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Assessing Physical Characteristics for Precision Harvester Design: A Comparative Study of Spinach, Fenugreek, and Coriander Leafy Vegetables

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RHN, PKS and HLK designed the study. Authors MBS, SKR and AKK involved in data curation. Authors RHN, PKS and AK wrote the first draft of the manuscript. Authors RHN, MBS, and SKR managed the analyses of the study. Authors RHN and AK helped in literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This study aims to assess the physical characteristics of spinach, fenugreek, and coriander, focusing on parameters essential for the design of a precision harvester. Given the labor-intensive and costly nature of manual harvesting, this research addresses the need for mechanization in leafy vegetable farming.

Methodology: The physical characteristics analyzed include plant dimensions such as height, leaf width and length, stem and petiole diameter, leaf height from the ground, plant weight, and leaf-petiole/branch ratio. Additionally, crop geometry was examined, considering plant spacing, row spacing, the number of petioles per plant, and crop density. Measurements were collected from 30 samples of each crop, with data analysis focusing on mean values, standard deviations, and other statistical parameters

Results: The study found significant variability in the physical characteristics of the three crops. Spinach exhibited the tallest crop height (42.8± 9 cm) and largest leaf dimensions (7.3±2 mm), whereas fenugreek and coriander had smaller leaves and shorter crop heights. Spinach also had the highest bulk density (103.9±7.3 kg/m^3) and leaf-stalk ratio (1.08±0.11), which are crucial for the design of storage and cutting mechanisms. In contrast, coriander had the highest crop density, impacting the design of the cutter and conveyor systems.

Conclusion: The differences in physical characteristics among spinach, fenugreek, and coriander necessitate tailored design considerations for precision harvesters. Spinach's larger size and higher density require more robust harvesting mechanisms, while the smaller and denser crops like fenugreek and coriander demand precision in cutter bar and conveyor designs. These findings will guide the development of efficient, crop-specific precision harvesters.

Keywords: Crop geometry; leafy vegetables; physical characteristics; precision harvesting.

1. INTRODUCTION

Man has had tremendous pressure on green leafy vegetables (GLVs) since the start of civilization and these vegetables can survive in adverse environmental conditions such as droughts. Traditional vegetables are valuable sources of nutrition in rural areas where exotic species (sp.) are not available. They provide good nutrition at a low cost, in contrast to the costly exotic sp. Different parts of the world have a valuable heritage of various Indigenous leafy vegetables and some of them are also used as medicinal plants traditionally [1]. The most commonly used green leafy vegetables in the Indian diet are spinach, fenugreek, cabbage, coriander, etc. These are known as conventional plants. But tribal people live in unexploited areas and are devoid of their significant supply. Tribal people use maximum plants that are found in their local areas where exotic species are scarce. These plants are generally used at the time of famines or during natural disasters. Hence these plants are known as nonconventional, underutilized, or Indigenous plants [2]. Green vegetables are a good source of antioxidants, but the exact mechanism in the prevention and treatment of chronic diseases by these vegetables is still not fully understood. It is assumed that the combination of antioxidants and phytochemicals found in vegetables may improve health by inhibiting the formation of free radicals responsible for the early-stage development of some chronic diseases [3]. Green leafy vegetables' overlapping nutritional and therapeutic advantages offer greater encouragement for human wellness [4]. Diets high in fruits and vegetables are protective against several prevalent chronic diseases, including cancer, obesity, and cardiovascular disease [5].

The physical properties of leafy vegetables are essential for the design of equipment and facilities for the harvesting, handling, conveying, separation, drying, aeration, storing, and processing of different leafy crops [6]. Various types of cleaning grading and separation equipment are designed based on their physical properties as a function of moisture content [7]. Studied baby spinach's physical and mechanical characteristics, such as the density of leaves, Young's modulus, strength at which fracture occurs, and coefficient of friction. Baby spinach leaves had an apparent density of 0.5666 g/mm^3 on average [8]. The friction coefficients between the two surfaces were found to be 1.3635 for kinetic friction and 1.2735 for static friction [8]. Assessed plants of fenugreek for some of their mechanical and physical qualities. Fenugreek

plant measurements of length, width, and stalk diameter were reported to have mean values of 593 mm, 118 mm, and 2.5 mm, respectively. The measured average values for various parameters were as follows: sphericity - 0.70 mm, surface area - 18.42 mm^2, volume - 5.34 mm^3, thousand seed weight - 11.93 g, bulk density - 687.62 kg/m^3, actual density - 1360.58 kg/m^3. The required cutting force for fenugreek stalks was found to be 24.72 N on average [9].

