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ORIGINAL ARTICLE

Evaluation of vinegar effectiveness in carabid traps (Coleoptera: Carabidae): A viable alternative to conventional liquids

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Abstract. In response to the growing challenges of sustainable agriculture and the preservation of functional biodiversity, robust entomological monitoring protocols now require large-scale sampling, leading to significant operational costs. In this context, the adoption of cost-effective alternatives to preservation liquids is crucial. Vinegar, propylene glycol, and brine are three solutions commonly used in the literature, raising questions regarding the comparability of data across studies. We compared the effectiveness of vinegar, propylene glycol, and brine in Barber traps for the census of carabids (Carabidae), key auxiliaries in agroecosystems. Trapping campaigns were conducted in 2023 across 20 sugar beet plots (vinegar vs. propylene glycol) and in 2024 across 17 winter cereal plots (vinegar vs. brine), following standardized protocols. The results indicate that traps containing vinegar captured significantly more individuals overall than the other liquids, while maintaining a comparable species diversity and assemblage composition to those obtained with propylene glycol. In contrast, brine showed more variable captures compared to the other liquids and should be excluded for more reliable surveys. These findings suggest that vinegar, as an economical option, represents a promising alternative to propylene glycol for carabid census. However, the choice of preservation liquid should align with the specific objectives of each study: propylene glycol remains preferable for specimen preservation, particularly for DNA analyses, while vinegar offers an affordable solution for studies not requiring such analyses.

INTRODUCTION

Modern agroecosystems face numerous challenges in the sustainable management of pests. While the widespread use of insecticides is part of the toolkit employed to maintain high agricultural yields, it also has deleterious effects: it causes a notable decrease in biodiversity by affecting non-target organisms and disrupting ecological balances (Geiger et al., 2010; Fritsch et al., 2025; Wan et al., 2025), and leads to numerous negative impacts on human health (Costa et al., 2014; Mostafalou & Abdollahi, 2017). In response to these environmental and health concerns, regulations governing the use of insecticides have significantly strengthened, reducing the number of authorised active substances. Paradoxically, this reduction has favoured the emergence of resistance in pest species, limiting the long-term effectiveness of chemical treatments (Onstad & Knolhoff, 2023). Faced with a future where insecticide use could be drastically reduced, it is essential to reinvest in conservation biological control, a sustainable strategy that promotes the value of crop auxiliaries. Increasingly, studies are focusing on the influence of factors such as soil management, the use of phytosanitary products, or landscape configuration on these auxiliaries, particularly carabids, effective predators of numerous pests (Holland et al., 2016; Müller et al., 2022; Deppe & Fischer, 2023). However, to maximise the effectiveness of biological control and better understand the complex interactions within agroecosystems, an accurate assessment of the functional composition of communities is essential. This requires the development of robust and ecologically adapted assessment methods (Montgomery et al., 2021).

Barber traps, also known as "pitfall traps," are commonly used devices for capturing epigeic arthropods in ecology, due to their efficiency and ease of use (Marrec et al., 2017; Boeraeve et al., 2022; Tougeron et al., 2022; Triquet et al., 2022; Woodcock, 2005). Introduced by Hertz (1927) and Barber (1931), this method involves placing a container level with the ground to trap epigeic invertebrates that fall into it over time. Barber traps thus allow the sampling of various taxonomic groups, such as carabids, staphylinids, ants, spiders, harvestmen, and collembolans. Despite their widespread use, these traps have limitations regarding the generation of comparable data across various spatial and temporal scales. The characteristics of pitfall traps, such as size (Santos et al., 2007; Gardarin & Valantin-Morison, 2021) and container material (Luff, 1975), colour (Buchholz et al., 2010), choice of preservation liquid (Koivula et al., 2003; Aristophanous, 2010; Skvarla et al., 2014; Knapp et al., 2016), and the addition of drift barriers (Boetzl et al., 2018), roofs (Császár et al., 2018; Litavský & Prokop, 2024), or funnels (Knapp & Růžička, 2013; Saska et al., 2021), vary widely across studies and may impact the results.

Among these many factors, the choice of preservation liquid in Barber traps is crucial and varies significantly across studies, with options such as ethylene glycol, propylene glycol, vinegar, brine, and formaldehyde, the latter now largely avoided in ecological research due to its carcinogenic properties, toxicity to operators, and regulatory restrictions on its use. An effective preservation liquid must meet several criteria: (a) immobilise/kill invertebrates effectively to prevent escape, (b) preserve their morphological integrity throughout the sampling period, (c) not volatilise excessively, and (d) avoid biased attractiveness that might alter the composition of captured samples. The ability to kill organisms effectively is crucial, as some species, such as *Bembidion* sp. (Latreille, 1802) and *Bathyphantes* sp. (Menge, 1866), can escape less lethal solutions like water (Luff, 1975; Topping, 1993). The catch size therefore depends on the killing power of the fluid: traps filled with a preservative capture more beetles than empty or water-filled traps (Santos et al., 2007), and for a given agent, this efficiency can increase with concentration, as documented for formaldehyde (Pekár, 2002). Additives such as detergents may be added to reduce the surface tension of the liquid, improving organism capture by preventing them from rising to the surface (Topping & Luff, 1995).

