

Spatial Distribution of Insects Associated with Stored Maize and Assessment of Damage in Odienné Department (North-Eastern Côte d'Ivoire)

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ABSTRACT: In Côte d'Ivoire, maize (*Zea mays* L.) is the second most widely cultivated and consumed cereal after rice. However, this commodity is subject to severe post-harvest losses caused by insect pests. This study aimed to map the spatial distribution of the main pests and to assess the damage caused to maize stocks. A sample of 189 kg of maize grains was collected from 21 storage structures across seven localities. Insects collected after sieving the grain were identified under a stereomicroscope using identification keys. A total of 10 species belonging to 9 families and 10 genera were identified. The dominant and ubiquitous species across all surveyed localities were *S. zeamais* and *T. castaneum*. The highest mean infestation rate was $94.0 \pm 0.48\%$, followed by a mean weight loss of $71.1 \pm 1.85\%$. These findings highlight the importance of implementing surveillance strategies to develop effective management methods for stored-product pests in view of the high infestation levels.

KEYWORDS: Post-harvest, Maize stocks, Cereals, Pests, Côte d'Ivoire

INTRODUCTION

Maize covers nearly 33 million hectares of arable land and is one of the major cereals produced worldwide (Kambale et al., 2023). This crop and its derivatives are widely used for human and animal food, cosmetics, and pharmaceutical applications (Kouakou et al., 2024). In Côte d'Ivoire, maize is the second most widely cultivated and consumed cereal after rice (Johnson, 2009). It is grown in several regions of the country (RONGEAD, 2014). The average national production is estimated at 1,140,000 tonnes (FAOSTAT, 2021). In 2022, maize production in the country was estimated at 1.19 million tonnes from a total cultivated area of 575,000 hectares (FAOSTAT, 2023). Maize cultivation occurs throughout the country, particularly in the northern regions, which account for 68% of national production (Timité et al., 2022). In northern Côte d'Ivoire, maize production is well established in the Poro, Hambol, Kabadougou, Folon, Worodougou and Béré regions (Laopé et al., 2020). Despite the strategic importance of maize at national and international levels, this cereal is highly exposed to post-harvest losses, thereby affecting its quality and availability (N'da et al., 2022). These losses are mainly caused by insect pest attacks (Johnson et al., 2024). Indeed, insect pests are responsible for substantial losses, ranging from 30 to 40% after six months of storage (Affognon et al., 2000), and reaching as much as 100% after 12 months of storage (Johnson et al., 2024). The presence of insect pests in stored maize poses a threat to food security among local populations, for whom maize is an important household commodity, as well as to the maize value chain (Coulibaly et al., 2025). In this context, this study aimed to map the spatial distribution of the main pests and to assess the damage caused to maize stocks.

MATERIALS AND METHODS

1. Materials

1.1 Study area

The study was conducted in Odienné, a department located in north-eastern Côte d'Ivoire, at geographical coordinates of 9°27'25.315" N and 5°38'40.52" W (Figure 1). In this department, three sub-prefectures were selected, and seven localities were surveyed based on the availability and accessibility of maize stocks.

1.2 Collection and identification of insects

Sampling was conducted between October and December 2023 in maize stocks that had been stored for 12 months. The selected storage period was based on the findings of Johnson et al. (2024), which reported particularly high insect abundance and diversity after 12 months of maize storage. Accordingly, three storage structures were surveyed in each locality, giving a total of 21 structures across seven localities. Maize was stored as grain in polypropylene bags. In each storage structure, nine sampling zones were defined to cover the entire structure. A 1-kg batch of maize was collected from each sampling zone, giving a total of 9 kg per storage structure and 189 kg per 21 structures. The sampled batches were sieved using a 2 mm sieve to collect any insects.

