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RESEARCH ARTICLE

Black bean (*Phaseolus vulgaris* L.) production in response to phosphorus sources and doses applied to soil

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Abstract

Black bean (*Phaseolus vulgaris* L.) is a crop of significant economic and nutritional value for local producers. This study aimed to assess the effect of 3 phosphate fertilizer sources, applied at different phosphorus levels, on growth and yield of black bean. The experiment was conducted from May to August 2023 in the district of Loreto, Paraguay. The experimental design used was a Randomized Complete Block Design (RCBD) arranged in a factorial design (3 × 4). Factor A consisted of phosphorus sources: triple superphosphate, single superphosphate and diammonium phosphate. Factor B included levels of phosphorus (0, 30, 60 and 90 kg P_2O_5 ha^{-1}). Each treatment had 3 replications. The variables evaluated were plant height at 30 and 90 days after emergence (DAE), number of pods per plant, number of grains per pod, 1000-grain weight and yield. The data obtained were subjected to a normality test and subsequently to analysis of variance using Fisher's test. When significant effects were detected for phosphorus source, means were compared using Tukey's test at a 5 % significance level. Regression analysis was performed to calculate the optimum level of phosphorus. The results showed that triple superphosphate produced the highest yield (895.83 kg ha^{-1}), significantly outperforming other sources. In addition, increasing P_2O_5 doses (60 kg P_2O_5 ha^{-1}) had a positive effect on plant height and yield components.

Keywords: black bean; mineral nutrient; P_2O_5 rates; vegetative growth; yield

Introduction

Black bean (*Phaseolus vulgaris* L.) is a crop of nutritional significance worldwide (1), particularly in tropical and subtropical regions (2). It is a staple food in many diets due to its high content of proteins, carbohydrates and essential minerals (3, 4), with special relevance to American and developing countries (5). However, black bean productivity is often constrained by several factors (6), mainly poor soil management practices that contribute to accelerated erosion, enormous nutrient loss in sandy soils thereby reducing nutrient availability (7).

Among essential nutrients, phosphorus plays a key role in plant development, participating in critical physiological processes such as root growth, flowering and pod formation which directly affect yield (8). Legumes generally required higher phosphorus demand than cereals (9). Nevertheless, the low mobility and limited availability of phosphorus in many agricultural soils hinder its efficient uptake (10). Phosphorus availability is influenced by fixation and adsorption processes that depend on the mineralogy and chemical characteristics of the soil. In acidic soils (pH < 5.5), phosphorus tends to precipitate with iron ions, whereas in alkaline conditions (pH > 7), forms insoluble complexes with calcium (11).

The response of phosphorus on the crop is not merely determined by the availability of nutrient in the soil but also by fixation and mobility processes, as well as fertilization management practices, which are critical for plant uptake (12). Therefore, selecting the appropriate phosphorus fertilizer source, with distinct chemical properties that affect nutrient release and applying at optimal doses are crucial strategies to improve phosphorus use efficiency and enhance productivity (13). This study aimed to assess the effect of 3 phosphate fertilizer sources, applied at different phosphorus levels, on growth and yield of black bean.

Materials and Methods

The study was conducted between May and August 2023 in the Loreto district, Paraguay. The experimental site is situated at 23°22′ 03.0'' S latitude and 57°24′ 05.1'' W longitude. In general, is bestowed with hot summers and cold winters. The mean annual rainfall of the location varies from 1300 mm. The meteorological data recorded for temperature and rainfall parameters for the entire crop growing period have been presented graphically in Fig. 1 (14).

The soil of the experimental site was classified as belonging to the order Alfisol and subgroup Mollic Paleudalf (15). Soil chemical properties were analyzed from samples collected at a depth of 0-20cm and processed according to the standard methodology (16). The results were as follows: available P (Mehlich^{-1}): 8.10 mg dm^{-3}; organic matter: 8.52 g dm^{-3}; pH ($CaCl_2$): 4.88; K: 0.16 cmol dm^{-3}; Ca:

