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ENHANCING PORK CASING YIELD WITH PHOSPHORIC ACID: A COST-REDUCTION APPROACH IN CALABRIAN SAUSAGE PRODUCTION

– Research paper –

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Abstract: Sausages, one of the oldest forms of meat processing, rely heavily on the quality of casings to achieve desired texture, appearance, and stuffing efficiency. This study aimed to improve the hydration process of natural pork casings for Calabrian sausage production by employing phosphoric acid as a substitute for trisodium phosphate dodecahydrate. Key quality control tools, including the Ishikawa diagram, 5W1H tool, and PDCA cycle, were utilized to identify and address production inefficiencies. The implemented modifications led to significant advancements: stuffing yield increased from 0.87 to 1.0 kg/m over seven months, surpassing the recommended standard of 0.91 kg/m, and casing consumption decreased by 10.39%. These improvements not only enhanced operational efficiency but also reduced casing costs by 10.37%. The findings confirm the viability of phosphoric acid as an effective, cost-efficient alternative in the hydration process, paving the way for improved sausage production standards.

Keywords: Natural casing; 5W1H; PDCA; stuffing yield.

INTRODUCTION

Sausages are among the oldest forms of meat processing, preserved by methods such as drying, salting, smoking, seasoning, and sometimes cooking (Lonergan et al., 2019). The variety of sausages results from small modifications in basic processes, including the type and quantity of meat, the size of the cut or the diameter of the holes in the grinding disc, the condiments used, the types of casing, the length of the segments, and the presence or absence of drying, smoking, etc. (Carballo, 2021).

Casings play a crucial role in sausage processing (Djordjevic et al., 2015). They are cylindrical coverings that allow the production and protection of certain raw, cooked, or matured sausages. Casings are classified into three types: natural casings, artificial casings, or bladders, which are used in the production of sausages, mortadella, and other sausage products (Suurs & Barbut, 2020). Natural casings are obtained from the intestines of sheep, pigs, and cattle.

The processing begins shortly after slaughter, where the fat and intestinal contents are removed. The intestines are then salted and cured for sale. In the industry, casings undergo washing to remove excess salt and are hydrated in water at room temperature or slightly heated. Hydration is essential for flexibility and ease of stuffing (Rebecchi et al., 2015). Artificial casings emerged at the end of the 19th century due to increased sausage production and the resulting shortage of natural casings. Today, collagen and plastic or nylon casings are increasingly popular. The national artificial casing sector has achieved high-quality standards (Yan et al., 2022).

Calabrian sausage is made exclusively from pork, cured with added ingredients, and must have the characteristic spicy flavor of Calabrian pepper. It may or may not undergo a stewing process or similar methods for dehydration and/or cooking, with smoking being optional (Brazil, 2000).

Casings for Calabrian sausage must be impermeable to water vapor, easy to handle with mechanical stuffing machines, and have an attractive appearance after filling without air pockets. They should also be cost-effective and consistently sized

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for uniform weight, shape, and size. To address these complexities, a scientific approach is essential to identify and optimize key parameters (Jakubowska, 2023). Natural casings often have issues with variability, elasticity, and tensile strength (Rust & Knipe, 2014). When using natural casings, precautions are necessary, such as removing excess salt with running water and hydrating the casings by soaking them in fresh water for an hour, ensuring to massage and separate them to prevent stains. During stuffing, the casings should be placed in heated water to facilitate shaping the sausage mixture inside. Collagen casings are ready for stuffing after a five-minute brine soak (Barbut et al., 2020).

Natural pork casings consist primarily of collagen, a structural protein responsible for strength and elasticity (Gunn et al., 2022). When treated with phosphoric acid at controlled concentrations, the acid partially hydrolyzes collagen fibrils, disrupting some intermolecular cross-links. This softens the casing, increasing its pliability and stretchability, which enhances stuffing capacity (Burke, 1976; Oechsle et al., 2014). Additionally, collagen modification improves fiber hydration, boosting elasticity and water-binding capacity. As a result, the casings maintain integrity under mechanical stress during sausage filling, reducing material waste and lowering casing consumption, contributing to cost reduction in large-scale production (Suurs & Barbut, 2020; Liu et al., 2023).