The liquid's ability to preserve the samples is also crucial, particularly when organisms need to be stored for several days before analysis (Schmidt et al., 2006). While water and brine are low-cost options, they quickly lead to specimen decomposition, attracting dipterans due to putrefaction odours (Aristophanous, 2010). Alcohols such as ethylene glycol, propylene glycol, and ethanol ensure better preservation of invertebrates, but they present specific disadvantages: ethanol, though effective, is highly volatile and evaporates within a week (Schmidt et al., 2006), whereas ethylene and propylene glycol, being less volatile, are better suited to prolonged sampling without frequent replacement (Martin, 1978; Nakamura et al., 2020). For studies requiring DNA extraction, propylene glycol is particularly interesting, as it preserves DNA as effectively as ethanol while being less volatile and less toxic (Moreau et al., 2013; Nakamura et al., 2020).

The impact of the preservation liquid on the attractiveness of traps is another critical variable, as some species respond differently depending on the product used. For example, formaldehyde seemed to attract certain carabid and staphylinid species while repelling groups such as harvestmen and millipedes (Luff, 1968; Gerlach et al., 2009). Similarly, ethylene glycol may attract *Bembidion* sp., although this effect varies by season and the sex of the captured individuals (Holopainen, 1992).

Today, although some standardised Barber trap models are proposed (Brown & Matthews, 2016; Hoekman et al., 2017; Hohbein & Conway, 2018), few authors comment on the use of a specific preservation liquid. Propylene glycol, frequently employed in trapping studies due to its efficiency and low volatility (Brown & Matthews, 2016; Knapp et al., 2016), represents a significant financial constraint, particularly for large-scale studies when used in pure form. Consequently, other lower-cost liquids, such as vinegar, have been proposed as promising alternatives, although their use remains marginal in the literature. Some research suggests that vinegar-filled traps perform comparably to those using brine in terms of taxonomic and functional composition of the sampled communities (Gardarin & Valantin-Morison, 2021). However, few studies have directly compared the capture efficiency between vinegar and propylene glycol, limiting conclusions about their potential interchangeability in specific contexts, such as large-scale crops. It is crucial to determine whether vinegar can be used effectively in Barber traps without its strong odour altering the composition of the captured arthropod populations in agricultural environments.

In this study, we aim to assess the effectiveness of vinegar as an alternative to propylene glycol and brine, commonly used as preservation liquids in Barber traps, within agroecosystems. To strengthen the robustness of the results, the experiment was replicated across different time periods (April, July, and August) and in contrasting crop systems. Specifically, vinegar was compared to propylene glycol in sugar beet fields across three sampling periods (April, July, August), while vinegar was compared to brine in cereal fields during two periods (April, July). This experimental design allowed us to test the effectiveness of vinegar against different reference preservation liquids across varying agricultural contexts and phenological stages. Trapping campaigns targeting carabids, recognised for their role as crop auxiliaries, were conducted using the different liquids under investigation. We hypothesise that the use of vinegar as a preservation liquid does not affect carabid captures in terms of abundance, diversity, and community structure compared to traditionally used liquids such as propylene glycol or brine. Validating this hypothesis could pave the way for the adoption of vinegar as an economical solution, enabling large-scale studies while maintaining the scientific integrity of trapping protocols.

MATERIAL AND METHODS

Study site

The experiment was conducted on 20 commercial agricultural plots located in the loamy and Condruzian regions of Belgium (Fig. 1). The region is characterised by a temperate oceanic climate, with average annual precipitation of 800 mm and an average annual temperature of 10°C. All the farms included in the study practise conventional farming and follow a crop rotation that includes the "sugar beet – winter cereals" sequence, which is widespread in the region. Conventional farming in this context refers to a production system that employs chemical inputs (syn-