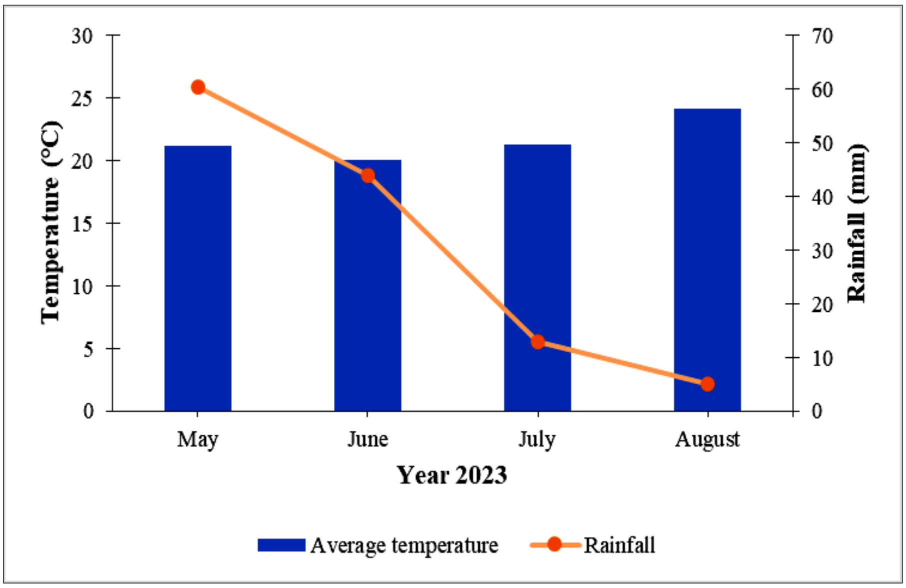

Fig. 1. Average temperature and rainfall data during the experiment.

4.78 cmol dm^{-3}; Mg: 0.97 cmol dm^{-3}; H-Al: 2.36 cmol dm^{-3}; base sum: 5.91 cmol dm^{-3}; cation exchange capacity: 5.93 cmol dm^{-3}; and base saturation: 71.53 %. The experimental field was acidic in reaction, low in organic carbon, available phosphorus, potassium and magnesium.

The experimental design was a randomized complete block design (RCBD) arranged in a factorial design (3 × 4). The experiment consisted of 3 phosphorus sources as factor A and 4 levels of phosphorus as factor B (Table 1). Each treatment had 3 replications. Each experimental unit (EU) measured 20 m^2 (5 m length by 4 m width) totalling 36 experimental units.

The black bean crop was sown at a spacing of 50 cm × 20 cm. Thinning was performed 15 days after emergence (DAE). Whole quantity of nitrogen (50kgha^{-1}) and potassium (100kgha^{-1}) was applied as basal dose at the time of sowing. However, phosphorus was also applied at the time of sowing as per treatment of the experiment. The nutrients were supplied in form of urea and muriate of potash.

Table 1. Description of the formulated treatments

Factor A (Phosphorus sources)	Factor B (Levels of phosphorus)	Combination
Triple superphosphate (TSP)	0 kg ha^{-1} P_2O_5	TSP + 0 kg ha^{-1} P_2O_5
	30 kg ha^{-1} P_2O_5	TSP + 30 kg ha^{-1} P_2O_5
	*60 kg ha^{-1} P_2O_5	TSP + 60 kg ha^{-1} P_2O_5
	90 kg ha^{-1} P_2O_5	TSP + 90 kg ha^{-1} P_2O_5
Single superphosphate (SSP)	0 kg ha^{-1} P_2O_5	SSP + 0 kg ha^{-1} P_2O_5
	30 kg ha^{-1} P_2O_5	SSP + 30 kg ha^{-1} P_2O_5
	60 kg ha^{-1} P_2O_5	SSP + 60 kg ha^{-1} P_2O_5
	90 kg ha^{-1} P_2O_5	SSP + 90 kg ha^{-1} P_2O_5
Diammonium phosphate (DAP)	0 kg ha^{-1} P_2O_5	DAP + 0 kg ha^{-1} P_2O_5
	30 kg ha^{-1} P_2O_5	DAP + 30 kg ha^{-1} P_2O_5
	60 kg ha^{-1} P_2O_5	DAP + 60 kg ha^{-1} P_2O_5
	90 kg ha^{-1} P_2O_5	DAP + 90 kg ha^{-1} P_2O_5

The dose of 60 kg ha^{-1} of P_2O_5 was determined based on soil analysis and the recommendation of Cubilla et al. (34), while the doses of 30 and 90 kg ha^{-1} of P_2O_5 corresponded to 50 % below and above the recommended rate respectively.

