



Accepted date: 30 June 2026
Published online: 20 July 2026
Doi: 10.20372/cjst.2026/0005

Choke Journal of Science and Technology
(CJST)

“Grow Wiser at the Water Tower”
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PRINT ISSN: 2789-2565,
ONLINE ISSN: 2789-2575

Phosphorus Fertilizer Calibration to Increase Bread Wheat Yield in the Highland Farms of Gozamin District, Ethiopia

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Keywords: Grain Yield, Nitisols, Phosphorus concentration, Phosphorus requirement factor, Relative Yield

Abstract

Bread wheat production in Ethiopia's highland areas is often constrained by nutrient limitations, particularly inadequate phosphorus (P) supply and poor fertilizer rate selection. This study aimed to calibrate phosphorus fertilizer rates to increase bread wheat yield in the highland farms of Gozamin District, Ethiopia, and to determine the critical phosphorus concentration (Pc) and phosphorus requirement factor (Pf) for improved phosphorus management. A field experiment was conducted in the highland farms of Gozamin District using a randomized complete block design with three replications. Seven phosphorus fertilizer rates (including a control: 0, 10, 20, 30, 40, 50, and 60 kg ha⁻¹ P) were evaluated, alongside a uniform nitrogen application of 138 kg ha⁻¹ during ten growing seasons (2018/19–2019/20). Soil sampling and analysis using the Olsen method were performed to assess plant-available phosphorus and relate soil test P to grain yield. Statistical analyses were conducted to determine treatment effects and identify the most responsive phosphorus rate(s). Phosphorus fertilizer application significantly improved bread wheat grain yield compared with the control. Grain yield increased by up to 24.4% over the zero-phosphorus treatment, with 80% of sites showing favorable responses to phosphorus fertilization. The study established a critical phosphorus concentration (Pc) of 12.0 ppm and an average phosphorus requirement factor (Pf) of 5.8, indicating that phosphorus fertilizer recommendations should be calibrated to local soil test P levels. Results were consistent across seven treatments with replication across 10 sites (10/year). Phosphorus fertilizer calibration using locally derived Pc and Pf effectively enhanced bread wheat yield in the study area by identifying phosphorus management parameters that maximize grain production under highland conditions. Implications: The calibrated phosphorus recommendation can support farmers and extension services in Gozamin District to apply phosphorus more efficiently, improving productivity and potential economic returns while reducing the risks of under- and over-application in highland wheat production systems.

Introduction

Land makes up only 29% of the Earth's surface, while water covers about 71%. In addition, only a limited portion of land is suitable for cultivation, and much of the available terrain is constrained by steep slopes, harsh desert conditions, and shallow or otherwise infertile soils. Only a small fraction of the Earth's soil contains sufficiently deep topsoil to sustain agricultural production at a level that can support humanity [1]. This scarcity of arable land directly affects population density and food security, making sustainable land and nutrient management essential for feeding a growing population.

Soil fertility and productivity vary widely across regions, and these differences strongly influence crop yields. While some soils support abundant vegetation, others are nearly barren. According to FAO [2], only a small fraction of global soils exhibits exceptionally high fertility. Agricultural productivity is therefore shaped by multiple factors including profitability, cropping systems, sustainability, and the effective use of organic matter and essential nutrients [3]. However, low productivity in many farming systems is often linked to inadequate management practices and a lack of site-specific strategies. In particular, fertilizer management must be

guided by soil and crop response principles so that the right type of nutrient is applied at the correct rate, timing, and placement. Effective fertilizer use is therefore essential for optimizing agricultural outputs while limiting environmental harm [3].

Triticum aestivum L. (bread wheat) is one of the most important cereal crops in Ethiopia and a staple food source. Ethiopia produces wheat yields averaging about 3.0 t/ha, which is lower than the global average of 4.4 t/ha [4]. Although fertilizer use has increased substantially since the 1980s, wheat yields in Ethiopia remain variable, reflecting differences in management and the availability of nutrients required for high productivity [5]. High-yielding wheat varieties require adequate mineral nutrient inputs, and maintaining nutrient balance is critical because deficiencies or toxicities can restrict nutrient uptake and limit plant growth. Moreover, soils buffering capacity and local soil conditions influence how nutrients behave and how plants access them [4-7].