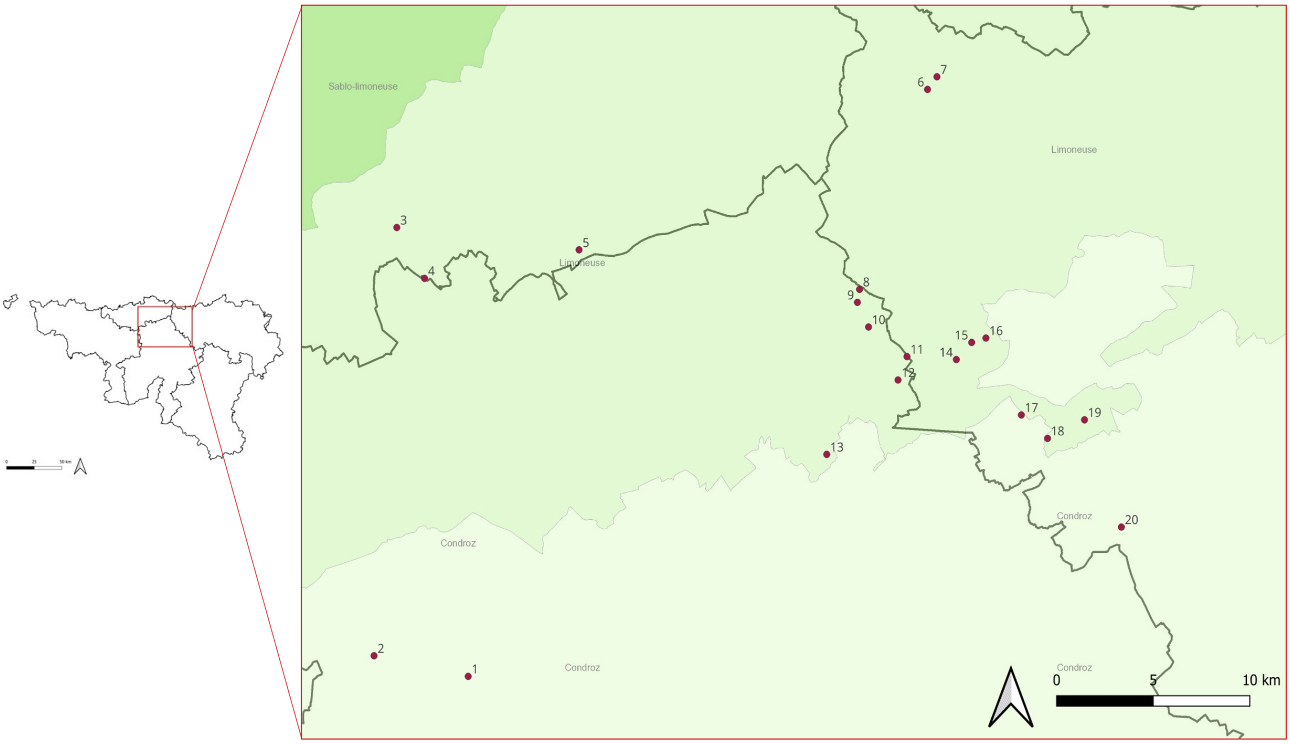

Fig. 1. Geographic area of the study located in northern Wallonia. The 20 sampled plots (red dots) are distributed across the provinces of Namur (south), Liège (east), and Walloon Brabant (west), outlined in black. These plots are situated in different agricultural regions: Condroz (light green), the loamy zone (medium green), and the sandy-loamy zone (dark green).

thetic fertilisers and pesticides) and mechanised methods to maximise yields, while also allowing the adoption of practices such as reduced tillage or decreased pesticide use, without compromising the farm's conventional status.

Sampling

This experimental design allows comparison of vinegar's effectiveness with that of more conventional liquids in terms of carabid capture, taking into account seasonal variations and the cultivation conditions of two contrasting crops: sugar beet and winter cereals.

In 2023, trapping campaigns were conducted on sugar beet plots during three periods, each lasting three weeks. Each period included three sampling events, with each trap being replaced after one week and repeated twice. This design compared vinegar to propylene glycol using 1080 traps distributed across 20 plots. The first period, "Post-Sowing", occurred from 7 May to 1 June 2023. The second period, "Mid-Crop", took place from 27 June to 20 July 2023. The third period, "Pre-Harvest", extended from 8 August to 31 August 2023.

In 2024, trapping campaigns on winter cereal plots were conducted over two three-week periods. Each period again included three sampling events, with each trap being replaced after one week and repeated twice. This second setup compared vinegar to brine using 612 traps distributed across 17 plots. The first period, "Mid-Crop", was from 1 to 26 April 2024. The second period, "Pre-Harvest", took place from 10 June to 5 July 2024.

In each plot, six Barber traps were set on the ground to capture terrestrial arthropods. The traps were placed at the centre of the plots to minimise edge effects. The six traps per plot were spaced at least 15 m apart and arranged according to a constant spatial layout (Fig. 2). Each trap consisted of two nested containers (volume: 400 mL; height: 100 mm; upper diameter: 85 mm; lower diameter: 72 mm). The outer container serves as a support and stabilises the inner container, reducing soil disturbance during installation. A funnel, made from the upper part of a plastic bottle, was added to each trap to minimise the escape of captured individuals and to prevent the entry of small unwanted vertebrates. A translucent plastic roof was installed 15 cm above each trap to protect the contents from precipitation. This setup follows the standardised protocols recommended by Brown & Matthews (2016) and Hohbein & Conway (2018). Carabid identification was carried out to species level using identification keys provided by Coulon et al. (2011) and Roger et al. (2012).

To test the effectiveness of vinegar as a trapping liquid, the Barber traps were compared with traps containing propylene glycol or brine. This experimental study was conducted in conjunc-

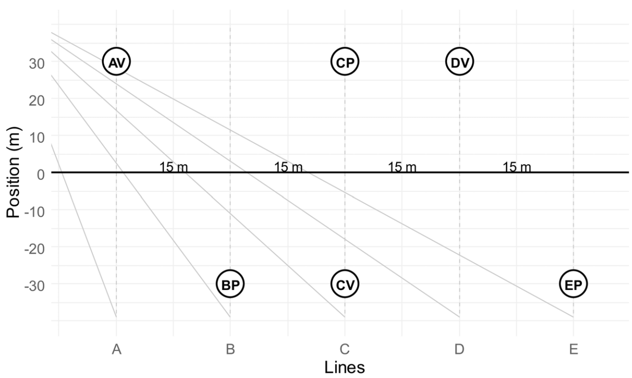

Fig. 2. Spatial sampling design deployed across the 20 agricultural plots. Five parallel lines, spaced 15 m apart, were drawn at the center of each plot to minimize edge effects. Six Barber traps were distributed according to this design: one trap per line in lines A, B, D, and E, and two traps in the central line (C), arranged in a staggered pattern 30 m on either side of the center of the line. The circles represent the trap positions, identified by their installation line (A–E) and the preservation liquid used: V for vinegar, P for propylene glycol or brine.