Manual weeding was done to keep the plant free from weeds. Pest control included 2 applications of insecticides: cypermethrin (2.5 mLL^{-1} water) and abamectin (1 mLL^{-1} water) were sprayed at 15 and 30 DAE for the control of pest. Fungicide is used to treat the seeds to prevent soil borne disease. Black bean seeds were treated with 4 g kg^{1} of seed to protect the seeds from seed borne disease.

Data pertaining to plant height, yield attributes and yield were obtained at harvest. A sampling area of 12 m^2 containing 120 plants was marked out to evaluate each experimental unit. For plant height and number of pods plant^{1}, 10 plants were selected randomly and tagged in each plot. However, data with respect to number of grains pod^{-1}, 30 number of pods were taken and manually counting number of grains. The recorded data were averaged to determine the mean value. 1000-grains were randomly taken from the bulk produce of each plot were counted and weighed. The weight was expressed as 1000-grain weight in grams. The threshed grains of black bean obtained from each net plot were sun dried to obtained 14 % moisture and weighed separately and finally converted into kg ha^{-1}. The target moisture content was determined using the following formula (17).

$$FSW = \frac{ISW \times (100 - IMC)}{(100 - FMC)}$$

Where FSW: Final Seed Weight; ISW: Initial Seed Weight; IMC: Initial Moisture Content and FMC: Final Moisture Content.

The data obtained were subjected to a normality test and subsequently to analysis of variance using Fisher's test with the Agroestat® statistical software, version 1.1.0.712 rev 77 (18). When significant differences were found for phosphorus source, Tukey's test (5 % significance) was applied. Regression analysis was performed to calculate the optimum level of phosphorus. The maximum fertilizer dosage was calculated using the formula

$$X_{max} = -b/2a.$$

The point of maximum productivity was calculated using the formula

$$Y_{max} = D/(4a),$$

Where $D = b2 - 4ac$.

Results and Discussion

The analysis of the data obtained for variables plant height evaluated at 30 and 90 DAE, number of pods per plant, number of grains per pod and 1000-grain weight did not show significant effects. However, in yield, significant differences attributed to phosphorus sources were observed, increasing levels of phosphorus recorded significant effect in plant height, number of pods $plant^{-1}$ and number of grains pod^{-1}. The interaction between sources and levels of phosphorus was found to be insignificant (Table 2).

Data presented in Table 3 revealed that among the sources of phosphorus, non-significant results were obtained with respect to plant height and yield attributes. This might have attributed to the homogeneity in nutrient availability which led to non-significant increase in plant height and yield attributes (19). This behaviour could be due to the nature of the soil which influenced P fixation and other biochemical reactions that affect its availability for the crop (20).

However, increased levels of phosphorus resulted in significant increase in plant height, yield attributes and yield. At 30 DAE, an optimal dose of 63.00 kg ha^{-1} of P_2O_5resulted in significant increase in plant to tune of 16.26 cm. In the case of plant height at 90 DAE, significantly higher plant height (46.19 cm) was obtained with 68.62 kg ha^{-1} of P_2O_5 (Fig. 2). Experimental findings clearly indicated the essential role of phosphorus in promoting plant development. Whereas deficiency of phosphorus in control treatment led to a significant reduction in growth parameters. Similar findings were also reported that lack of phosphorus resulted in shallow roots and lower vegetative growth (21). In contrast, a previous study found that high phosphorus availability resulted in higher plant height of leguminous plants (22).

The regression analysis of the number of pods per plant at different P_2O_5 levels (Fig. 3A) showed a fit to a second-degree polynomial model. According to equation, a maximum number of 30.93 pods per plant was obtained with an estimated optimal dose of 48.75 kg ha^{-1} of P_2O_5. This might have happened due to phosphatic

Table 2. Statistical probability (F) of detecting differences between P_2O_5 source and dose treatments in beans for different variables

