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The Use of Unmanned Aerial Vehicles in the 3D Documentation of Historical and Cultural Heritage: The Case of Ceyhan Kurtkulağı Caravanserai

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Tarihi ve Kültürel Mirasın 3 Boyutlu Olarak Dokümantasyonunda İnsansız Hava Araçlarının Kullanımı: Ceyhan Kurtkulağı Kervansarayı Örneği

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Abstract
Detailed documentation of historical and cultural heritage is a necessity for further analysis, interpretation, and physical reconstruction. Usage of The Unmanned Aerial Vehicles (UAVs) in this role have been increasing day by day. As a result of its important contributions to the production of three-dimensional (3D) terrain models, it has reached an important point in the discipline of surveying engineering. Especially in 3D modeling and documentation of historical and cultural heritage, UAVs are advantageous tools in terms of time and cost when compared to the classical methods. The aim of this study is to generate a 3D model of the Kurtkulağı Caravanserai, located in the Kurtkulağı town of Ceyhan District of Adana, using UAV (DJI Phantom 4 RTK) and to reveal the importance of UAV in the documentation of this historical structure. In this context, according to a planned flight on the UAV, following the capture of the images of the caravanserai in a multiview aspect, a metric 3D model was produced using photogrammetric methods. Root Mean Square Errors (RMSEs) in X, Y, Z coordinates were calculated based on the Ground Control Points (GCPs) and corresponding model coordinates. The RMSEs for X, Y, Z coordinates were calculated 0.019m, 0.025m, and 0.033m, respectively.

***Keywords:** UAV, Cultural Heritage, 3D Model, Photogrammetry, Kurtkulağı Caravanserai, Ceyhan*

Öz
Tarihi ve kültürel mirasın ayrıntılı bir şekilde belgelenmesi, daha fazla analiz, yorum ve yeniden yapım için bir zorunluluktur. İnsansız Hava Araçları'nın (İHA) bu rolde kullanımı gün geçtikçe artmaktadır. Üç boyutlu (3D) arazi modellerinin üretimine sağladığı önemli katkılar sonucunda, harita mühendisliği disiplininde önemli bir noktaya ulaşmıştır. Özellikle tarihi ve kültürel mirasın 3D modellemesi ve dokümantasyonunda, klasik yöntemlerle karşılaştırıldığında İHA'lar zaman ve maliyet açısından avantajlı araçlardır. Bu çalışmanın amacı, Adana'nın Ceyhan ilçesine bağlı Kurtkulağı kasabasında bulunan Kurtkulağı Kervansarayı'nın İHA (DJI Phantom 4 RTK) kullanarak 3D modelini geliştirmek ve bu tarihi yapının dokümantasyonunda İHA'nın önemini ortaya koymaktır. Bu bağlamda, İHA ile planlanan bir uçuşa göre kervansarayın çoklu görüntü açısından fotoğrafları alındıktan sonra, fotogrametrik yöntemlerle metrik bir 3D model oluşturulmuştur. X, Y, Z koordinatlarındaki Karesel Ortalama Hata (KOH), Yer Kontrol Noktalarına (YKN) ve karşılık gelen model koordinatlarına göre hesaplanmıştır. Buna göre X, Y, Z koordinatları için KOH sırasıyla 0,019m, 0,025m ve 0,033m olarak hesaplanmıştır.

***Anahtar Kelimeler:** Keywords İHA, Kültürel Miras, 3B Model, Fotogrametri, Kurtkulağı Kervansarayı, Ceyhan*

1. Introduction

Nowadays, documentation of historical and cultural heritage is becoming more important. Detailed 3D modeling and documentation of heritage is a necessity for further analysis, interpretation, and physical reconstruction (Barsanti et al., 2014; Murtiyoso and Grussenmeyer, 2017). In the literature, distance-based techniques like Terrestrial Laser Scanning (TLS) or photogrammetry-based image processing techniques like Structure from Motion (SFM) are used in realizing these works (Remondino et al., 2012). Image-based approaches are advantageous for easy acquisition and low-cost tools (i.e., a camera, a computer, a tool for scaling and directing). On the other side, using low-cost tools can

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affect the accuracy and quality of the work (Murtiyoso and Grussenmeyer, 2017).