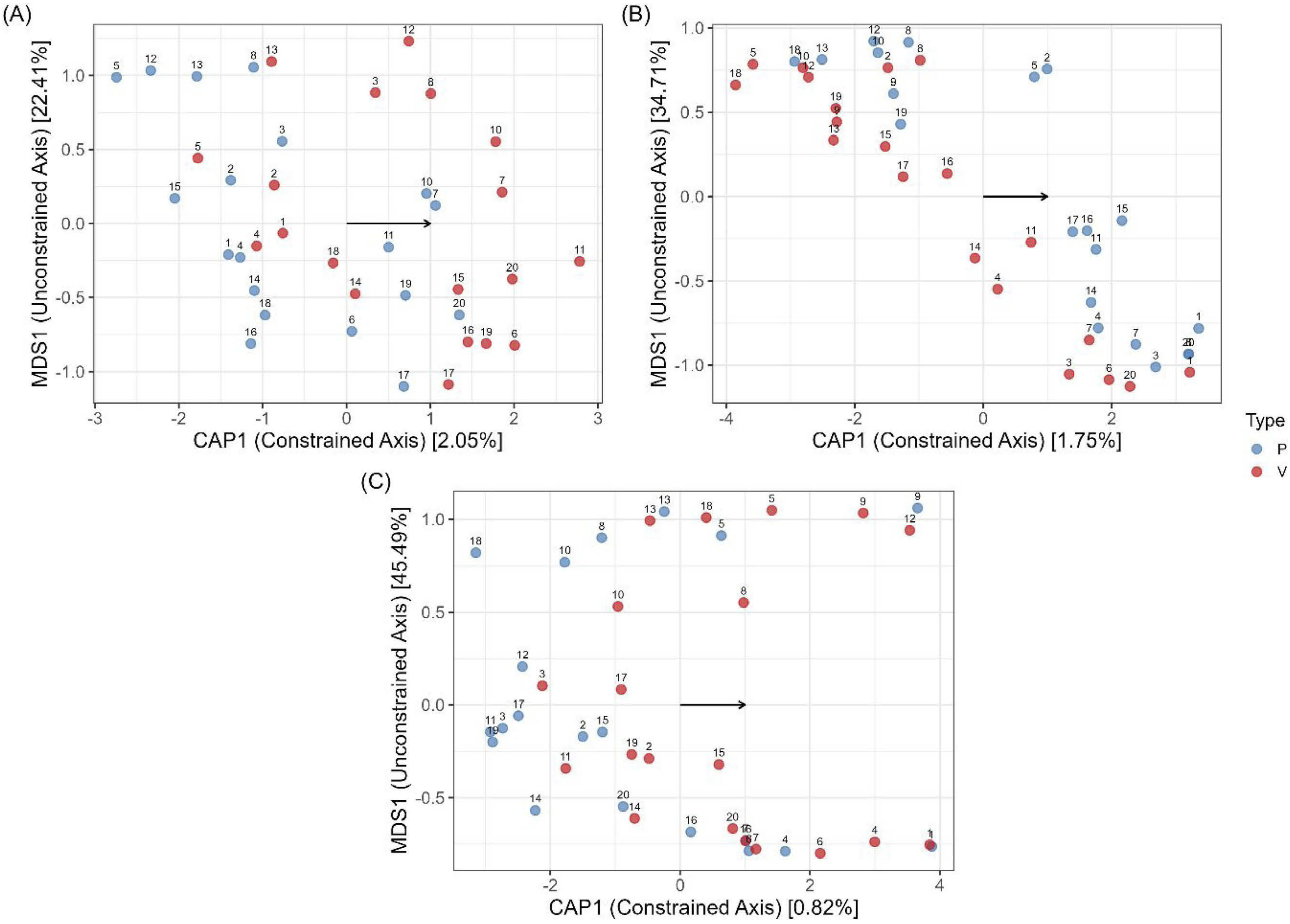

Fig. 3. Canonical Principal Coordinates Analysis (CAP) of carabid assemblage composition based on trap type (propylene (P) vs vinegar (V)). The graph presents a biplot of the constrained axis (CAP1) and the unconstrained axis (MDS1), each explaining a percentage of the total variance in assemblage composition. Coloured points represent samples according to trap type, while plot numbers are displayed near the corresponding points to illustrate the spatial distribution of assemblages. The analysis is based on Bray-Curtis distance for species composition and was conducted for the 2023 surveys in beet fields during the April (A), July (B), and August (C) sampling periods.

tion with a broader research programme evaluating ground beetle dynamics throughout crop succession. Consequently, sampling periods were primarily determined by the objectives of the larger study, and we deliberately avoided testing all three preservation liquids simultaneously within the same plots to prevent potential interference with the primary study's dataset, as substantial differences in trapping efficiency between liquids could have biased the ecological conclusions of the main research.

In 2023, on the 20 sugar beet plots, three of the six traps per plot were filled with 200 mL of 7° alcohol vinegar (standard commercial grade), while the other three were filled with 200 mL of 50% diluted propylene glycol. In 2024, on 17 of these same plots, during the winter cereal cultivation, three traps per plot were filled with 200 mL of 7° alcohol vinegar and the other three with 200 mL of brine (200 g/L, maximum salt concentration before precipitation).

Data analyses

Statistical analyses were performed using R software, version 4.4.1 (R Core Team, 2024). Prior to any statistical analysis, trap losses (pitfall traps that were missing, overturned, or visibly damaged at the time of collection) were recorded for each sampling session and excluded from the dataset. To test whether trap loss rates differed among liquid types, and in particular whether vinegar might attract vertebrates more strongly than propylene glycol or brine, we fitted a generalised linear mixed model (GLMM) with a binomial distribution, with trap status (lost/intact) as the response, liquid type as a fixed effect, and plot as a random effect. For the subsequent analyses, the data were aggregated by plot and period, resulting in 120 observations for the vinegar-propylene comparison and 68 for the vinegar-brine comparison. The carabid captures were then analysed along four axes: (i) assemblage composition, (ii) total abundance, (iii) species diversity (species richness and Shannon index), and (iv) the presence of certain indicator species.