Machinery and equipment play a crucial role on farms, enabling various tasks to be accomplished efficiently [10]. The electronics and instrumentation play a vital role in precision agriculture and farm mechanization [11–13]. In the study of spinach's mechanical properties, parameters such as burst strength, toughness, and displacement were analyzed, which are crucial for processes like transportation, separation, and packaging [14]. Similarly, research on hydroponic lettuce focused on determining its physical and mechanical properties—including moisture content in the stem, root, and leaf, geometric characteristics, pulling force, and root cutting force—which are essential for designing automated harvesting machines. The pulling force was measured through tensile testing, while the root cutting force was examined using shear tests on an electronic universal testing machine [15]. Systematic research into the physical, mechanical, and rheomechanical properties of green leafy vegetables is foundational for designing efficient harvesting equipment. These properties provide critical parameters for simulation and optimization in harvester design. For instance, extended properties such as static and dynamic friction coefficients, along with the restitution coefficient of various plant parts (root-root, stem-stem, root-steel, and stem-steel), were measured using a combination of inclined plane methods and high-speed photography [16]. In the context of fenugreek harvester design, the frictional properties were explored, revealing an angle of repose of 55.22°, an average internal friction angle of 42°, and a static coefficient of friction of 0.89. Additionally, the cutting force required for fenugreek was quantified at 0.686 N [17]. While numerous research papers exist concerning the seed properties of various leafy vegetables, there is a notable scarcity of related data about the physical properties of fresh crops with relevance to precision harvester design. Consequently, this study aims to investigate and analyze the physical characteristics of spinach, fenugreek, and coriander at the harvesting stage.

2. MATERIALS AND METHODS

Selection of crop for harvesting: When selecting a crop for mechanical harvesting, several crucial factors come into play. Firstly, the crop's characteristics, including plant height, structure, stem strength, and ease of detachment, should align with mechanical harvesting equipment. Secondly, harvesting efficiency depends on factors like crop distribution, canopy density, and accessibility. Minimizing losses and damage during harvesting, including shattering, bruising, or seed loss, is essential. Uniform maturity across the field ensures consistent quality. A high crop yield justifies the investment, and market demand, post-harvest requirements, and price impact marketability. Compatibility with other field operations and a comprehensive cost-benefit analysis round out the considerations, ensuring the economic viability of mechanical harvesting for the chosen crop.

Measurements taken from the field: Engineering properties and crop geometry were obtained from the Unit of Vegetables Research and Demonstration (UVRD), IARI-New Delhi for selected leafy vegetables i.e., spinach, fenugreek, and coriander. All the crops were sown in the line sowing method at different spacings for rows i.e., from 25 cm to 40 cm spacing. 30 observations of crop height, width of leaves, length of leaves, stem diameter, petiole diameter, height of leaves from the ground, plant-plant spacing, and row-row spacing were measured using a scale and the vernier calipers. All these properties were measured at different locations selected at random, and their lowest, maximum, mean, and standard deviation were calculated and presented in Table 1.

2.1 Crop Height

To assess the relationship between the height of plants above the ground surface and the cutting height, measurements were conducted for spinach, fenugreek, and coriander. The height of the plants above the ground surface was measured at thirty randomly selected locations using a scale as shown in Plate 1. These measurements were then averaged to obtain the mean value, which was subsequently used for further investigation. By obtaining this mean value, it was easy to understand the typical

Plate 1. Study of Physical properties and crop geometry

height of the plants and how it relates to the cutting height to optimize the harvesting process.