The use of Unmanned Aerial Vehicles (UAV) in documentation of historical and cultural heritage has been frequently encountered in national and international studies, especially in recent years. Yakar et. al. (2015) studied on 3D modeling with surface and photogrammetric measurements of Bezariye Han in Konya. Besides, UAVs are used in 3D modeling of Kalender Baba and Kesikbaş Tomb (Mırdan and Yakar, 2017). Mahmod and Yılmaz (2018) generated a 3D model of Aksaray University Campus Mosque with UAV images using two different heights and two different accuracy values. The accuracy of the model was calculated over 24 ground control points using the terrestrial measurement technique. Murtiyoso and Grussenmeyer (2017) created reference points with a terrestrial laser scanner (TLS) for the Rohan Palace façade and St-Pierre-le-Jeune Catholic church, and they made laser scanner surveys and compared the dense matching results from UAVs by testing them with different software solutions. Karachaliou et al. (2019) used the UAVs for Historic Building Information Modeling (HBIM) to compose the 3D model of "Averof's Museum of Neohellenic Art" located in Metsovo, Greece. Orthoimages of the facades and architectural designs of both the exterior and interior parts of the building were obtained by UAV photogrammetry techniques. Korumaz et al. (2014) worked on the 3D modeling of the Harzburger Hof hotel in Bad Harzburg, Germany, which was damaged in a fire. In that study, 11 control points were utilized, four of which were on the building. Pictures were obtained using two different UAVs and a terrestrial laser scanner survey was also carried out. These two types of data were used in the creation of the 3D model. As seen from the previous literature, UAV photogrammetry is a unique technique to effectively model any structure, and thus this study focuses on using the UAV data for 3D modelling of a historical structure, namely, Kurtkulağı Caravanserai. The aim of this study is to model Kurtkulağı Caravanserai in 3D by using UAV and photogrammetric techniques for the protection, documentation, and restoration of historical and cultural heritage. Even though identical 3D modeling of historical structures were carried out in Türkiye (Yakar et. al., 2015; Erdoğan et al., 2021; Şenol et al., 2021), the lack of any cultural heritage's 3D model is a kind of threat in case of a damage due to the natural disasters or unforeseen events. Therefore, the original contribution of this study is not only the visual representation of the caravanserai but also to provide 3D metric information, which is crucial for the preservation, documentation, and potential restoration of this valuable heritage.

Kurtkulağı Caravanserai is a historic Ottoman caravanserai located in Adana Province, Turkey. It was built by the Ottoman Empire in the 18th century on the Adana-Aleppo part of the Silk Road. Thus, it has both historical and cultural representativeness. The geographic location and one of the aerial photos of the caravanserai is given in Figure 1.

Figure 1. Location of Kurtkulağı Caravanserai and one of its aerial photos.

2. UAVs in 3D Modelling

There is an increasing use of UAVs in civilian applications. UAVs provide close range images for various areas thanks to ongoing developments in versatile sensor technology and an advance in computing power (Murtiyoso et al., 2017). There are many classifications for UAVs. They can be lighter-than-air, fixed-wing, or rotary-wing platforms. Lighter-than-air platforms are low-cost solutions, but they are hard to control in windy conditions. Fixed-wing UAVs have limited payload and large-scale imaging capabilities. On the other hand, rotary-wing UAVs have a bigger payload specification and more robustness for wind effects but low surface coverage when compared to fixed-wing types (Murtiyoso and Grussenmeyer, 2017). UAVs can also be classified according to their usage areas. Considering that UAVs can be used in photogrammetric applications, it is also important whether they have a built-in camera or not. With a built-in camera, focal length and sensor size gain importance. In the case of low values of these two features, closer flight is required for better image quality. In this case, there is no need to purchase a camera and gimbal system. In other cases, separate camera and gimbal systems can be added to

UAVs. Adding a DSLR camera, for example, allows images to be taken at a higher resolution (Federman et al., 2017). The selection of the type and model of an UAV depends on the dimensions of the study site. The UAV used in this study is a Phantom 4 Real Time Kinematic (RTK) model that is used to acquire all the aerial images (Figure 2). Many companies and researchers employ the Phantom 4 RTK for daily mapping and surveying operations. This is because the Phantom 4 RTK is a small, dependable, and affordable drone. With its high precision mapping capability, the Phantom 4 RTK helps to provide a balance of quality and speed, cutting survey time to a matter of hours while maintaining precise metadata.