Deep, well-drained soils with slightly acidic pH (approximately 6.0–7.0) and adequate organic matter are generally favorable for bread wheat. Productive soils are also characterized by active microbial communities and balanced nutrient availability, particularly

nitrogen (N), phosphorus (P), and potassium (K), among other essential factors [4, 7]

In Ethiopia's highlands, the EARO soil test crop response approach and FAO calibration criteria indicate that phosphorus (P) and nitrogen (N) are among the main nutrient limitations affecting wheat productivity. However, the effectiveness of phosphorus management depends strongly on site-specific soil conditions. Phosphorus availability is influenced by soil pH, where higher pH can promote phosphorus binding to calcium, while lower pH can increase binding to aluminum. In addition, organic matter can reduce phosphorus adsorption by limiting the crystallization of iron and aluminum oxides. Furthermore, nitrogen dynamics affect the rhizosphere environment; uptake of ammonium nitrogen tends to acidify the root zone and can improve phosphorus availability while slowing fixation processes [6]

Despite the recognized importance of phosphorus management, in the Gozamin district there are few or no local studies that calibrate phosphorus fertilizer recommendations for wheat productivity using soil-test crop response approaches. This gap limits the availability of site-specific guidance for determining appropriate phosphorus rates based on soil-test

results. Consequently, farmers may apply phosphorus inefficiently, leading to suboptimal wheat yields and inefficient fertilizer utilization. In turn, these outcomes can contribute to declining soil fertility and weaken long-term agricultural sustainability in the region. Therefore, this study aims to calibrate phosphorus fertilizer recommendations for bread wheat in the highlands of Gozamin district using soil-test crop response principles. It is expected that the resulting site-specific calibration guidelines will support improved wheat yield and more efficient phosphorus use, while contributing to regionally sustainable soil fertility management.

2. Materials and methods

2.1 Experimental Design

A field experiment was conducted in the highland farms of Gozamin District using a randomized complete block design with three replications [8]

2.2 Overview of the Research Area

During the 2018–19 and 2019–20 cropping seasons, the study was carried out in Northwestern Ethiopia's Gozamin district (see figure 1). According to [9], the study area lies between latitudes 10°1'46" and 10°35'12" N and longitudes 37°23'45" and 37°55'52".

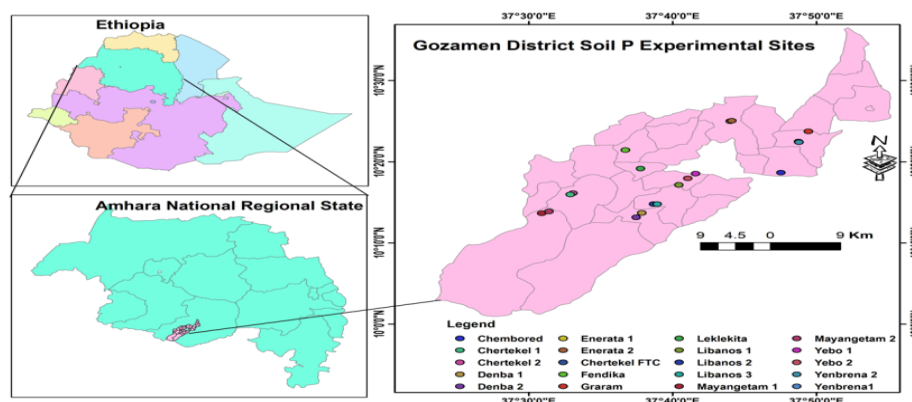


Figure1. Map of the study area

Gozamin district experiences a single growing season with monomodal rainfall, typically occurring from March to November. The average growing season lasts about 180 days, starting in July and extending to December. Temperatures in the district range from a minimum of 11.04°C to a maximum of 25°C, and the district receives between 1448 and 1888 mm of rainfall annually [10]. The district's topography ranges from 900 to 2640 meters above sea level, with a comparatively flat terrain that includes wetland plains and floodplains. The soil types are classified by the FAO as follows: 75% are Eutric Nitisols, 14% are Dystric Nitisols, and 11% are Rendzinas. Despite being typically productive, nitisols frequently have inadequate amounts of phosphorus accessible. According to [11], these are deep, red, well-drained tropical soils with desirable characteristics, such as 40–60% porosity and a

good response to both organic and mineral fertilizers.