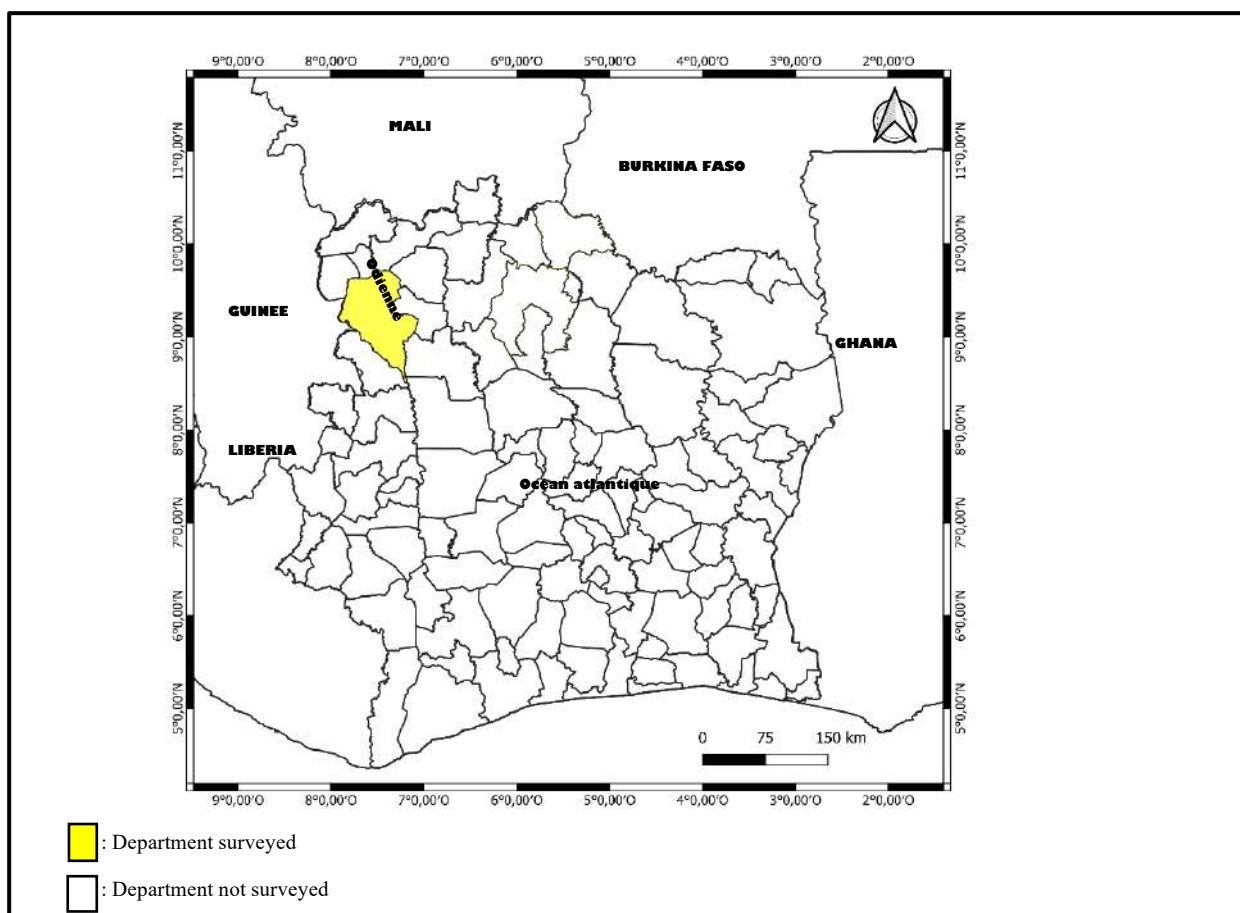


Figure 1: Map showing the Odienné department in north-eastern Côte d'Ivoire

The collected insects were preserved in labelled vials containing 70% ethanol and subsequently identified in the laboratory under a stereomicroscope. They were classified into Order, Family, Genus and Species using identification keys provided by Weidner & Rack (1984), Delobel & Tran (1993) and Farrell & Haines (2002). Identified insects were classified according to their agronomic status as primary pests (I), secondary pests (II), tertiary pests (III), predators (Pr) and parasitoids (Pa) (Huchet, 2017).

1.3 Determination of ecological diversity indices

Three ecological diversity indices were determined in this study, namely species richness (S), relative abundance (Ar) and frequency of occurrence (C). These indices were used, first, to characterise the composition of insect communities colonising stored maize and, second, to assess species diversity and the dominance of pest species in order to better guide pest management strategies.

- Species richness (S) corresponds to the total number of species recorded at a given site (Jaulin, 2009). The following formula was used to calculate species richness:

$$(S) = \sum Ni$$

where S represents the observed species richness and Ni represents species i.