2.2 Width and Length of Leaves

The width of a leaf was measured by laying it flat on a surface, and the measuring tool was positioned perpendicular to the midrib or central vein. The tool was aligned carefully to measure the widest section of the leaf, spanning from one side to the other. For length measurements, the leaf was placed on a flat surface, and the ruler was aligned parallel to the midrib or central vein. Starting from the base of the leaf, the measurement was taken along the midrib to the tip of the leaf.

2.3 Stem Diameter

This is the central, vertical part of the plant that supports the leaves. Measurements of the stem diameter were done using a vernier caliper with millimeter markings. The vernier calipers are placed perpendicular to the stem, ensuring that they are in contact with the widest part of the stem during measurement.

2.4 Petiole Diameter or Branch Diameter

The stalk that joins the tip of the leaf blade to the stem is known as the petiole. Part of a ripe spinach leaf's petiole that can be measured with ease was chosen. The diameter of the petiole was measured using a caliper marked in millimeters. The measuring instrument was perpendicular to the petiole and touched its widest point during measurement. Similarly, branch diameters were also measured for fenugreek and coriander.

2.5 Height of Leaves from the Ground

The height of the leaves from the ground surface was measured using a ruler. The ruler was placed vertically from a point on the ground up to the base of the leaf. The measurement device was kept parallel to the plant's stem or main axis when observations were taken.

3. LABORATORY EXPERIMENTS

3.1 Weight of Plant

To determine the weight of a leafy vegetable plant, start by harvesting the entire plant, including its leaves and main stem. After gently shaking off any excess soil, place the plant on a weighing scale positioned on a flat and stable surface. Take note of the weight displayed on the scale, which represents the total weight of the leafy vegetable plant.

3.2 Leaf-Stalk Ratio

Leaf-petiole/branch ratio was determined using a 100g sample of each crop, the leaves were separated from petioles/branches, and weights were recorded. The ratio of leaf weight to petiole/branch weights is considered as leaf-petiole/branch ratio. Both of these properties were measured with an electronic balance having a sensitivity of 0.01g and a maximum capacity of 1kg.

3.3 Bulk Density

The bulk density of the chosen green vegetables was determined using the standard procedure. A container with a specified capacity was taken, and the quantity of produce that container could carry was weighted. The measurements of the box were 285x85x65 mm, and the procedure was carried out a total of five times with various combinations of the selected crops. The total weight of the crop was determined with a digital balance with a resolution of 0.01g and a maximum weight of 1kg [18]. It was determined from the following equation:

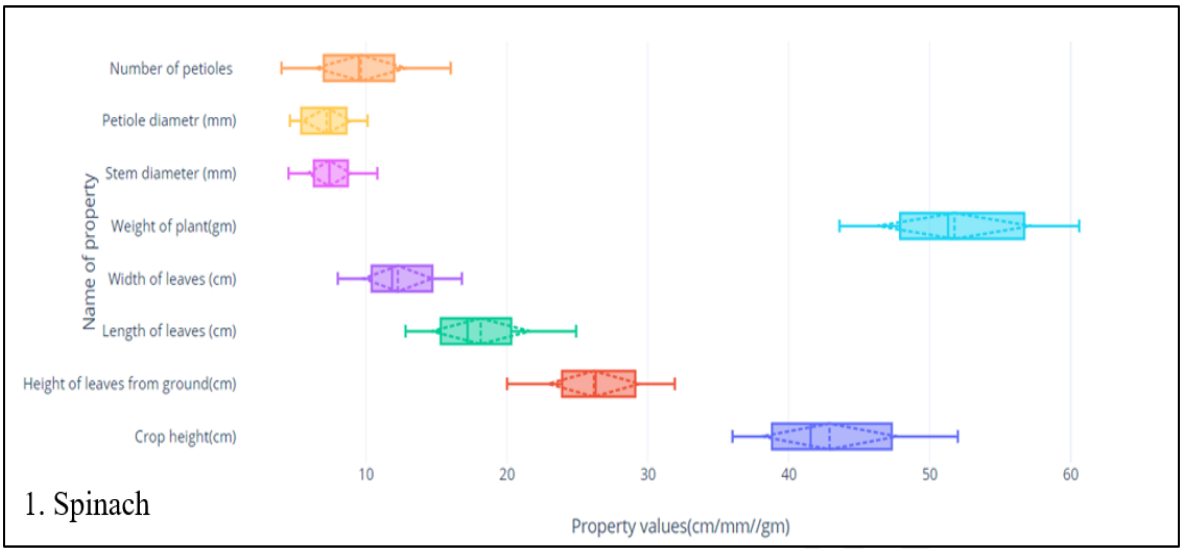
$$\rho b = \frac{M}{V}$$

ρ_b = Bulk density, kg m^{-3};
M = Mass of the crop sample, kg;
V = Volume of the sampler, m^3