For quality control, various tools allow the evaluation and treatment of issues based on the company's needs, providing a basis for quality management decisions (Paiva, 2014). The 5W2H tool helps develop action plans by answering seven questions: What will be done? Why will it be done? Where will it be done? When? Who will do it? How will it be done? How much will it cost? This method eliminates doubts throughout a process or activity (Luo et al., 2024). The 5W1H tool has the same concept, but the cost is removed from the analysis (Su, 2014). The PDCA cycle - Plan, Do, Check, Act - is a continuous improvement system aiding in strategic planning and problem-solving within companies. It helps define goals, execute actions, check the efficiency of activities, and correct deviations to align with new standards (Pietrzak & Paliszkiewicz, 2015). Brainstorming generates numerous ideas quickly and is useful during problem investigation (Monica, 2017). The Ishikawa diagram, or fishbone diagram, effectively identifies root causes of problems by categorizing and relating different causes under six groups: machine, labor, method, maintenance, material, and environment. The problem is placed on the right side, with major contributing causes listed on the left (Barsalou, 2023).

This study aimed to evaluate the effect of using quality control tools to increase the stuffing yield of natural pork casings hydrated with phosphoric acid in the production of Calabrian sausages.

MATERIAL AND METHODS

Local

The work was developed in a food industry located in the region of Dourados, MS, Brazil.

Hydrating of casings

The regular process of hydrating pork casings started with the decontamination by immersing 120 packs in 500 mL of sodium hypochlorite diluted in a tank with 500 L of water (1 mL/L) at 33.5 ± 3.5 ºC for 30 min, followed by desalting the casings in bubbling water for a period of 4 ± 1 h. Then, casings were immersed in a water solution containing 0.1% trisodium phosphate dodecahydrate at 35 ± 5 ºC to increase flexibility of the casings, to facilitate embedding in the threading funnel of an automatic vacuum filler (VF 828 S, Handtmann, Germany).

In the proposed method, the hydration procedure was carried out with 85% (w/w) phosphoric acid diluted in water at a ratio of 1 mL/L, resulting in a final concentration of approximately 0.1% (w/v). The casings were immersed in this solution at 33.5 ± 3.5 ºC for 6.5 ± 1.5 min. After that, the casings were washed in bubbling water and rinsed under running water.

The concentration of the phosphoric acid solution changes slightly due to the dilution effect from water on the wet casings and the absorption of acid by the casings' collagen. However, this change is considered minimal given the large volume of the tank and does not significantly impact the process's overall effectiveness.

Casing consumption and stuffing yield

To calculate the number of casings consumed (packs), the embedded mass (Kg) was divided by the filling capacity (Kg/pack), as described in Eq. 1. Considering that each pack contained 90 m length, the casing consumption (m) was calculated according to Eq. 2. Finaly, the stuffing yield (Kg/m) was calculated by dividing the embedded mass (Kg) by the casing consumption (m), as shown in Eq. 3.

$$\text{Casing consumption (packs)} = \frac{\text{Embedded mass (kg)}}{\text{Filling capacity}\left(\frac{\text{kg}}{\text{pack}}\right)} \qquad \text{Eq. 1}$$

$$\text{Casing consumption (m)} = \text{Number of packs x 90 (m)} \qquad \text{Eq. 2}$$

$$\text{Stuffing yield (kg/m)} = \frac{\text{Embedded mass (kg)}}{\text{Casing consumption (m)}} \qquad \text{Eq. 3}$$

Plan of action

The regular process was evaluated for two months. Then, a 5-months action plan was developed to evaluate the new hydration method and address specific characteristics of size, length, and weight of the Calabrian sausages.

Some steps were developed to apply the PDCA plan, such as: (1) Planning (Plan): analysis of the problem to be solved and preparation of the action plan, including brainstorming, Ishikawa diagram and 5W1H to be carried out; (2) Execution (Do): application of the new hydration method; (3) Check: analyze daily check items to monitor the evolution of values and possible deviations presented; and (4) Corrective Action (Action): standardization of the new method.

Statistical analysis

Statistical results were evaluated through analysis of variance (ANOVA) and the Tukey test for comparison of means, at a level of 5% of significance, using the statistical software Statistica 8.0.