2.3 Agronomic Management Practices

Wheat (*Triticum* spp.) is a crucial cool-weather crop in the Ethiopian highlands, thriving at altitudes between 1000 and 2300 meters. In Gozamin, wheat occupies approximately 2.1 million hectares, providing flour for staple foods such as bread and 'injera'. Wheat production relies heavily on inorganic fertilizers and herbicides [12]. The crop grows best in fertile, well-drained soils with high organic carbon content (300-600 t/ha) and adequate levels of nitrogen (N) and phosphorus (P). Initial land preparation depends on sufficient moisture, with farmers utilizing oxen for tillage. Early preparation is critical for weed control and environment+

2.3.1 Planting Time and Methods

Bread wheat is typically planted in the first two weeks of July. Farmers prefer row

planting, which improves input use efficiency, facilitates weed management, and aids in harvesting.

2.3.2 Control of Weeds and Pests

In regions where wheat is produced, weeds are common, especially broadleaf types. Herbicides (such as 2,4-D) and hand weeding are the main methods used by farmers for control. Farmers claim that there are few ways to prevent yellow rust, the primary disease that affects wheat [13]

2.3 Analysis and Sampling of Soils

Table1. Some Physical and Chemical properties of surface soil samples collected from experimental sites on farmers' fields in Gozamin district

pH	Clay (%)	Sand (%)	Silt (%)	SOC (%)	Total N(%)	C:N	P(ppm)	K(ppm)	CEC (meq/kg)	EC (ds/m)
4.8	30	10	6	1.5	0.06	2.5	2	176	24.4	0.03
5.8	58	36	60	2.6	0.1	22	36	437	34.4	0.06

CEC: Cation exchange capacity, EC: Electrical conductivity

The physical and chemical properties of surface soil samples taken from test locations in the Gozamin district are shown in Table 1. Important characteristics include soil organic carbon (SOC) content, which indicates fertility; total nitrogen (N) content; the carbon to nitrogen (C:N) ratio; levels of available phosphorus (P) and potassium (K); pH, which indicates soil acidity; and percentages of clay,

In cooperation with the district's Office of Agriculture, soil sampling locations were chosen to provide uniform geomorphology and ideal growing conditions for wheat. Before planting, composite soil samples were taken with an Edelman Auger to a depth of 20 cm. Three weeks later, more samples were taken for phosphorus measurement. Using standardized techniques, 420 soil samples were gathered and examined for pH, organic carbon content, total nitrogen, texture, and accessible phosphorus.

sand, and silt, which characterize soil texture. Electrical conductivity (EC) gauges salinity, whereas cation exchange capacity (CEC) shows how well the soil holds onto nutrients. Together, these characteristics help determine if the soil is suitable for growing wheat and offer information about its requirements for managing nutrients and fertility.

2.4 Experimental Procedure

In addition to a uniform nitrogen application of 138 kg ha^{-1} , the experiment was planned using a randomized full block design with three replications and seven doses of phosphorus fertilizer (0, 10, 20, 30, 40, 50, and 60) kg ha^{-1} . With a net harvested area of $3 \text{ m} \times 3 \text{ m}$, each gross plot had dimensions of $5 \text{ m} \times 4 \text{ m}$. In order to provide the necessary phosphorus calibration recommendations, the study sought to identify connections between soil phosphorus levels and wheat grain output. The several nutritional treatments used in the experiment are described in Table 2, with an

emphasis on combinations of nitrogen (N), phosphorus (P), and potassium (K). While nitrogen is always fixed at 138 kg/ha throughout all treatments (except from the control), each treatment is distinguished by distinct kg/ha rates of P. The various phosphorus levels being examined to determine their effect on wheat growth and yield are depicted in the table. Establishing efficient fertilization plans suited to regional soil conditions requires an understanding of these combinations.

Table3.Description of treatments in the field

Treatment in block one			Treatment in block two		Treatment in block three	
No	Plot No.	Treatment No.	Plot No.	Treatment No.	Plot No.	Treatment No.
1	101	T_3	201	T_6	301	T_2
2	102	T_5	202	T_2	302	T_7
3	103	T_2	203	T_4	303	T_1
4	104	T_7	204	T_1	304	T_6
5	105	T_1	205	T_7	305	T_5
6	106	T_4	206	T_5	306	T_3
7	107	T_6	207	T_3	307	T_4

Table 3 details the allocation of different nutrient treatments across three experimental blocks, highlighting the randomization of treatments to ensure statistical reliability.