Variable	PH (30 DAE)	PH (90 DAE)	NPP	NGP	1000-GW	Yield
			Sources of phosphorus (S)			
F Test	1.12ns	0.99ns	1.85ns	0.96ns	0.06ns	7.49**
			Levels of phosphorus (L)			
F Regr. L[a]	11.66**	20.67**	0.90ns	4.72*	0.86ns	8,24**
F Regr. Q[b]	10.03**	7.39**	15.97**	9.81**	1.71ns	11.86**
			Interaction (SxL)			
SxL	0.50ns	0.31ns	0.71ns	0.29ns	0.30ns	2.53ns

ns: not significant; (*) (**) significant at 5 and 1 % probability. [a]Linear regression; [b]Quadratic regression. PH: plant height; NPP: number of pods per plant; NGP: number of grains per pod; 1000-GW: 1000-grain weight; SxL: Sources of phosphorus × Levels of phosphorus.

Table 3. Effect of P_2O_5 source on plant height (PH) at 30 and 90 DAE, number of pods per plant (NPP), number of grains per pod (NGP), 1000-grain weight (1000-GW), yield (Yield)

Factor	PH (30 DDE)	PH (90 DDE)	NPP	NGP	1000-GW	Yield
			Sources of phosphorus			
Triple Superphosphate	15.75	43.96	28.10	5.38	257.5	895.83[a]±75.67
Single superphosphate	15.28	42.11	24.61	5.20	255.0	696.66[b]±36.38
Diammonium phosphate	15.32	43.76	27.71	5.33	255.2	757.50[b]±49.04
LSD (5%)	0.86	3.62	4.98	0.34	20.8	132.48
CV %	5.46	8.16	18.13	6.31	7.92	16.49

Means with different letters indicate significant differences between sources by Tukey's test at 5% probability. LSD: least significant difference; CV: coefficient of variation. ± corresponds to the standard error.

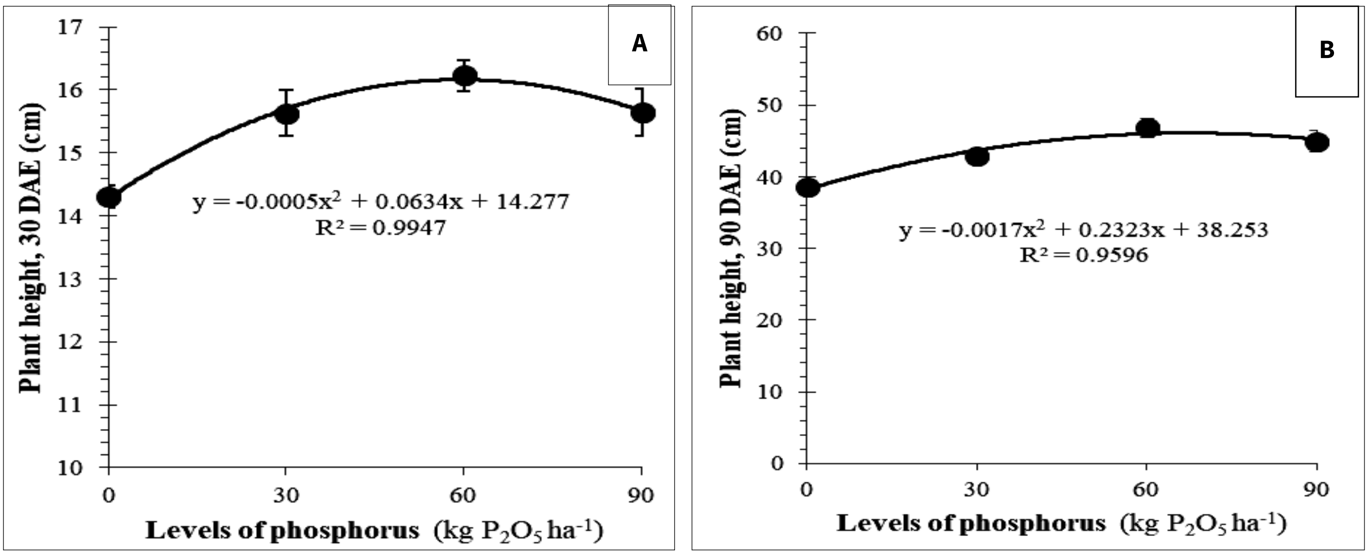

Fig. 2. Regression analysis between levels of phosphorus and plant height at 30 DAE (A), 90 DAE (B). Vertical bars represent the standard error.