4. RESULTS AND DISCUSSION

The three chosen leafy vegetables, spinach, fenugreek, and coriander, were represented by the cultivars Pusa All Green, Pusa Early Bunching, and a local variety of coriander, respectively. The crop height is a crucial factor in designing a reel to bend the crop onto a cutter for smooth cutting, minimizing header losses. Among these leafy vegetables, spinach has the tallest crop height, while fenugreek and coriander have comparatively shorter heights. Specifically, coriander has a minimum crop height of 20.4 cm, while spinach has a maximum height of 52.0 cm. The size of leaves, both in terms of length and width, is a significant factor to consider when designing a harvester. This is particularly important because spinach has long and wide leaves, whereas fenugreek and coriander have much smaller leaves in comparison. These leaf dimensions are also crucial when determining the length of the conveyor belt on which these crops are spread after harvesting, before being collected in the storage box. The length of spinach leaves ranges from 181±47 mm, fenugreek leaves measure 34.8±7.05 mm in length, and coriander leaves have a length of approximately 56.9±12.7 mm. As for the width, spinach leaves have a range of 122±32 mm, fenugreek leaves measure 30.4±4.6 mm in width, and coriander leaves have a width of approximately 33.8±8.48 mm.

In the design process of a storage box, the bulk density of crops plays a significant role. To determine the suitable capacity of the container, the quantity of produce it can hold is weighed. For spinach, fenugreek, and coriander, the bulk densities were measured as 103.9 ± 7.3 kg/m^3, 83 ± 5.1 kg/m^3, and 68.2 ± 8.4 kg/m^3, respectively. It was observed that the bulk density of spinach was higher compared to the other two crops. As a result, spinach was chosen as a crucial factor in the design considerations. The diameter of the stem and the petiole or branch plays a crucial role in the design considerations of the cutter bar. In particular, the petiole diameter of spinach is significantly larger when compared to the branch diameter of fenugreek and coriander. The calculations for the power requirement of the cutter bar take into account the varying petiole diameter of spinach, which ranges from 7.2±2.1 mm. Another important parameter for designing the cutter bar is the height of the leaves from the ground, as it provides information about the position of the first leaf. This information helps determine the appropriate height of the cutter bar to ensure that no crops are missed. For spinach, fenugreek, and coriander, the height of the leaves from the ground varies as 26.1±5.7 cm, 14.3±2.7 cm, and 6.7±1.76 cm, respectively.