Figure 2. Courtesy of Phantom 4 RTK (DJI, 2023)

Phantom is a rotary wing platform manufactured by the company DJI. Phantom 4 is a low-cost, lightweight (take-off weight: 1,391g), compact, and accurate low altitude mapping solution. It is equipped with a 1'' CMOS with effective 20 megapixels (MP) camera and an RTK module. Ground sample distance (GSD) is 2.74 cm at 100 meters of flight altitude. The Phantom 4 supports both automatic and manual flight modes. With multiple planning modes, it is an ideal UAV for 2D and 3D Photogrammetry. RTK horizontal and vertical positioning accuracies are 1cm+1ppm and 1.5cm+1ppm, respectively. As external hardware, a backup battery and a smart control unit are used to perform the flight.

3. *3D Modelling Methodology with UAVs*

The documentation process of historical and cultural heritage requires the use of large multimedia data sets, including photographs, photographic panoramas, corrected photographs, orthophotos, technical drawings, different 3D models, including point clouds, and other data such as videos, reports, images, and texts. Basically, this process can be considered under five main headings: (1) planning documentation, (2) data collection, (3) data processing, (4) data management, and (5) data distribution (Korumaz et al., 2014). All these steps involve the diverse and intensive use of digital technologies. In this case, choosing the appropriate technology, procedure, and workflow is always difficult and depends on the size and complexity of the study and the level of accuracy required (Korumaz et al., 2014). Figure 3 represents the work-flow chart showing the basic steps in data acquisition and processing with the UAV (Nex and Remondino, 2014). The main steps in the workflow include mission planning, image acquisition, image triangulation, and feature extraction such as orthoimage, Digital Surface Model (DSM), and 3D model.

3.1 Mission Planning

A flight plan and measurements of GCPs are required to make a typical image-based observations with an UAV. At this stage, in addition to the flight plan, it is recommended to create a subcategory that includes the safety procedures of the relevant country and the flight log (i.e., flight pattern, time of flight, battery life, wind speeds, temperature, etc.) (Federman et al., 2017). While creating the flight plan, Ground Sample Distance (GSD) should be calculated. It is to determine how much area a pixel value on the GSD image corresponds to on the surveying object. GSD can be calculated with the following formula:

$$\text{GSD}=\frac{\text{Pixel Size}}{\text{Focal Length}} \text{x Distance to object} \qquad (1)$$

The fact that the GSD is 3 mm means that a pixel in the camera corresponds to 3 mm on the object. For the most ideal resolution, the 'Distance to Object" value should be selected as the minimum distance from the camera to the object. Considering the camera focal length value used in similar flights, the flight should be planned by considering the closest GSD value at the most inaccessible points. The camera angle should be determined by defining the flight altitude, the dimensions of the object, and the areas that create obstacles (Federman et al., 2017). Flight modes are also a user-selectable option. There are three types of flight modes: manual, assisted, or autonomous (Nex and Remondino, 2014). The flight pattern can also be chosen as circular or linear to provide optimum overlap. (Aicardi et al., 2016). In this study, manual and autonomous flight modes were used. In autonomous flight, nadir images of the Caravanserai were taken in 3D photogrammetry mode. On the other hand, in manual flights, nadir images of the Caravanserai were taken.

3.2 *Image Acquisition*

For the overlapping image acquisitions, the higher overlapping ratio will result in higher accuracy in the modeling. By using a spatial intersection point of view, it will be best practice to take the images with a wide overlapping area. Coordinate and dimensional features should be measured for later georeferencing and 3D model construction (Murtiyoso and Grussenmeyer, 2017).