RESULTS AND DISCUSSION

Data collected prior to the implementation of the phosphoric acid method revealed several deviations: high daily incidence of burst casings, wrinkling and marks on sausages due to insufficient casing elasticity, low weight and size per segment, and poor visual appearance. These observations allowed the probable causes of the issues to be identified using an Ishikawa Diagram, which detailed the situation (Figure 1).

The analysis focused on five main axes: labor, method, raw material, machine, and measurement. Key causes identified included the operator's skill level on the filling machine (labor); stuffing parameters deviating from process standards (method); natural casings with small holes (raw material); improper adjustment of brake parts for casing tensioning (machine); and inconsistencies in the size, weight, and length of casing segments (measurement).

An action plan was developed using the 5W1H tool to define improvements aimed at increasing efficiency (Table 1). The main objectives were to reduce casing consumption per kilogram of processed sausage by increasing the filling capacity, minimize casing damage, enhance stuffing yield, and achieve standard values for optimizing cost-benefit outcomes.

Initial data collection over the first two months highlighted a lack of standardized embedding practices and lower-than-ideal production volumes compared to process benchmarks. To address these challenges, one processing stage was modified, as illustrated in the flowchart in Figure 2. Specifically, trisodium phosphate dodecahydrate was replaced with phosphoric acid during casing hydration (Figure 2E).

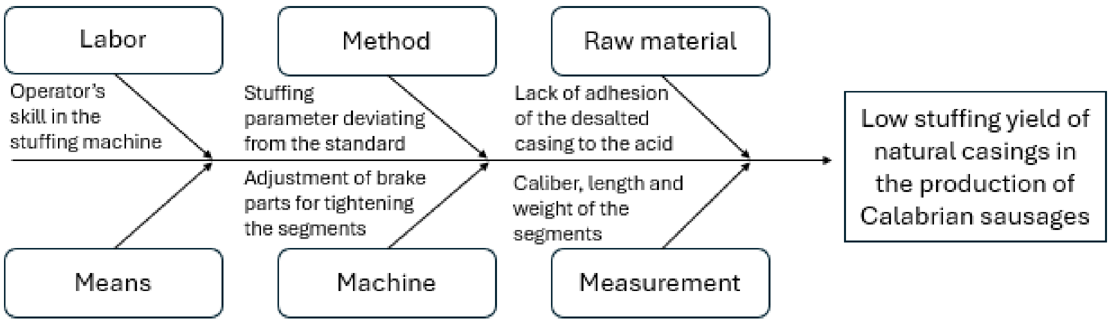

Figure 1. Ishikawa diagram: possible causes for the low stuffing yield.

Table 1. 5W1H tool used to develop an action plan to improve the yield of natural pork casings for stuffing Calabrian sausages.

What?	Why?	How?	When?	Who?	Where?
Replace phosphate for phosphoric acid	To increase stuffing yield	Applying a new hydration method into the process	Month 1	Production Supervisor	Embedding
Train 100% of the employees responsible for the hydration of the intestines with the new method	Ensure safety, quality and efficiency in the procedure	Making clear each step of the procedure	Month 3	Production Supervisor	Embedding
Daily monitoring the tripe consumed per turn of work, taking actions in case of deviation	Avoid major losses	Calculating stuffing yield based on the daily casing consumption and embedded mass	Months 1-7	Production Supervisor	Embedding
Monitor sausage filling patterns *in situ*, evaluating filling parameters (caliber, length, and weight)	Ensure that the segments do not fall outside the desired pattern	Filling out control items for the sector, monitoring data every hour of production	Months 1-7	Production Supervisor	Embedding
Meet minimum stuffing yield of 91 Kg/m	Take advantage of the greater efficiency of casings per embedded mass	Achieving maximum filling in the stuffing machine parameters so that the segments do not burst	Months 3-4	Production Supervisor	Embedding