- Relative abundance (Ar) is the ratio of the number of individuals of the species (Ni) under consideration to the total number of individuals collected (Dajoz, 2000). Based on relative abundance (Ar), four classes were defined:
 - Very abundant species ($Ar > 50\%$)
 - Abundant species ($25\% \leq Ar < 50\%$)
 - Moderately abundant species ($10\% \leq Ar < 25\%$)
 - Slightly abundant species ($Ar < 10\%$)
- Frequency of occurrence (C) is the ratio of the number of samples containing the species under consideration (Pi) to the total number of samples (P) (Dajoz, 2000). Five categories were distinguished according to the value of C:
 - Ubiquitous species ($C = 100\%$)
 - Constant species ($50\% \leq C < 100\%$)
 - Frequent species ($25\% \leq C < 50\%$)
 - Accessory species ($5\% \leq C < 25\%$)
 - Accidental species ($C < 5\%$)

1.4 Mapping the distribution of the main insects infesting stored maize in Odienné Department

The geographical coordinates of specimen collection sites were recorded using a Garmin GPSMAP 65s global positioning system (GPS) and converted into DMS (Degrees, Minutes, Seconds) format. The DMS data were then converted into CSV format (semicolon-delimited) using Microsoft Excel. The relative abundance of the main species in each sub-prefecture was imported into QGIS and linked to administrative boundaries to produce a distribution map of the main pests.

1.5 Statistical analyses

The Shapiro–Wilk and Levene tests were used to assess data normality and homogeneity of variances, respectively. The Kruskal–Wallis test was used to compare the mean numbers of collected insects, infestation levels and weight loss among localities. These tests were performed using R version 4.4.3.

2. RESULTS

2.1 Diversity of insects associated with stored maize in Odienné Department

The inventory of insects in the surveyed maize stocks resulted in the collection of 13,686 individuals from 189 kg of maize grain. The collected insects belonged to four orders, 9 families, 10 genera and 10 species. Coleoptera was the most abundant order (99.85%). Pests accounted for 97.88% of the collected insects, whereas beneficial insects accounted for 2.12% (Table I). ANOVA followed by Tukey's test revealed a significant difference in the numbers of insects collected among the seven localities ($df = 6$; $p < 0.001$). The mean number of insects collected at Foula was the highest, at 329.56 ± 25.40 individuals, compared with 97.89 ± 20.43 individuals at Miniadougou (Figure 2).

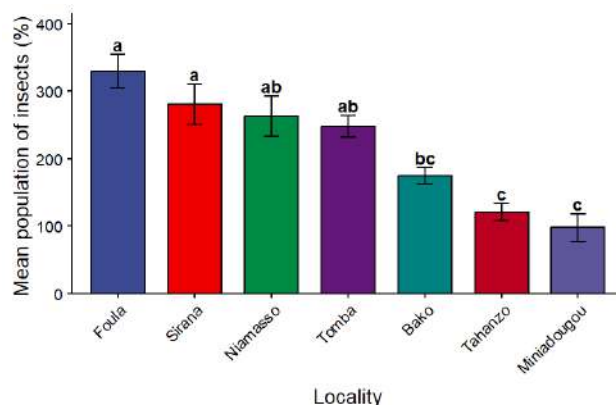


Figure 2: Mean population of insects collected by surveyed locality
(Bars topped by the same letter are statistically identical)

2.2 Species richness, relative abundance and frequency of occurrence of collected insects

Species richness

Ten species were collected during the study: *Sitophilus zeamais*, *Rhyzopertha dominica*, *Tribolium castaneum*, *Tenebrio molitor*, *Cryptolestes pusillus*, *Carpophilus dimidiatus*, *Oryzaephilus surinamensis*, *Sitotroga cerealella*, *Xylocoris flavipes* and *Lariophagus distinguendus* (Table I). The primary pests were *S. zeamais*, *R. dominica* and *S. cerealella*, which attack intact grains. The secondary pests were *T. castaneum* and *C. dimidiatus*, which attack broken grains or grains previously damaged by primary pests. *O. surinamensis* was the only tertiary pest and feeds on debris in the stored grain. In addition, three beneficial insect species were recorded in the maize stocks: the predators *T. molitor* and *X. flavipes* and the parasitoid *L. distinguendus*.