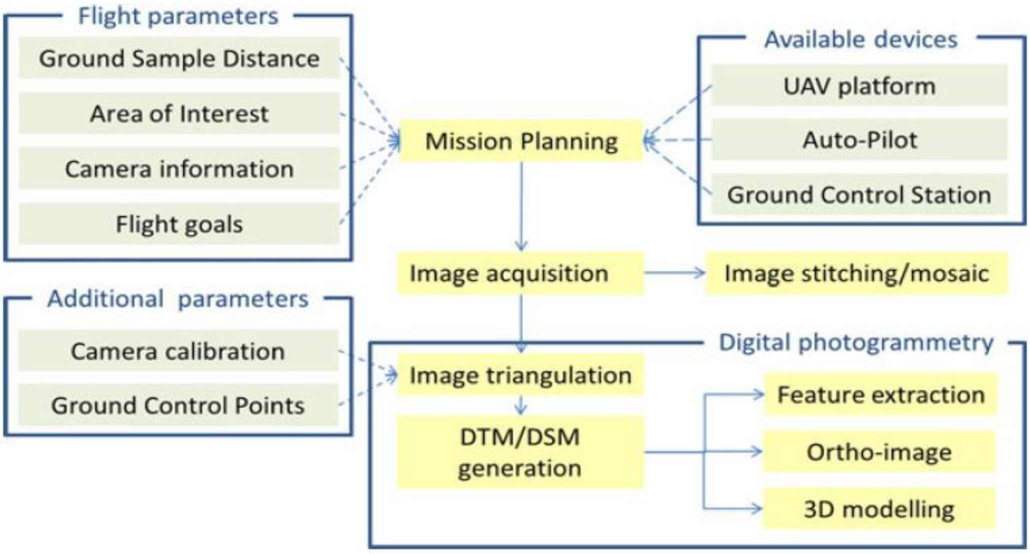

Figure 3. UAV Image Acquisition Workflow (Nex and Remondino, 2014)

After acquisition, images can be used for mosaicking purposes or as inputs to the photogrammetric process. There are some protocols and procedures that standardize the calibration and documentation of image acquisition. Some examples are: (International Committee for Documentation of Cultural Heritage (CIPA) (Grussenmeyer et al., 2017), Tools and Acquisition Protocols for Enhancing Artifacts Documentation (TAPENADE) (Pierrot-Deseilligny et al., 2011; Nony et al., 2012) and "One panorama each step" (Grussenmeyer et al., 2013). These all commonly suggest good calibration, procedural documentation, and a large percentage of overlap (Murtiyoso and Grussenmeyer, 2017).

In this study, a flight is performed, and in total 672 overlapping images were taken from various viewpoints of the caravanserai according to the UAV flight plan for the study area. Some of the images were taken with nadir (vertical) photogrammetry, and some of them were taken with oblique photogrammetry. The overlapping percentage was set 80% front and 80% side in nadir image acquisitions. In manual flight, the overlapping rate was determined by the rule of thumb. In nadir photogrammetry, images of the caravanserai were taken from above (close to a bird's eye view), as shown in Figure 4, while in oblique photogrammetry, images of the facades of the caravanserai were taken, as shown in Figure 5.

Figure 4. Sample images of Kurtkulaği Caravanserai taken by nadir photogrammetry.

Figure 5. Sample images of Kurtkulağı Caravanserai taken by oblique photogrammetry.

After these images were transferred to the computer environment as a laboratory study, 3D model production was carried out using trial version of Agisoft Metashape photogrammetric software. In this context, it is of great importance to use the 3D models of the historical and cultural heritage in the restoration of damages that may occur in the future.

3.3 Digital Photogrammetry

Photogrammetry is a technique that is used for mapping applications to produce orthophotos of an area of interest. UAVs are getting more popular by providing quick inspections of buildings for smaller cartography (Murtiyoso et al., 2017). This kind of transformation in photogrammetry is called UAV photogrammetry. Eisenbeiß (2009) defined the UAV photogrammetry as a remote measurement technique achieved by a vehicle operated semi-autonomously, or autonomously.

Digital Photogrammetry workflow is initiated by camera calibration. Camera calibration can be achieved by two orientation methods: nadir and oblique. UAV photogrammetry uses mostly nadir orientation (a camera is located vertically) to produce top-down images of an object. On the contrary, nadir orientation is not always enough to complement a 3D model because of its weakness in photographing facades. Oblique images give the option to rotate the camera to a given angle for (facal) imaging. This is an easy configuration when the UAV has a built-in camera with this feature. But when the camera is mounted externally, rotation should be configured manually (Federman et al., 2017).