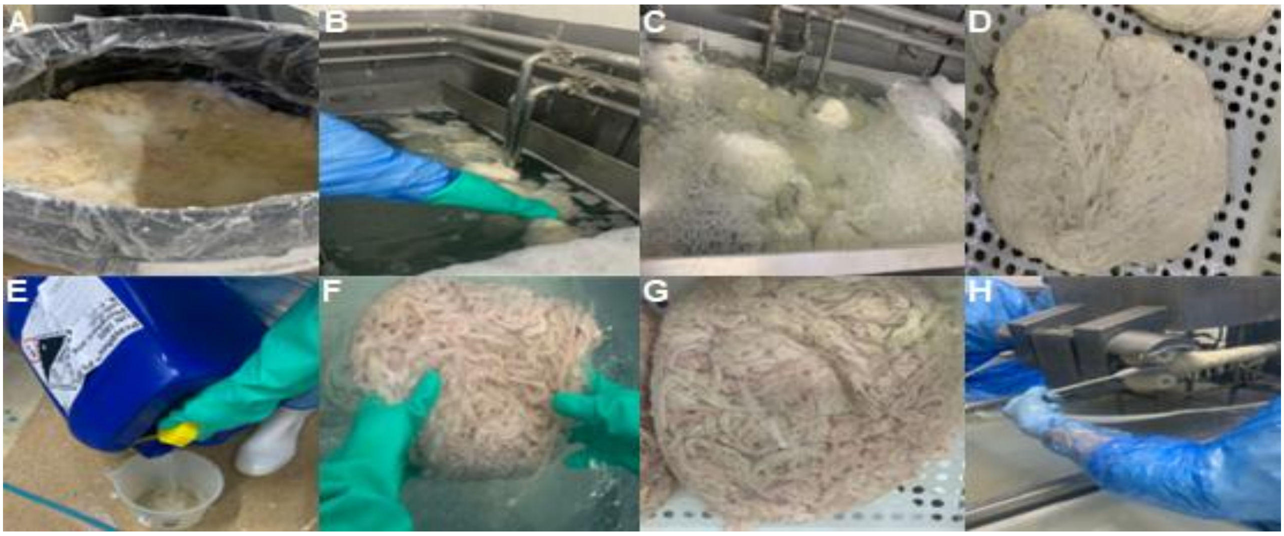

Figure 2. Flowchart of the preparation of the natural pork casings to produce Calabrian sausages. (A) Opening of the pork casings packed in brine; (B): Decontamination of the pork casings; (C) Hydration of the casings in bubbling water; (D) Appearance of the casings after desalting; (C) Addition of phosphoric acid to water; (F) Massage of the casings in the phosphoric acid solution; (G) Appearance of the casings after the phosphoric acid procedure; (H) Threading of the casings for filling Calabrian sausages.

After implementing and testing the new procedure, a visible improvement in casing appearance was observed (Figure 3). The segment on the left side of the image showcases casings with enhanced elasticity, achieved through the updated hydration process. This improvement not only increased the stuffing capacity per segment but also resulted in a more visually appealing sausage product.

To enhance operational consistency and optimize the hydration stage, a new Standard Operating Procedure (SOP) was implemented based on the PDCA cycle. The revised SOP is as follows: (1) Opening of pork casing drums packed in brine; (2) Decontamination of pork casings using a sodium hypochlorite solution (1 ml of salt per 1 L of water) by immersion for 30 min; (3) Hydration of casings in aerated water for 3 to 5 h; (4) Addition of phosphoric acid to the hydration water (1 ml of acid per 1 L of water); (5) Massaging casings in the phosphoric acid solution at a temperature between 30°C and 37°C for 5 to 8 min; (6) Rinsing the casings in aerated water to remove residual acid; (7) Threading of casings to prepare them for stuffing Calabrian sausages.

Figure 3. Difference in the appearance of natural pork casings hydrated with phosphoric acid (left) and trisodium phosphate dodecahydrate (right).

Figure 4 illustrates the average length, diameter, and weight of Calabrian sausage segments over a seven-month period.

The target length range of 22–24 cm was achieved in the third month and maintained consistently until the seventh month (Figure 4A). This improvement was attributed to enhanced casing elasticity facilitated by phosphoric acid, which likely reduced surface tension (Rodríguez et al., 2006).

The diameter standards of 40–44 mm were met by the fifth month and sustained until the seventh month (Figure 4B). The diameter is extremely variable and may present different measurements over 1 m of embedded casing, thus requiring precise adjustments to the filling machine and brake tightening. These changes ensured the casings expanded without exceeding upper limits, reducing the risk of bursting. This parameter is critical to control because larger diameter sausages have higher stuffing yields (Palumbo et al., 1976).