To assess the differences in assemblage composition based on the liquids used, a Bray-Curtis distance matrix was calculated (package vegan, Oksanen et al., 2019). A canonical principal coordinate analysis (CAP, Anderson & Willis, 2003) was then conducted using the type of liquid as the explanatory variable. The relevance of the resulting axes was assessed by the explained variance, and a permutation-based analysis of variance (ANOVA) with 9999 permutations was applied to evaluate the significance of the observed effects. The effects of the trapping liquids on total carabid abundance and on species richness were assessed using generalised linear mixed models (GLMM) with a Poisson distribution and log link, with liquid type as a fixed effect and plot as a random effect (1|Plot). For analyses combining all sampling periods, sampling period was added as an additional random effect (1|Period). When overdispersion was detected (dispersion ratio > 1.5), models were refitted with a negative binomial distribution using the glmmTMB package (Brooks et al., 2017). Model assumptions were checked using simulated residuals (package

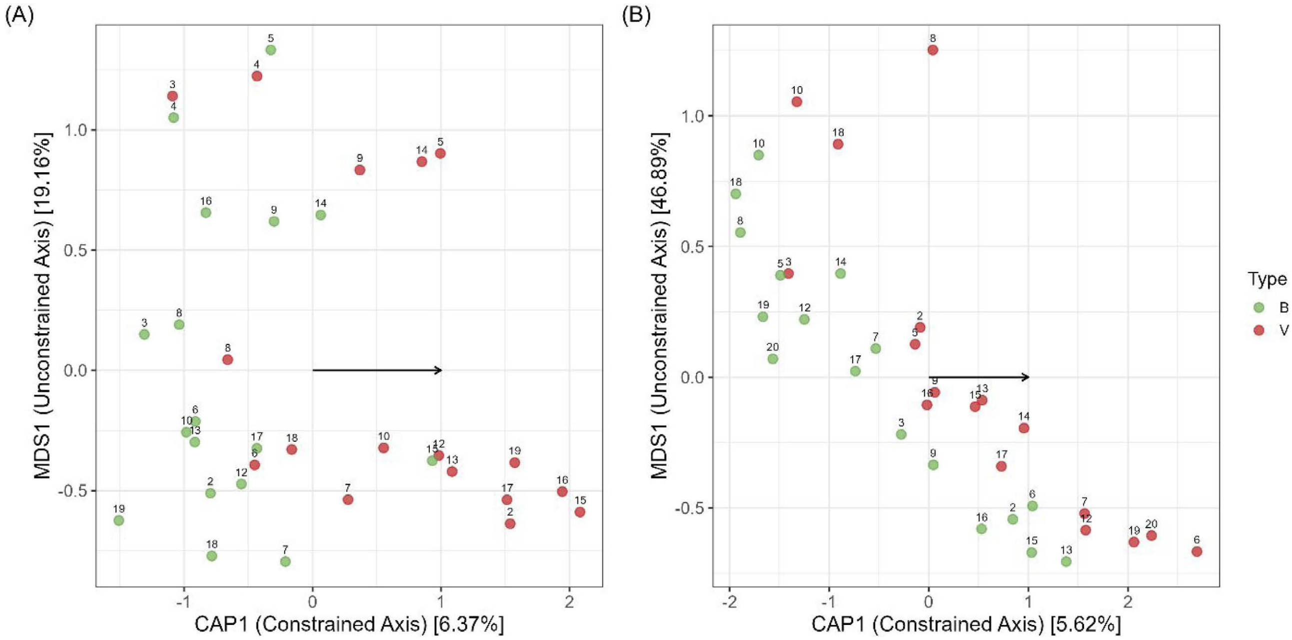

Fig. 4. Canonical Principal Coordinates Analysis (CAP) of carabid assemblage composition based on trap type (brine (B) vs vinegar (V)). The graph represents a biplot of the constrained (CAP1) and unconstrained (MDS1) axes, each explaining a percentage of the total variance in assemblage composition. Coloured points indicate samples according to trap type, with plot numbers displayed next to the corresponding points to illustrate the spatial distribution of assemblages. The analysis is based on Bray-Curtis distance for species composition and was conducted for the 2024 winter cereal surveys for the periods of April (A) and July (B).

DHARMa, Hartig, 2016). Pairwise comparisons between liquid types were performed using estimated marginal means (package emmeans, Lenth, 2026). The Shannon diversity index, being a continuous variable, was analysed using linear mixed models (LMM) with the same random effect structure (package lmerTest, Kuznetsova et al., 2017). Finally, the association between specific species and the types of liquids was explored by calculating the indicator value (IndVal) for each taxon (package labdsv, Roberts, 2023). To confirm the results, statistical modelling was conducted for each species with at least five non-zero occurrences. Generalised linear mixed models (GLMM) were fitted on the raw, ungrouped data with preservation liquid type as the main fixed effect and plot as a random effect (1|Plot), using a Poisson distribution with log link (package lme4, Bates et al., 2015). In cases of model singularity, a generalised linear model (GLM) without random effects was used instead. When overdispersion was detected (dispersion ratio > 1.5), models were refitted using a negative binomial distribution with the glmmTMB package (Brooks et al., 2017), maintaining the same random effect structure when possible. P-values associated with the liquid type effect were extracted to evaluate species-specific differences.

RESULTS

Trap losses across liquid types

Out of 1692 pitfall traps deployed during the study, 88 (5.20%) were missing, overturned, or damaged at the time of collection. Trap loss rates did not differ significantly between liquid types in either comparison. In the vinegar-propylene comparison (2023), the loss rate was 1.71% for vinegar and 3.40% for propylene glycol (GLMM, odds ratio V/P = 0.49, P = 0.08). In the vinegar-brine comparison (2024), the loss rate was 9.18% for vinegar and 11.0% for brine (GLMM, odds ratio V/B = 0.81, P = 0.45).