Nowadays, the use of commercial or open-source software solutions for digital photogrammetry is very common. By using the integrated photogrammetry and computer vision algorithms with process flows, dense clouds, image orientation, 3D modeling, and orthophoto image creation can easily be achieved in an efficient way. Most ell-known open-source software products are Agisoft Photoscan (PS), Pix4D (P4D), Photomodeler (PM), Micmac (MM), 3Df Zephyr (3DZ), Acute3D, VisualSFM (VSFM), SURE and ContextCapture (CC). MM and VSFM.
Although these software tools use different algorithms with various parameters for image processing, they all implement the process steps given as orientation, point cloud composition, and, as a result, triangulated mesh, orthophoto, and DEM production. Except, when SURE software is preferred, image alignment should be performed outside the tool (Aicardi et al., 2016).

In photogrammetry, image triangulation is an initial image processing step for extracting interior and exterior features used to orient images. Image correspondences (dense matching) are needed to begin this step. These types of correspondences (i.e., tie points) can be manually or automatically extracted. This process begins with point or feature extraction in the study area. Correspondences are discovered by using the descriptor values or grayscale values of the different combinations (comparisons) of the images in a search window. Feature-Based Matching (FBM) and Area-Based Matching (ABM) are two different approaches in feature matching. ABM is advantageous in precision sensitivity but requires a texture, on the other hand, FBM is generally the first choice in the first step of photogrammetry by generating automatic tie points, resulting in a sparse cloud. This sparse cloud is enough for dense matching. Scale-Invariant Feature Transform (SIFT) algorithm (Lowe, 2004) and the SURF (Chiabrando et al., 2015) algorithms are scale invariant FBM algorithms for descriptor extraction. Semi-global matching (SGM) (Hirschmuller, 2005) is an example of an ABM type algorithm that uses local or global methods in a search window by using the energy minimisation approach. (Remondino et al., 2012, Murtiyoso and Grussenmeyer, 2017). Subsequently, robust outlier detection is performed by using algorithms like RANSAC, MAPSAC, LMedS etc. Finally, the image correspondence set for the entire block is obtained by organizing dual or triplet image correspondences clustered in tracks.

Bundle adjustment is the next step of photogrammetric step which starts by calculating the 3D coordinates of the correspondences as input. Bundle adjustment method (Chiabrando et al., 2015) is an 3D optimization method which estimates a 3D renconstruction model in optimal conditions by using camera parameters. Estimations are calculated by minimizing a cost function to extract the 3D model features and camera parameters. Also a reference coordinate system should be defined by giving a datum value for orientation and scale.

In this study, as seen in Figure 3, initially, camera calibration and image stabilization (triangulation) are performed to create a Digital Surface Model (DEM). Image stabilization requires the exact alignment and scale of the images with the ground. To achieve this, there are two approaches. First, Ground Control Points (GCP) can be stationed traditonally by surveying the study area and photographs of these point should be taken with an UAV. On the other hand using built-in Global

Navigation Satellite Systems (GNSS) sensors of an UAV to compliment image acquisition is another option. Photogrammetric softwares are used to expose the exif information embedded on the image data for registration. This approach doesn't provide an accurate output as GCP method (Federman et al., 2017). In this study GNSS option of the UAV is used for image triangulation. Images taken by UAV used as material and trial version of Agisoft Metashape software was used as 3D modeling software.

4. Results

In addition to the images obtained by nadir (vertical) photogrammetry, detailed images of the facades of the building are needed in order to create an accurate 3D model. Thus, in this study, Images taken with oblique photogrammetry were used to model these facades correctly in addition to the nadir images. Since the RTK module is installed on the UAV used in this experiment, only 5 ground control points (GCPs) were placed to the study area and their central coordinates were determined with a GNSS receiver. Root Mean Square Errors (RMSEs) in X, Y, Z coordinates were calculated based on the GCPs and corresponding model coordinates. The RMSEs for X, Y, Z coordinates were calculated 0.019m, 0.025m, and 0.033m, respectively. The orthophoto and DEM data of Kurtkulağı Caravanserai produced after the processing of the UAV data with the methodology used in Figure 3 are shown in Figures 6 and 7, respectively.