Relative abundance

Relative abundance ranged from 0.10 to 56.96% (Table I). *S. zeamais* was the most abundant species (Ar = 56.96%), whereas *S. cerealella* was the least abundant (Ar = 0.10%). *T. castaneum* was moderately abundant, with a relative abundance of 30.50%.

Frequency of occurrence

Frequency of occurrence ranged from 42.86 to 100%. The ubiquitous species (C = 100%) were *S. zeamais*, *T. castaneum*, *R. dominica*, *C. pusillus* and *X. flavipes* (Table I).

Table I: Diversity of insects collected from 189 kg of maize grain in stored maize stocks in Odienné Department, north-eastern Côte d'Ivoire

Order	Family	Genus	Species	N	% Ar	% C	Status
Coleoptera	Curculionidae	<i>Sitophilus</i>	<i>Sitophilus zeamais</i> (Mostschulsky, 1855)	7796	56.96	100.00	I
	Bostrichidae	<i>Rhyzopertha</i>	<i>Rhyzopertha dominica</i> (Fabricius, 1792)	684	6.40	100.00	I
	Tenebrionidae	<i>Tribolium</i>	<i>Tribolium castaneum</i> (Herbst, 1797)	4403	30.50	74.10	II
		<i>Tenebrio</i>	<i>Tenebrio molitor</i> (Linné, 1758)	41	0.30	42.86	Pr
	Cucujidae	<i>Cryptolestes</i>	<i>Cryptolestes pusillus</i> (Shönherr, 1877)	402	2.90	100.00	II
	Nitulidae	<i>Carpophilus</i>	<i>Carpophilus dimidiatus</i> (Fabricius, 1792)	26	0.20	71.43	II
	Silvanidae	<i>Oryzaephilus</i>	<i>Oryzaephilus surinamensis</i> (Linné, 1758)	79	0.50	71.43	III

Lepidoptera	Gelechiidae	<i>Sitotroga</i>	<i>Sitotroga cerealella</i> (Olivier, 1789)	6	0.10	28.57	I
Hemiptera	Anthocoridae	<i>Xylocoris</i>	<i>Xylocoris flavipes</i> (Reuter, 1875)	228	1.40	100.00	Pr
Hymenoptera	Pteromiladae	<i>Lariophagus</i>	<i>Lariophagus distinguendus</i> (Forster, 1840)	21	0.20	42.86	Pa
4	9	10	10	13686	100.00		

N: Number of individuals; % Ar: Relative abundance; % C: Frequency of occurrence; I: Primary pest; II: Secondary pest; III: Tertiary pest; Pr: Predator; Pa: Parasitoid

2.3 Distribution range of the main insect pests in Odienné Department

The predominant pests were *S. zeamais* and *T. castaneum*. *S. zeamais* was very abundant at Miniadougou (Ar = 70.26%), Bako (Ar = 66.88%), Tahanso (Ar = 65.94%), Tomba (Ar = 64.04%), Niamasso (Ar = 59.86 %) and Sirana (57.90%). *T. castaneum* was abundant at Foula (42.75%), Sirana (Ar = 35.88%), Niamasso (Ar = 29.71%), Bako (Ar = 29.23%), and Tomba (Ar = 28.30%) (Figure 3).