Each plot number corresponds to a specific treatment, allowing for a clear understanding of how each nutrient combination is distributed throughout the study area. This

design is essential for assessing the effects of varying phosphorus applications on wheat yield while controlling for environmental variability across the experimental blocks.

These summaries provide a concise explanation of the tables, emphasizing their relevance to your research objectives and the insights they offer into soil properties and treatment effects.

2.5 Analysis of Statistics

Using SPSS software version 24, an analysis of variance was performed on the bread wheat grain yield data collection. The least significant difference (LSD) level probability was used to identify significant changes between treatments. Multiple comparisons

within the treatments for the years 2018/19 and 2019/20, as well as tests between subject effects and treatments, were determined to be significant. The following process was then used to make the interpretation.

3.0. Results and Discussion

3.1. Treatment Combinations and Yield Data

Table 4 presents the treatments applied, detailing nitrogen, phosphorus, and potassium combinations. The treatments ranged from zero phosphorus (T-1) to 60 kg P/ha (T-7) with a constant nitrogen application of 138 kg/ha. The yield data for bread wheat across different treatments are summarized as follow (see Table 4).

Table4. Experimental results of the grain yield of bread wheat

Treatment No.	Frequency (Hz)	Mean mini.grain yield/9m ² (Kg)	Mean max.grain yield/9m ² (Kg)	Mean grain yield /9m ² (kg)	Mean grain yield/ ha (kg)
T-1	60	0.90	2.8	0.862	958
T_2	60	1.2	5.3	3.1	3439.9
T_3	60	1.7	6.0	3.4	3817.3
T_4	60	1.5	5.8	3.5	3847.2
T_5	60	1.6	5.7	3.6	3980.2
T_6	60	2.2	5.8	3.7	4075.0
T_7	60	2.3	5.7	3.8	4239.4

The results indicate a significant increase in wheat grain yield with higher phosphorus

applications. For instance, the yield of T-1 (control) was significantly lower than T-7,

which achieved the highest yield of 4239.4 kg/ha. This trend highlights the importance of phosphorus in enhancing wheat productivity.

3.2 Factor of Phosphorus

Requirement (Pf)

It was determined that the phosphorus requirement factor (Pf) was 6.0. This component shows how much phosphorus is required to increase soil phosphorus levels by 1 mg/kg. For instance, soil phosphorus increased by 3.8 ppm for treatment T-3 (20 kg P/ha) compared to the control. The available P

levels in samples taken from fertilized and unfertilized plots 21 days following the sowing date were used to calculate the value of the P requirement factor (Pf) [14]. Therefore, the following formula can be used to determine the amount of phosphorus fertilizer needed to attain the best yield:

$$P_a = (P_c - P_i) \times P_f \dots \dots \dots (1)$$

Where, Pf is the P-requirement factor, Pi is the site's initial P value, and Pc is the critical P concentration.

Table 5: Calculated phosphorus demand factor based on soil test results from various fertilizers
Rate treatments

Treatment No.	Fertilizer treatment (kg/ha)	P-Olsen method (ppm)		Increment/ Needed (kg/ha)	Pf requirement factor
		Range	Average (kg/ha)		
T_1	0	2.3-36	8.9	-	0
T_2	10	3.5-36	10.5	1.6	6.3
T_3	20	4.7-38	12.7	3.8	5.3
T_4	30	5.1-38	14.3	5.4	5.6
T_5	40	5.2-38	15.7	6.8	5.9
T_6	50	5.5-38	16.9	8.0	6.3
T_7	60	5-38	18.1	9.2	6.5

$$P_f (\text{P requirement Factor}) = 5.8$$

This calculation underscores the necessity of precise phosphorus management in achieving sustainable wheat production.

3.3. Determination of critical P concentrations

Relative Yield % = $\text{Yield} / \text{Maximum Yield} \times 100 \dots (2)$

The results clearly demonstrate that phosphorus application significantly enhances wheat yield using Equation 2. The establishment of critical phosphorus

concentrations and the phosphorus requirement factor provides valuable guidelines for optimizing fertilizer use in the region. These findings are crucial for improving agricultural practices and ensuring food security in the Gozamin district.