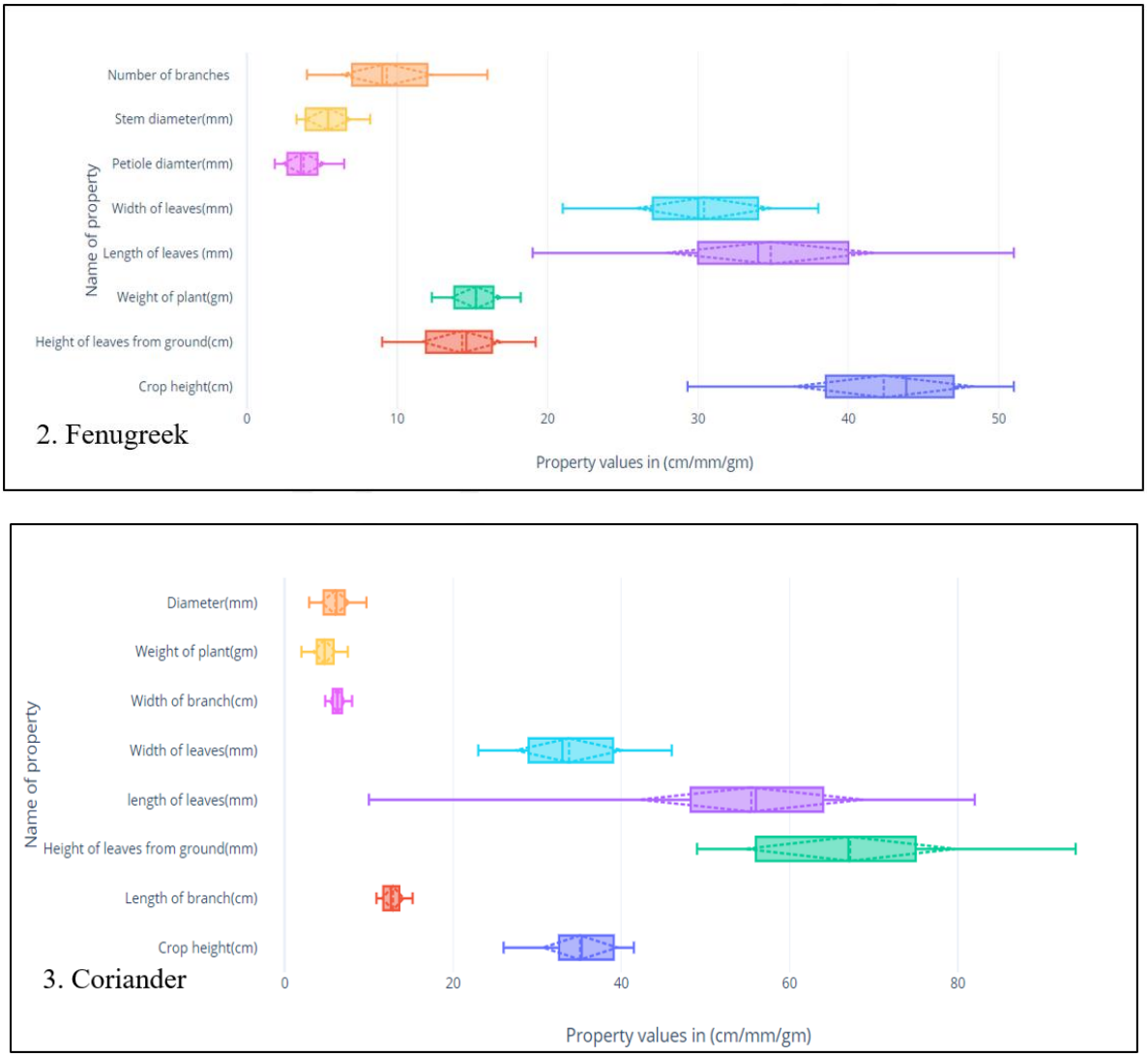


Fig. 1. Box &Whisker plot for physical properties of selected leafy vegetables

The weight of the plant provides valuable information about the amount of crop on the conveyor belt and is used in the calculations for conveyor capacity and storage box capacity. Additionally, the actual productivity of the machine is measured in terms of weight per unit of time, which is determined by weighing the uprooted plants from the field. The weight of plants for spinach, fenugreek, and coriander varies as 51.7±10.7 g, 15.2±1.68 g, and 4.7±1.8 g, respectively. The leaf-stalk ratio, which indicates the proportion of leaf content to stalk, is highest for spinach. This is because spinach has a higher leaf content compared to fenugreek and coriander. Specifically, the leaf stalk ratios for spinach, fenugreek, and coriander are 1.08±0.11, 0.71±0.03, and 0.54±0.05, respectively. To determine the moisture content of leafy vegetables during the harvesting window, measurements were taken at three different stages: at the time of harvest, 7 days before harvest, and 7 days after harvest. It was observed that there were no significant differences in the moisture content at these different phases of the harvest. The moisture content was found to be higher in the leaves compared to the stalks of the selected leafy vegetables. At the time of harvesting, the highest moisture content was observed in spinach leaves, reaching 95.02%, while the lowest moisture content of 83.41% was found in coriander leaves. Fenugreek leaves had a moisture content of 89.1%. Similarly, the moisture content in the stalks of spinach, fenugreek, and coriander was measured to be 92.01%, 89.08%, and 91.43%, respectively.