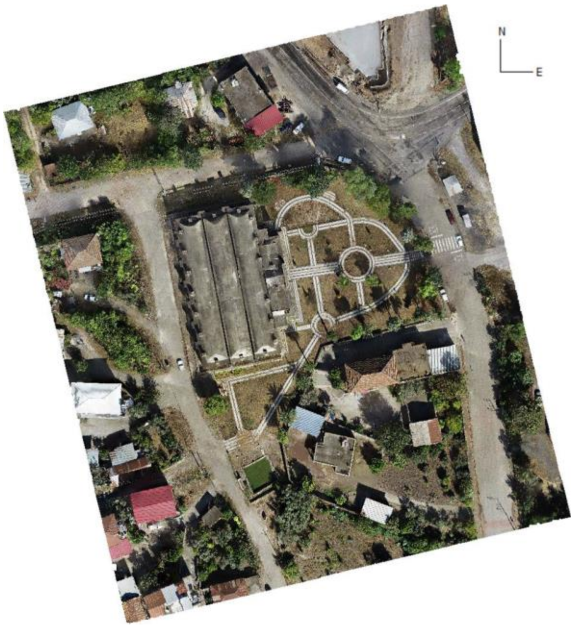

Figure 6. Orthophoto of the study area produced with the UAV data.

As the final product, the general view of the 3D model of the caravanserai is presented in Figure 8. In addition, screenshots of the 3D model taken from all sides of the building are given in Figure 9. As visual interpretation, the 3D model, which was generated using UAV images, provided satisfactory results compared to the real one.

By extracting metric information from the 3D models obtained from the images taken with real coordinates, it becomes very easy to restore the structure in case of a possible destruction. Considering the restoration, having a 3D model built ahead of time can be a great resource for ensuring a precise and successful intervention. The value of constructing 3D models is widely accepted for the extraction of metric and geometric information, which are essential for reconstruction of relief objects from the drawings. Figure 10 shows some metric information taken from the 3D model. The metric differences between the 3D model and ground measurements varied from 2mm to 8mm.

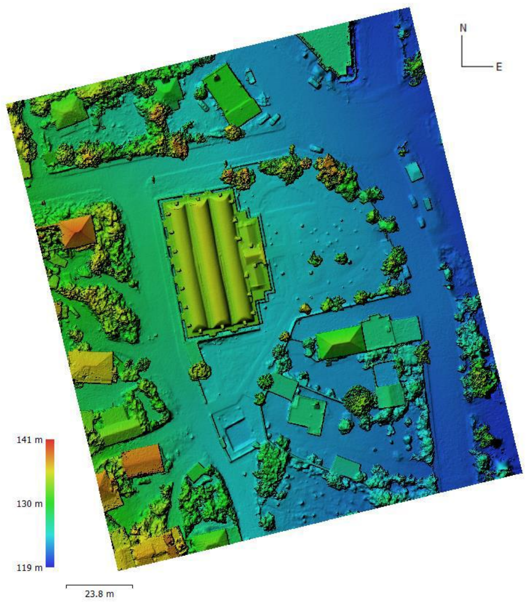

Figure 7. DEM produced with the UAV data for the study area.

Figure 8. General view of the study area and the 3D model of the caravanserai.

Figure 9. Screenshot examples for all facades from the 3D model of the caravanserai.

Figure 10. The metric information of some building elements taken from the 3D model of the caravanserai.

5. Conclusion

The aim of this study was to model Kurtkulağı Caravanserai in 3D using UAV and photogrammetric techniques for the protection, documentation, and restoration of this historical and cultural heritage in case of damage. In this context, the Kurtkulağı Caravanserai was modeled in 3D using the images taken from the UAV (provided with the project budget) and photogrammetric techniques. In the study area, firstly, UAV flight was planned, and after the flight, in total 672 overlapping images of the caravanserai were taken from various perspectives. Some of the images were taken with nadir, and some of them with oblique photogrammetry. Orthophoto, DEM, and 3D models were produced on the images by applying the processing steps specified in the 3D modeling method section. Images obtained from the UAV with real coordinates provide great convenience in the production of 3D models. In this way, 3D model production with real coordinates and therefore metric information is possible without the need for a ground control point. 3D modeling and documentation of the historical and cultural heritage provide great convenience for the restoration of the building in case of possible destruction due to a natural disaster or other events.

Declaration of Ethical Standards

The authors declare that they comply with all ethical standards.

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Credit Authorship Contribution Statement

Author-1: Conceptualization, investigation, methodology and software, visualization and writing – original draft, review and editing.

Author-2: Project Management, Experiment Design, Conceptualization, investigation, methodology and software, supervision and writing – review and editing.

Declaration of Competing Interest

The authors have no conflicts of interest to declare regarding the content of this article.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

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