The standard weight range of 265–367 g per segment was achieved by the third month and maintained through the seventh month (Figure 4C). Weight is one of the most important factors in the stuffing process (Lee et al., 2005). The observed gradual weight increase correlated with improvements in diameter, facilitated by phosphoric acid, equipment adjustments, and operator training. These enhancements aligned with the goals outlined in the action plan (Figure 1).

Overall, the introduction of phosphoric acid, coupled with procedural adjustments and staff training, significantly improved operational efficiency and product consistency.

Table 2 presents the production evaluation per cage of sausages, showing a 0.12% increase in cage weight, a 10.39% reduction in casing consumption, and a 10.33% decrease in package usage. This improved efficiency, measured by stuffing yield (kg/m), was tracked daily and reached the ideal standard of 0.91 kg/m by the fourth month. The yield continued to improve to 1.0 kg/m by the seventh month (Figure 5A), representing a 22% increase over the initial value. This substantial improvement in yield directly translated to a 10.37% reduction in casing costs (Figure 5B).

Comparative analysis with literature data showed that hydration of pork casings using a 1:20 lecithin:water presented a stuffing yield of 10.2% for Calabrese sausages before cooking (Santos et al., 2008). Therefore, the hydration with phosphoric acid proved to be more efficient. However, these same authors had improved their results by combining lecithin and oil at specific concentrations and conditions, but the phosphoric acid method offered a more straightforward and cost-effective alternative.