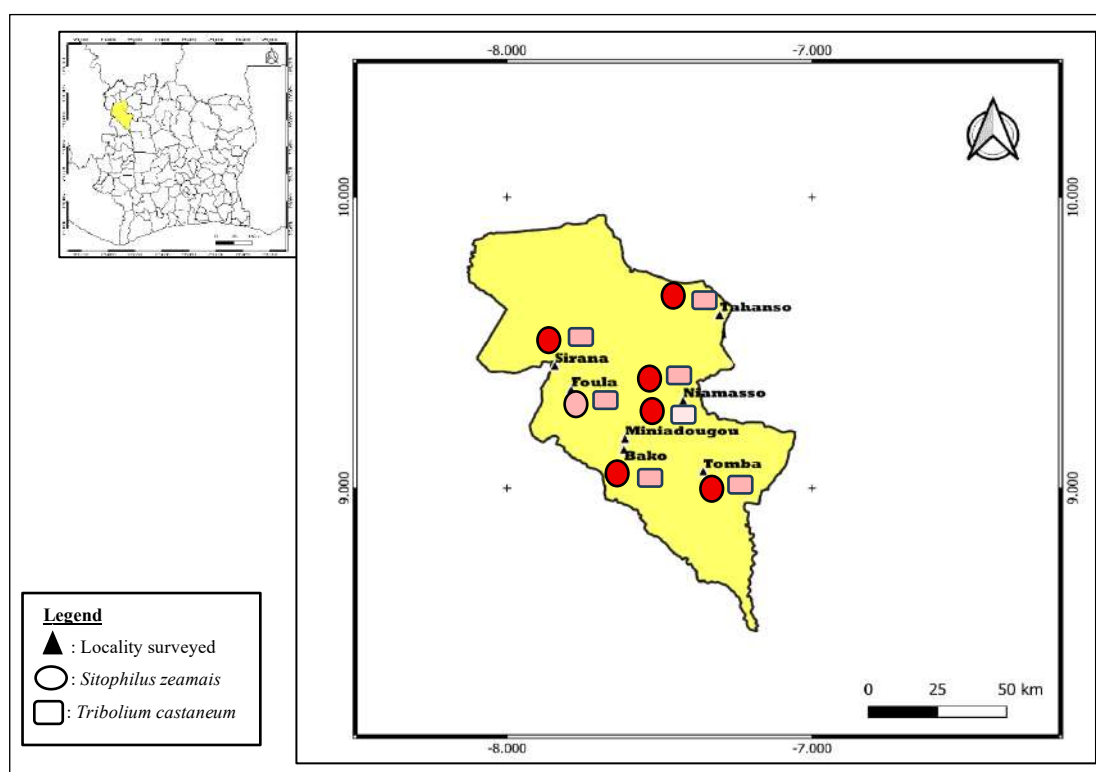


Figure 3 : Distribution map of the main insect pests affecting maize stocks in the Odienné department, north-east Côte d'Ivoire (Ar > 50% : very abundant ■; 25 ≤ Ar < 50% : abundant ■; 10 % ≤ Ar < 25% : fairly abundant ■)

2.4 Damage associated with stored maize stocks

The maize stocks sampled at Niamasso were the most heavily infested, with an average infestation rate of $94.02 \pm 0.48\%$, compared with those at Foula, which recorded a rate of $58.20 \pm 1.86\%$ (Figure 4). The same trend was observed with regard to weight loss. The average weight loss in Niamasso was $71.05 \pm 1.85\%$, whilst in Foula it was $16.61 \pm 0.71\%$ (Figure 5). The Kruskal-Wallis test, followed by Dunn's post-hoc test at a significance level of 5%, revealed that there is a significant difference between the infestation rates and the weight loss recorded in the maize stocks from the different localities.

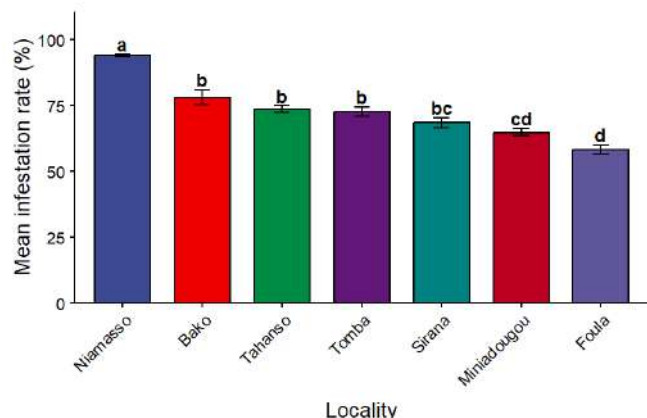


Figure 4: Mean infestation rate in maize stocks by surveyed localities (Bars topped by the same letter are statistically identical)

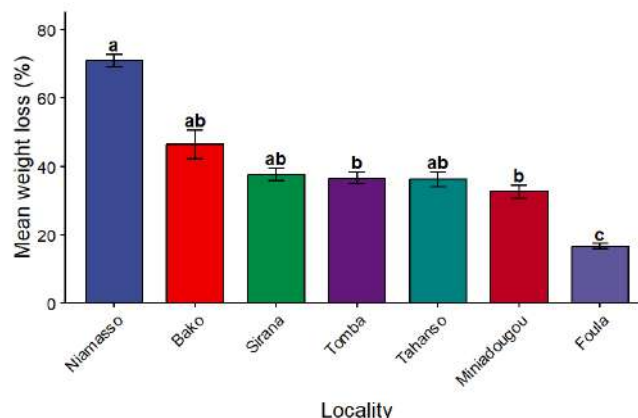


Figure 5: Mean weight loss of maize stocks by surveyed localities (Bars topped by the same letter are statistically identical)