Effect of the preservation liquid on the composition of carabid assemblages

The composition of carabid assemblages did not vary significantly according to the type of preservation liquid used (vinegar or propylene glycol) (P = 0.16). Constrained redundancy analyses conducted for all three sampling periods did not reveal any pronounced trends in the distribution of traps along the constrained axis, which explained between 0.82% and 2.05% of the variance in the samples (Fig. 3). These results were confirmed by permutation-based analysis of variance (ANOVA), which indicated non-significant p-values for each period (P = 0.67, P = 0.72, and P = 0.94 for April, July, and August, respectively).

In contrast, more pronounced differences were observed in the vinegar versus brine comparison. The constrained axis explained a greater proportion of the variance in carabid assemblages, reaching 6.37% and 5.62% for the April and July periods, respectively (Fig. 4). Only the April period showed a significant difference according to the permutation-based ANOVA (P = 0.009***), while no significant difference was detected in the July period (P = 0.1).

Effect of the preservation liquid on carabid abundance

For the vinegar-propylene comparison, GLMM analyses (negative binomial distribution, plot as random effect) showed that the mean abundance of carabids across all species captured was significantly higher in vinegar than in propylene glycol (ratio vinegar/propylene = 1.23, P = 0.0003***). However, when analysed separately by sampling period, this difference was primarily driven by the July sampling period (ratio = 1.50, P < 0.0001***), with no

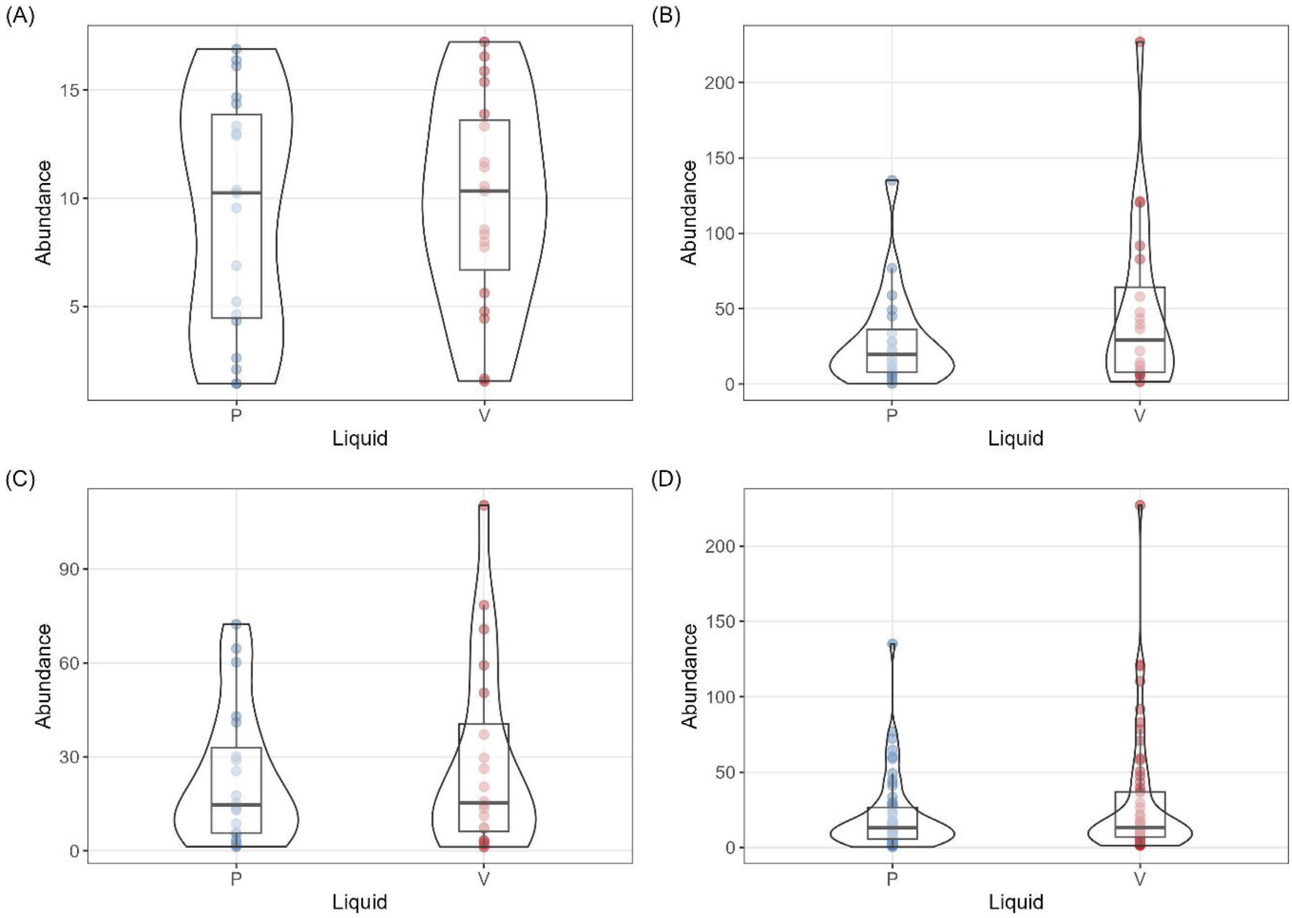

Fig. 5. Effect of preservation liquid (P – propylene, V – vinegar) on the mean abundance of carabids captured, across all species. The violin plots illustrate the paired comparison of carabid abundance between the two liquid types for each plot, in (A) April, (B) July, (C) August, and (D) across the entire study period.

significant differences observed in the April (ratio = 1.11, P = 0.21) or August periods (ratio = 1.08, P = 0.32) (Fig. 5).