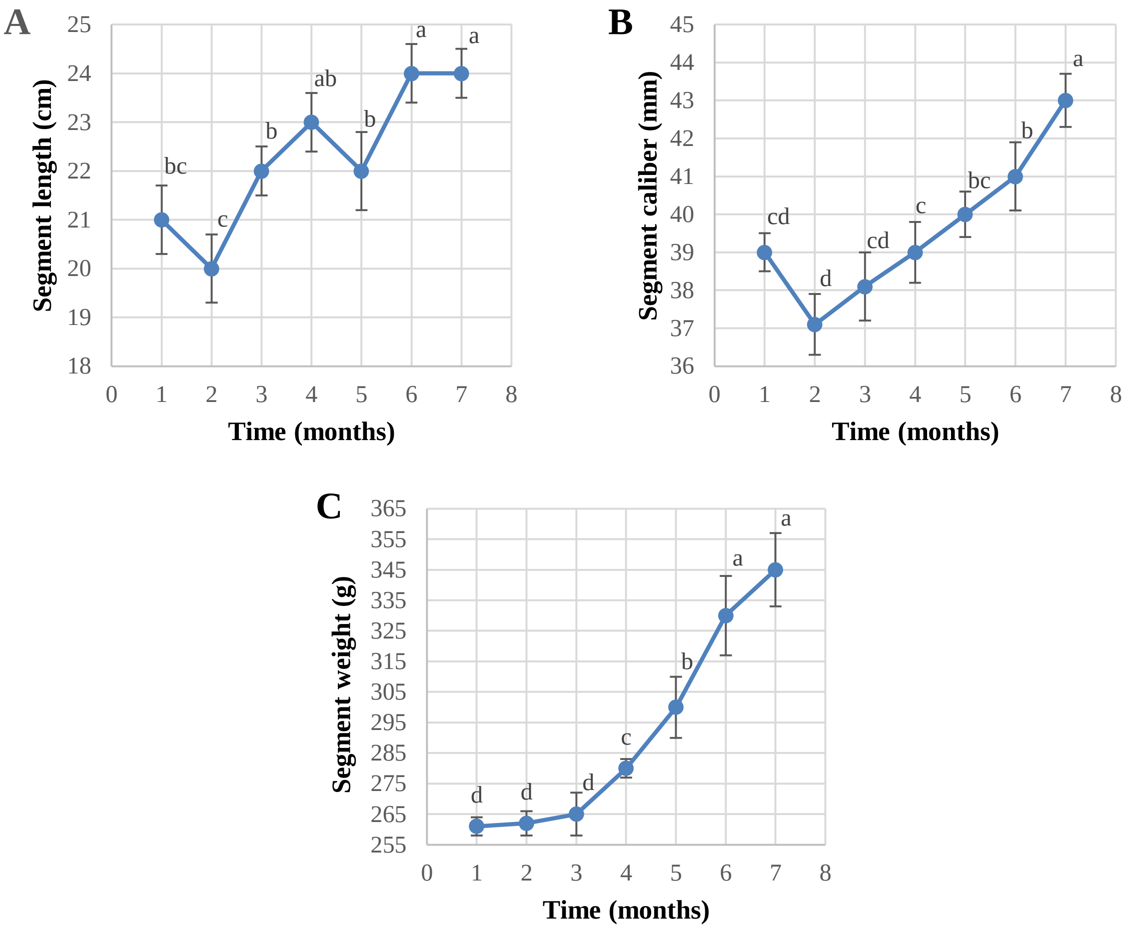

Figure 4. Average length (cm) (A), caliber (mm) (B), and weight (C) of the segments evaluated for 7 months. Means with the same letter do not differ statistically at 5% (P>0.05).

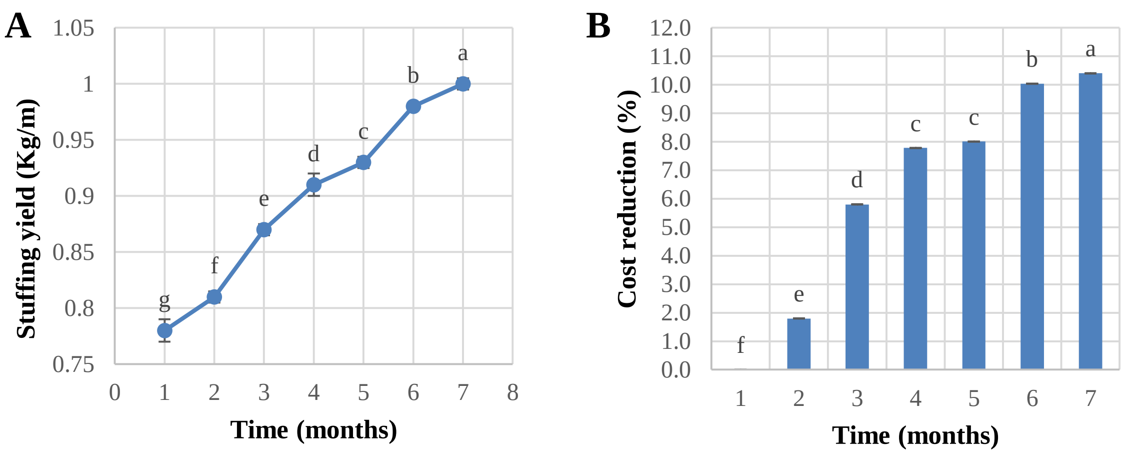

Figure 5. Stuffing yield (Kg/m) of the casings of sausages (A) and cost reduction (%) with casings (B) obtained per month based on the daily production. Means with the same letter do not differ statistically at 5% (P>0.05).

Table 2. Average values obtained per cage.

Parameter	Time (month)						
	1	2	3	4	5	6	7
Cage weight (kg)	338.98±6.8	46.2±2.4	358.1±3.6	366.2±3.3	374.2±4.1	383.4±3.3	390.5±5.3
Filling capacity (Kg/pack)	70.0±0.1	2.7±0.1	78.5±0.2	81.9±0.1	84.1±0.1	87.9±0.2	90.0±0.1
Casing consumption (packs)	4.84±0.10	76±0.03	4.56±0.05	4.47±0.04	4.45±0.05	4.36±0.04	4.34±0.06
Casing consumption (m)	435.8±8.8	28.0±3.0	410.6±4.1	401.9±3.6	400.9±4.4	392.1±3.4	390.5±4.1

CONCLUSION

This study successfully demonstrated that treating natural pork casings with phosphoric acid significantly improves filling yield, leading to a substantial reduction in casing costs for Calabrian sausage production. The implemented new method and quality control tools proved highly effective, as the stuffing yield increased from 0.87 to 1.0 kg/m over seven months, exceeding the industry standard of 0.91 kg/m. This enhanced performance directly translated to a 10.37% reduction in casing expenses. These findings confirm the efficacy of phosphoric acid as a viable and cost-effective alternative to trisodium phosphate dodecahydrate, providing a clear path to improved production standards and greater operational efficiency.

CONFLICTS OF INTEREST

The authors declare no conflict of interest in the present investigation.

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