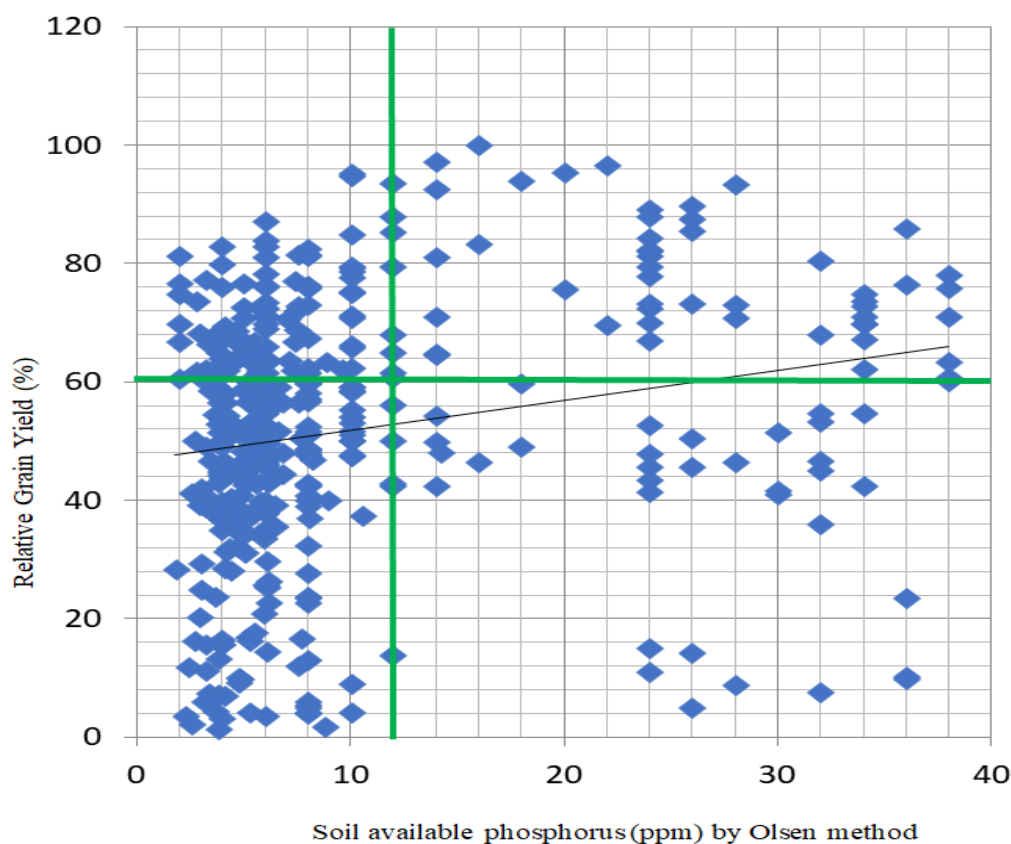


Figure 2: Relationships between the relative grain yields of bread wheat as determined by the Cate-Nelson graphical approach, which sets a critical limit of 12 P mg/kg, and soil extractable P as determined by the Olsen method

The authors may see how these two factors are related by using a scatter diagram that plots relative yield (Y-axis) against soil test phosphorus values (X-axis). Following phosphorus treatment, each point on the graph reflects the relative yield (see Equation 2) of

bread wheat corresponding to a particular soil phosphorus level.

Each plotted point represents a distinct treatment and shows how wheat yields in response to different soil phosphorus levels (see Figure 2). It is anticipated that the scatter

diagram's overall trend will demonstrate that wheat yields rise in tandem with soil phosphorus levels illustrates how phosphorus enhances wheat production and growth[15] .

3.4 Critical Phosphorus Concentration

According to Figure 2, critical phosphorus concentration (Pc) was determined to be 12.0 mg/kg. This value was obtained using the Cate–Nelson graphical method, where relative yield is plotted against soil test phosphorus [15,16]. In the graphical analysis, the vertical line crossing the X-axis represents the Pc,

indicating the lowest soil test phosphorus level required to achieve the best possible wheat production.