For the vinegar-brine comparison, GLMM analyses (negative binomial distribution, plot and sampling period as random effects) showed that the mean abundance of carabids captured was significantly higher in vinegar than in brine (ratio vinegar/brine = 1.36, P = 0.0003***). This difference was consistent across both sampling periods, although more pronounced in April (ratio = 1.45, P < 0.0001***) than in July (ratio = 1.31, P = 0.04*) (Fig. 6).

Effect of the preservation liquid on carabid diversity

For the vinegar-propylene comparison, GLMM analyses revealed no significant difference in species richness between liquid types, either across all periods (ratio vinegar/propylene = 1.07, P = 0.058) or within any individual sampling period (April: P = 0.20; July: P = 0.20; August: P = 0.42) (Table 1). Similarly, LMM analyses showed no significant differences in the Shannon index between vinegar and propylene glycol, neither globally (P = 0.60) nor within any sampling period (P > 0.34 in all cases) (Table 2). For the vinegar-brine comparison, GLMM analyses revealed that species richness was significantly higher in vinegar than in brine across all periods combined (ratio vinegar/brine = 1.15, P = 0.001**), with a significant difference in April (ratio = 1.20, P = 0.002**) but no significant difference in July (ratio = 1.11, P = 0.09) (Table 1). In contrast, LMM analyses showed no significant differences in the Shannon index between liquid types, although values were slightly higher in vinegar (mean = 1.01) than in brine (mean = 0.94), the difference was not significant across all combined periods (P = 0.08) (Table 2).

Table 1. Effect of preservation liquid (vinegar/propylene glycol) on species diversity and Shannon index of carabids captured in sugar beet in 2023. A generalised linear mixed model (GLMM) with a Poisson distribution was used for species richness, and a linear mixed model (LMM) for the Shannon index, both with plot as a random effect (and sampling period as an additional random effect for the global analyses). Estimated mean values per liquid type, ratios (richness) or differences (Shannon) between liquids, and associated *P*-values are presented for the periods of April, July, August, and across all periods combined (****P* < 0.001, ***P* < 0.01, **P* < 0.05).

Index	Liquid	April	July	August	Global
Species richness	Vinegar	3.52	2.65	3.50	3.21
	Propylene	3.27	2.44	3.34	3.00
	Ratio V/P	1.08	1.09	1.05	1.07
	P-value (GLMM)	0.196	0.197	0.419	0.058
Shannon index	Vinegar	0.97	0.54	0.72	0.74
	Propylene	0.92	0.52	0.75	0.73
	Difference V−P	+0.05	+0.02	−0.03	+0.01
	P-value (LMM)	0.347	0.528	0.474	0.595