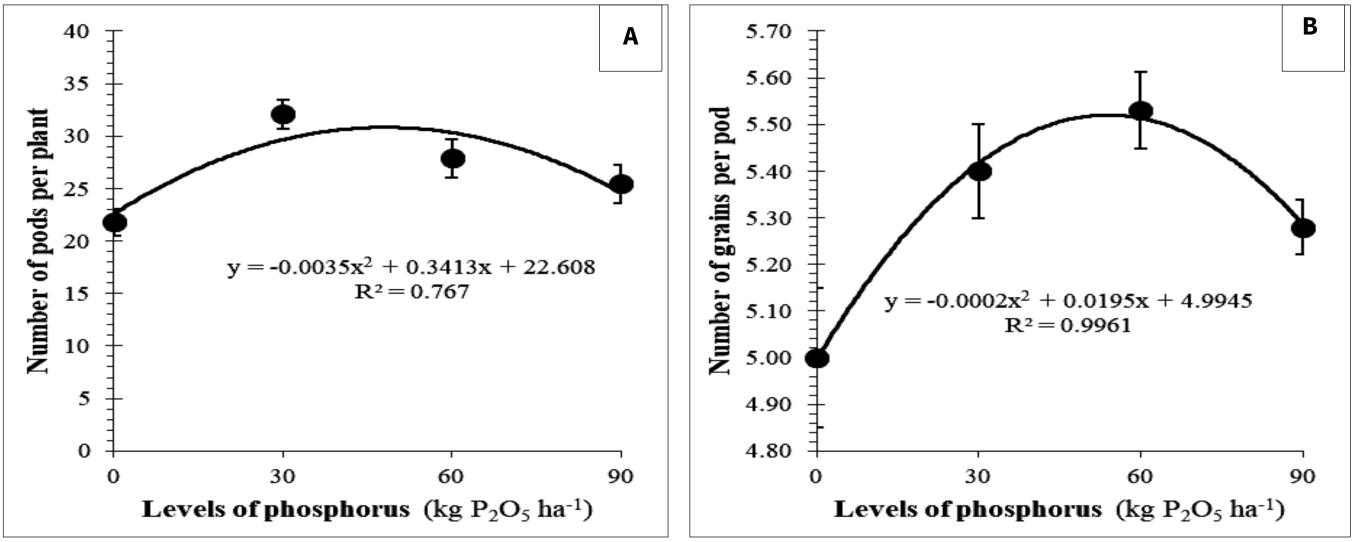

Fig. 3. Regression analysis between levels of phosphorus and number of pods per plant (A), number of grains per pod (B). Vertical bars represent the standard error.

fertilizers improves physiological expression of the plant and consequently, led to significant increase in the number of pods per plant (23). This aligns with earlier report (24) recorded an average of 38.13 pods per plant due to phosphorus applied to black bean crop, which aligns with the previous findings (25), it observed a significant increase in pods per plant as, compared to the unfertilized plot. Similarly, a significant difference in the number of pods per plant obtained at increased levels of phosphorus have been emphasized in earlier study (26).

In Fig. 3B, the regression analysis of the number of grains per pod as a function of P_2O_5 levels presented, which fit a quadratic equation. According to the obtained equation, a maximum point of 5.47 grains per pod obtained with the application of 48.75 kg ha^{-1} of P_2O_5. These findings coincide with the earlier research (26), recorded significant increases in the number of grains per pod.

On the other hand, insignificant results were obtained with increased levels of phosphorus for 1000-grain weight. Experimental findings with respect to 1000-grain weight clearly indicated that increased levels of phosphorus sufficient to meet the crop's needs and that this variable is more influenced by genetic factors than by the availability of this nutrient in the soil (27). Similar to previous findings (28), we observed no P_2O_5 dose effect on 1000-grain weight. In contrast, an earlier study (29) reported that 1000-grain weight increase could be due to a greater availability of phosphorus, which leads to better translocation of photosynthesis products to storage organs, consequently improved yield attributes (30).