Table 1. Engineering properties and crop geometry of selected leafy vegetables

Particulars	Spinach				Fenugreek				Coriander			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Crop height (cm)	36.0	52.0	42.8	9.0	29.3	51.0	42.3	6.0	20.4	38.5	29.4	4.0
Stem diameter(mm)	4.5	10.8	7.3	2.0	3.3	8.2	5.4	1.5	2.9	9.7	6.0	0.3
Height of leaves from the ground (cm)	20.0	31.9	26.1	5.7	9.0	19.2	14.3	2.7	4.9	9.4	6.7	1.76
Length of leaves (mm)	128	249	181	47	19.0	51.0	34.8	7.05	38.8	82.0	56.9	12.7
Width of leaves Max (mm)	80.0	168	122	32	21.0	38.0	30.4	4.6	23.0	46.0	33.8	8.48
Petiole diameter or branch diameter (mm)	4.6	10.1	7.2	2.1	1.86	6.47	3.7	1.4	1.31	4.94	3.0	0.6
Weight of plant (g)	43.6	60.6	51.7	10.7	12.3	18.2	15.2	1.68	1.98	7.48	4.7	1.8
Leaf-stalk ratio	0.92	1.22	1.08	0.11	0.66	0.76	0.71	0.03	0.49	0.61	0.54	0.05
Crop stand density	168	264	211.8	37.53	274	348	310	28.97	457	524	484.8	28.85
P-P spacing (cm)	3.8	8	5.54	1.2	3.6	6.4	4.5	0.82	3.8	5	4.48	0.42
R-R spacing (cm)	28.6	40	33.96	4.66	28.7	40	33.39	4.82	34.8	40	37.61	2.55
No. of Petioles or branches/Plant	8	16	12.1	2.66	5	16	10.3	3.52	6	11	8.2	1.39

The crops were sown using continuous line sowing, resulting in similar plant-to-plant spacing within the rows. However, the row-to-row spacing at harvest time differed among the crops. The measured row-to-row spacing was 33.96±4.66 cm for spinach, 33.39±4.82 cm for fenugreek, and 37.61±2.55 cm for coriander. These values can be approximated as 30 cm for both spinach and fenugreek and 35 cm for coriander. The number of petioles or branches on the plants played a crucial role in determining the cutting force or load on the cutter bar. Spinach had the highest number of petioles or branches, averaging 12.1±2.66, followed by fenugreek with 10.3±3.52, and coriander with 8.2±1.39. The crop stand density is a crucial parameter in the design of the cutter and conveyor systems. Coriander has a high crop stand density, while spinach has a low density. Fenugreek falls in between spinach and coriander in terms of crop density. Specifically, the crop density for spinach, fenugreek, and coriander was observed to be 211.8±37 plants/m^2, 310±28 plants/m^2, and 484.8±28 plants/m^2, respectively. However, it was noted that spinach had a dense crop stand compared to fenugreek and coriander. This can be attributed to the higher leaf area and the limited spacing available in spinach plants. Therefore, when designing the battery-operated leafy vegetable harvester, the dense nature (231 plants/m^2) of spinach crops was taken into consideration.

5. CONCLUSION

This study comprehensively assessed the physical characteristics of spinach, fenugreek, and coriander, providing essential data for the precision design of harvesters. The analysis revealed significant variations in plant height, leaf dimensions, stem and petiole diameters, and crop density among the three leafy vegetables. Spinach, with its larger leaf size, higher bulk density, and greater crop height, presents unique challenges and opportunities for harvester design. In contrast, fenugreek and coriander, with their smaller dimensions and differing crop geometries, require distinct design considerations. The findings underscore the importance of tailoring harvester components, such as the cutter bar and conveyor systems, to the specific physical properties of each crop to optimize efficiency and reduce harvest losses. Overall, this research provides a critical foundation for developing specialized machinery that can enhance the mechanization of leafy vegetable harvesting, ultimately leading to cost savings, improved labor conditions, and increased productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors declare that ChatGPT has been used to improve the language of the manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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