculation College, Gambang	22.8	45.1	27.9	4.2
Ishak, et al. [42]	UTM, JB	25.3	48.7	20.9	5.1
Salih [28]	UTM, JB	25.8		11.9	35.3
Duraisamy [43]	Gambang	1.5-2.2	15.0-17.4	74.7-77.9	2.4-4.9
Tan and Yew [52]	Kg. Awah, Pahang	18.0-79.0	15.0-53.0	3.0-51.0	0-38.0
Taha, et al. [51]	Cheras, Kuala Lumpur	49.0	13.0	38.0	-

3.1.4 Atterberg Limit

In Table 4, the Atterberg limits of residual soil are detailed, which are based on the findings of prior researchers from Malaysia conducting research. The information shown in Table 4 reveals that the plasticity index, the liquid limit, and the plastic limit of residual soil in Malaysia are within the ranges of 7.0–39.0%, 13.0-85.0%, and 20.0-99.0%, respectively. The present study shows that the results of the plasticity index, the liquid limit, and the plastic limit were in the range of 27.0%, 64.0%, and 37.0%, respectively.

Table 4 *Malaysia's residual soil Atterberg Limits*

Researcher & Year	Location	Plasticity Index, PI (%)	Liquid Limit, LL (%)	Plastic Limit, PL (%)
Present Study	Dusun UTM, JB	27.0	64.0	37.0
Zolkepli [26]	Pahang Matriculation College, Gambang	39.0	70.0	31.0
Ishak, et al. [42]	UTM, JB	32.0	71.0	39.0
Salih [28]	UTM, JB	25.6	68.4	42.8
Duraisamy [43]	Gambang	21.0-22.0	43.0-49.0	22.0-27.0
Tan and Yew [52]	Kg. Awah, Pahang	16.0-14.0	58.0-99.0	42.0-85.0
Taha, et al. [51]	Cheras, Kuala Lumpur	33.6	67.8	34.2

3.2 Engineering Properties of Soil

The CIU (Consolidated isotropic undrained) experiments were conducted to ascertain the most accurate values of the saturated shear strength parameters (c' and ϕ'), Three soil samples were collected from the designated study site, located at Dusun UTM. Fig. 10 depicts the relationship between deviator stress and the axial stress for residual samples. The results indicate that as the confining pressure increased, the deviator stress experience rapid increased. The residual exhibit hardening behavior which the samples did not exhibit a peak stress, and the stress continued to increase until the termination of tests.

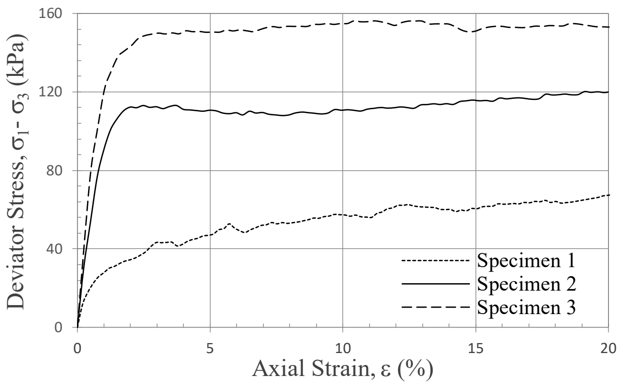


Fig. 10 *Deviator stress versus axial strain*

Fig. 11 shows the Mohr's Circles for the effective stress failure envelopes. According to the effective stress failure envelope as illustrated in Fig. 11, the effective cohesion (c') of specimens 1, 2, and 3 has been estimated to be 13.0 kPa, while the effective friction angle (ϕ') is found to be 27.0º. The results is in a good agreement with a study conducted by Zaini et al. [53], and Rustanto et al. [55].

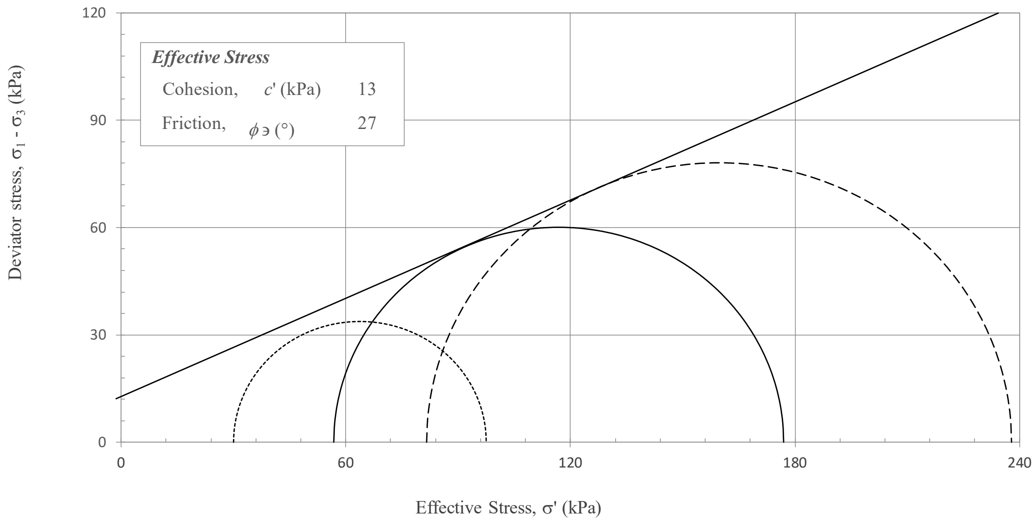


Fig. 11 *Mohr's Circles*

4. Conclusion

Soil types can be categorized using the laboratory test results. The physical index property results indicate that the soil has a specific gravity of 2.5 and a natural moisture content of 31.7%. With a plasticity index (PI) of 27.0%, the soil's composition is 4.8% gravel, 30.1% sand, 44.7% silt, and 20.4% clay. The soil's engineering properties are characterized by a cohesion (c') of 13.0 kPa and Effective friction angle (ϕ') of 27.0º. The results from laboratory work determined that the type of soil that existed in the study area was sandy silt with high plasticity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Ahmad Safuan A. Rashid, Azman Kassim;* ***data collection:*** *Mohd Fakhrurrazi Ishak, Zaihasra Abu Talib;* ***analysis and interpretation of results:*** *Muhammad Syamsul Imran Zaini, Muhammad Irfan Shahrin;* ***draft manuscript preparation:*** *Norhidayah Mohamed. Muhammad Farhan Zolkepli. All authors reviewed the results and approved the final version of the manuscript.*

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