Interpretation of the Pc is important for answering the study research questions because it provides a practical threshold for phosphorus management in wheat production. This finding is consistent with the interpretation approach used in previous studies and supports the idea that identifying critical nutrient levels can improve crop yield outcomes [17, 18] .

3.5 Comparison with Existing Literature

Table6. Comparison of the values of the phosphorus critical value (ppm), phosphorus Requirement grain production (kg/ha) for different districts across the nation factor, and in the literature currently in publication

Districts in Ethiopia	Crop	Phosphours Critical value in (pmm)	Phosphorus requirement factor	Grain yield in (kg/ha)	References
Degem	wheat	22	6.0	3342.3	[19]
Sinana	wheat	5.2	22	4409.0	[20]
Jamma	wheat	11	13.4	3122.2	[18]
Lume	wheat	19	4.5	4205.4	[21]
Dugda	wheat	10	6.5	3998.0	[17]
Shashemene	wheat	21	4.4	5358.0	[22]
Gozamin	wheat	12	6.0	4239.4	This study

4. Discussions

This study's main goal was to assess how different phosphorus treatments affected the output of bread wheat in Northwestern

Ethiopia's Gozamin district. Our results show that phosphorus levels and wheat production are significantly positively correlated, with the greatest yield of 4239.4 kg/ha occurring at 60

kg P/ha (T-7). [16-18] Local farmers see the 12.0 mg/kg critical phosphorus content as a crucial benchmark [17]; The literature that already exists emphasizes the critical role that phosphorus plays in promoting plant growth and development [20-22] and [17,18].

In order to maximize yields and guarantee sustainable production methods, farmers should keep soil phosphorus at or above this level. A useful tool for farmers to modify their fertilizer applications based on soil tests is the phosphorus demand factor of 5.8, which also specifies the amount of phosphorus required to elevate soil levels by 1 mg/kg [19] and [17]. These results are in line with past studies that demonstrate the critical role precise nutrient management plays in crop productivity [6] . However, this study also emphasizes the unique soil characteristics of the Gozamin district, suggesting that particular recommendations are needed for local farming practices [14] . Discussing the results requires interpreting the data, relating it to the study's goals, and comparing it to earlier studies [4]. Variability in weather and insect pressures are two limitations of this study that could affect yield results. Future studies should concentrate on the relationships between phosphorus and other nutrients in this particular agroecological setting as well as

long-term phosphorus management techniques. This study promotes sustainable farming methods that can improve regional food security by offering insightful information on managing phosphorus for wheat production.

5. Conclusion and Recommendation

This study investigated the effects of varying phosphorus (P) applications on bread wheat (*Triticum* spp.) yield in the Gozamin district of Northwestern Ethiopia during the 2018/19 and 2019/20 cropping seasons. The research aimed to determine the optimal phosphorus levels required to enhance wheat productivity while establishing critical phosphorus concentrations for effective soil management. With a constant nitrogen application of 138 kg/ha, seven treatments were assessed, ranging from 0 kg P/ha (control) to 60 kg P/ha. Higher phosphorus applications were shown to significantly boost wheat yield; the maximum yield was recorded at 60 kg P/ha (4239.4 kg/ha). Based on soil testing, the critical phosphorus concentration (P_c) was found to be 12.0 mg/kg, giving farmers a baseline to maximize phosphorus application. The quantity of phosphorus required to increase soil phosphorus levels by 1 mg/kg was determined to be 5.8 or the phosphorus demand factor. This element can help farmers

successfully modify the amount of fertilizer they apply.

The results highlight how crucial phosphorus management is to raising wheat yields in the district of Gozamin. Farmers can enhance their fertilizer management techniques and boost wheat farming's sustainability and production by using the phosphorus demand factor and the defined critical phosphorus levels. It is advised that more research be done to examine the long-term effects of phosphorus treatment on crop yield and soil health, as well as the relationships between phosphorus and other vital nutrients.

The authors' contribution

WAL designed, executed, and completed the laboratory and statistical analyses, sampling,

and sample preparation in addition to creating the current edition of the publication. SGA supervised the entire process, revised the text, made important changes, and took part in the experimental setup. The current edition of the paper was written, edited, and organized by YHA. The final text was reviewed and approved by all authors.

Data Availability

The data used for this study are available on request from the corresponding author.

Funding: Not applicable.

Conflicts of Interest: The author reports no conflicts of interest with regard to the publication of this work.

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