Data presented in Table 2 revealed that Triple Superphosphate resulted in increases 22.23 % and 15.4 % in grain yield as to Single Superphosphate and Diammonium Phosphate, respectively. This aligns with earlier report (31), which attributed TSP's superiority to its higher water solubility (93 %) compared to SSP (84 %), promoting early root uptake. However, among phosphorus levels, the regression analysis performed on yield values (Fig. 4B) and fitted to quadratic equation. The estimated maximum yield was 915.98 kg ha^{-1}, achieved with an optimal dose of 56.16 kg ha^{-1} of P_2O_5. Further yield showed tendency to decrease with the application of higher doses possibly due to soil saturation, lower efficiency in nutrient absorption or negative interactions in crop management practices (10). These results agree with findings that application of phosphorus in bean productivity, achieved significant increase in yield by optimizing the phosphorus dose (32). Similarly, other reports that highlighted the increased levels of phosphorus resulted an increase in the yield (24, 33).

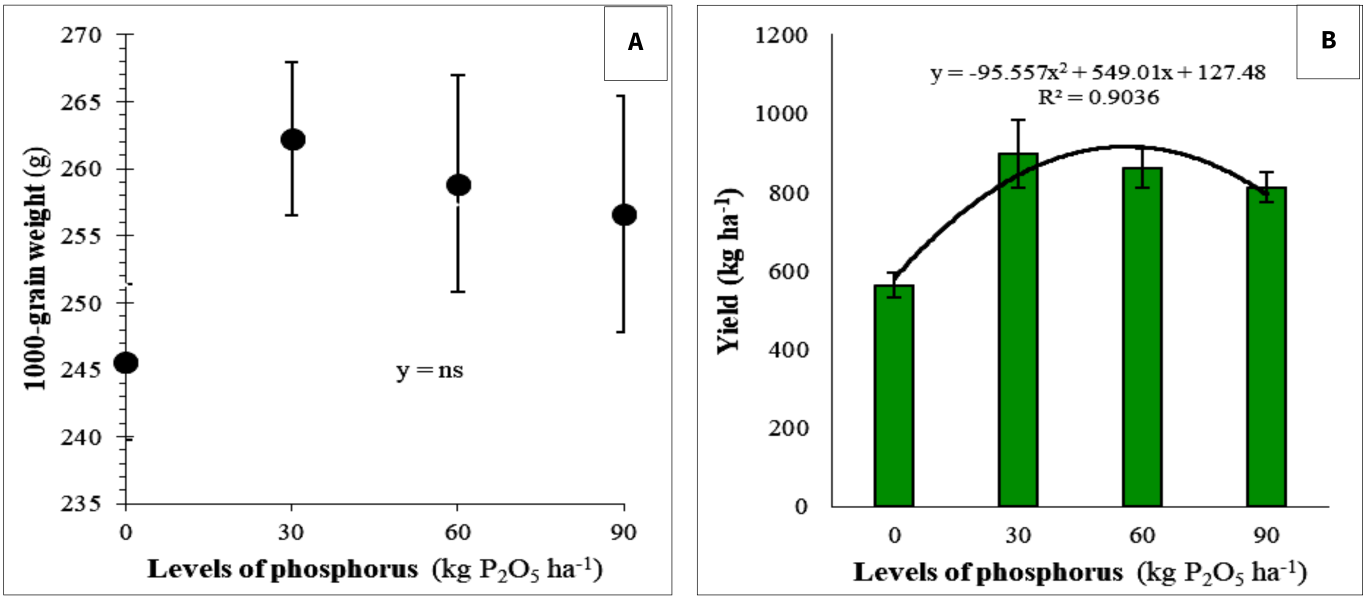

Fig. 4. Regression analysis between levels of phosphorus and 1000-grain weight (A), yield (B). Vertical bars represent the standard error.

Conclusion

The application of triple superphosphate significantly increased black bean (*Phaseolus vulgaris* L.) yields by 22.2 % compared to single superphosphate, with an optimal dose of 56.16 kg P_2O_5 ha^{-1}. This balanced fertilization strategy represents a viable alternative to optimize black bean management.

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Authors' contributions

LMTC contributed for the conception, design of the work, conduction and data collection of the experiment. EML and DFLA contributed for the conception, design of the study, analysis, interpretation of data, manuscript writing, critical review of the manuscript and approval of its final version. WDLP, REP and CFO conceived of the study and participated in its design and coordination. FDVO participated in the design of the study and performed the statistical analysis. REP and CFO conceived of the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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