3. DISCUSSION

This study revealed substantial diversity of insect pest species in maize stocks collected in Odienné Department, north-eastern Côte d'Ivoire. A total of 13,686 individuals were collected from a sample of 189 kg of maize grain after 12 months of storage. These insects belonged to four orders, nine families, 10 genera and 10 species. The number of species recorded in this study differed from that reported by Gindaba and Negeri (2023) and Nivethika et al. (2022). These authors recorded five species, respectively, in maize stocks sampled in Ethiopia and India. This difference may be attributable to storage duration and storage structures. In the study by Gindaba and Negeri (2023), maize stocks were sampled after three months of storage, whereas those examined by Nivethika et al. (2021) were sampled after five months. In addition, the high number of insects collected in the present study may be explained by storage practices that are often inadequate under smallholder conditions. These observations are consistent with those of Waongo et al. (2013), Sankara et al. (2017) and Johnson et al. (2024), who showed that traditional storage structures may influence pest proliferation. Indeed, storage structures are generally constructed from materials conducive to insect development. They may also contain cracks or galleries that provide refuges for insects and contribute to increased infestation. Among the insect orders recorded, Coleoptera was markedly predominant (99.85%), of which 97.88% were pests and 2.12% were beneficial insects. The high proportion of pests may be related to the physicochemical properties of maize. Maize grains are larger than those of other cereals and provide a more abundant substrate rich in carbohydrate reserves for insect development. These observations are similar to those reported by Waongo et al. (2013), who attributed pest diversity to grain size and the intrinsic properties of maize. Regarding ecological diversity indices, *S. zeamais* and *T. castaneum* were the most abundant species. These species are known to cause substantial damage to stored commodities in West Africa (Johnson et al., 2012; Oura et al., 2022). The findings of the present study indicate that these pests are well adapted to stored commodities and prevailing storage practices. This observation is consistent with Johnson et al. (2012) and Coulibaly et al. (2025), who reported the ubiquitous occurrence of these pests in maize and rice stocks in the Marahoué and Bagoué regions of Côte d'Ivoire, respectively.

The study of the distribution of the main pests in Odienné Department showed a strong dominance of *S. zeamais* across all surveyed localities, whereas *T. castaneum* was relatively abundant. The high abundance of *S. zeamais* in all localities may be attributable to its adaptive capacity to climatic conditions in African regions that are favourable to its development, as well as to its agronomic status (Okiwelu et al., 2011). Indeed, this pest attacks intact grains, thereby making them susceptible to infestation by other organisms, such as *T. castaneum*. The occurrence of *T. castaneum* in all surveyed localities may be explained by its status as a secondary pest and its high reproductive capacity (Nyabako et al., 2020; Shah et al., 2021).

The analyses of damage levels revealed significant differences among the surveyed localities. The area with the highest infestation rate also showed the greatest weight loss. Thus, maize stocks sampled at Niamasso had a mean infestation rate of $94.02 \pm 0.48\%$ and a mean weight loss of $71.05 \pm 1.85\%$. These results may be related to the duration of maize storage and the large number of

pests collected during the study. Indeed, Johnson (2009) and Coulibaly et al. (2025) showed that these two factors strongly affect infestation levels in maize stocks.

CONCLUSION

This study identified 10 insect species in stored maize stocks, belonging to four orders, nine families and 10 genera. The high proportion of pests (97.88%) indicates a substantial presence of harmful insects responsible for damage and losses in stored maize stocks. The predominant and ubiquitous species across all localities were *S. zeamais* and *T. castaneum*. The highest mean infestation rate was $94.0 \pm 0.48\%$, followed by a mean weight loss of $71.1 \pm 1.85\%$. The high pest pressure exerted on stored commodities highlights the urgent need to implement sustainable and appropriate management strategies to ensure improved storage conditions.

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CONFLICT OF INTEREST

All authors have approved the final version of the manuscript. No conflict of interest is declared.

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