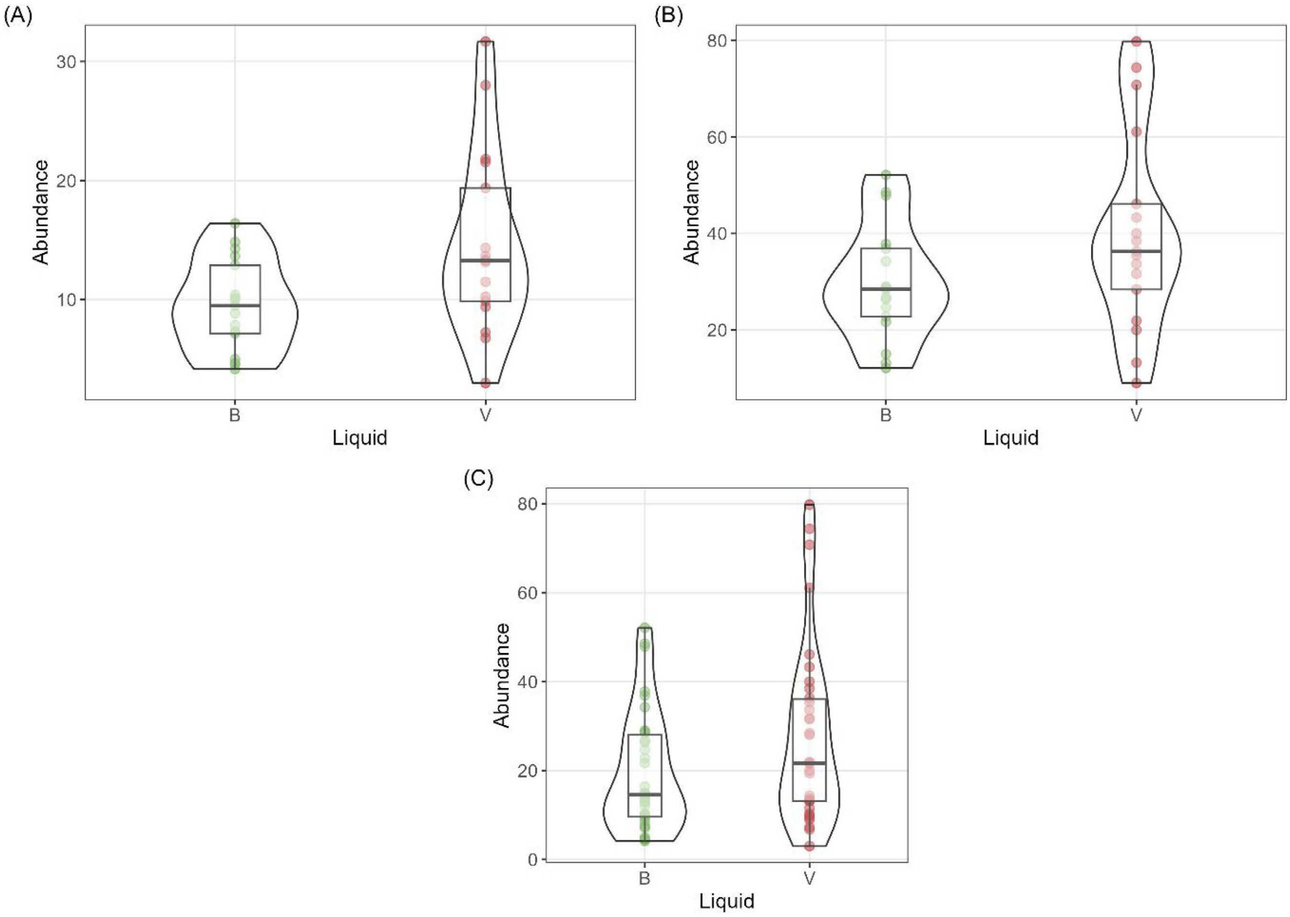

Fig. 6. Effect of preservation liquid (B – brine, V – vinegar) on the mean abundance of carabids captured, across all species. The violin plots illustrate the paired comparison of carabid abundance between the two liquid types for each plot, in (A) April, (B) July, and (C) across the entire study period.

Effect of the liquid on the presence of specific carabid species

Analyses using IndVal and GLMM methods revealed significant differences between liquid types in their effectiveness for capturing different species in the Barber traps. Overall, vinegar captured a higher number of individuals for certain species, while the other liquid tested proved more effective for others.

Table 2. Effect of preservation liquid (vinegar/brine) on species diversity and Shannon index of carabids captured in cereals in 2024. A generalised linear mixed model (GLMM) with a Poisson distribution was used for species richness, and a linear mixed model (LMM) for the Shannon index, both with plot as a random effect (and sampling period as an additional random effect for the global analyses). Estimated mean values per liquid type, ratios (richness) or differences (Shannon) between liquids, and associated *P*-values are presented for the periods of April, July, and across all periods combined (*** *P* < 0.001, ** *P* < 0.01, * *P* < 0.05).

Index	Liquid	April	July	Global
Species richness	Vinegar	4.74	4.03	4.39
	Brine	3.94	3.65	3.83
	Ratio V/B	1.20	1.11	1.15
	P-value (GLMM)	0.002**	0.090	0.001**
Shannon index	Vinegar	1.19	0.84	1.01
	Brine	1.09	0.78	0.94
	Difference V−B	+0.10	+0.06	+0.07
	P-value (LMM)	0.133	0.283	0.083

In the vinegar-propylene glycol comparison, GLMM results showed that propylene glycol captured significantly more individuals of *Phyla obtusa* (Audinet-Serville, 1821) and *Ocydromus tetracolus* (Say, 1823), particularly in April and July, while vinegar was more effective for *Poecilus cupreus* (Linnaeus, 1758) during the same periods (Table 3). Significantly more individuals of *Pterostichus melanarius* (Illiger, 1798) were also collected in vinegar in July, although this trend was not detected by the IndVal method.

For the vinegar-brine comparison, vinegar captured significantly more individuals of several species in April, including *Loricera pilicornis* (Fabricius, 1775), *Metallina properans* (Stephens, 1828), *Nebria brevicollis* (Fabricius, 1792), and *Poecilus cupreus* (Table 4). In July, this trend continued for *Anchomenus dorsalis* (Pontoppidan, 1763) and *Trechus quadristriatus* (Schrank, 1781). However, for *Notiophilus biguttatus* (Fabricius, 1779), the difference observed with IndVal was not confirmed by GLMM.

DISCUSSION

The results of our study indicate that vinegar is at least as effective as propylene glycol. Indeed, the analysis of assemblage composition reveals no significant differentiation between carabid communities captured in traps containing vinegar versus those filled with propylene glycol, while a

Table 3. Number of individuals captured per indicator species in Barber traps containing vinegar or propylene glycol for the months of April, July, and August. The *P*-values are derived from IndVal and GLMM analyses. Significant *P*-values ($P < 0.05$), indicating a difference between the liquids for a given species, are highlighted in bold.

Vinegar-propylene comparison	Species	Individuals captured in vinegar	Individuals captured in brine	*P*-value IndVal	GLMM *P*-value
April	*Phyla obtusa*	146	240	0.103	0.02
	Poecilus cupreus	329	206	0.351	0.01
July	*Ocydromus tetracolus*	53	150	0.07	0.0004
	Phyla obtusa	102	221	0.06	0.0006
	Poecilus cupreus	584	196	0.03	2.67e-07
	Pterostichus melanarius	6203	3657	0.332	0.01
August	*Loricera pilicornis*	30	4	0.01	0.003

significant divergence emerges when comparing vinegar and brine, particularly in April, suggesting that the nature of the preservation liquid may influence community structure. However, vinegar captured a higher number of individuals compared to both propylene glycol and brine. In some instances, vinegar even proved more effective than brine in reflecting diversity. Nevertheless, these differences were not uniform across all sampling periods. In terms of abundance, they were significant in July for propylene glycol and in April for brine. Furthermore, species diversity and the Shannon index remained generally similar between the different liquids, with the exception of a slight improvement in species richness with vinegar compared to brine, both in April and across all periods.

Influence of odours

The increase in abundance observed in vinegar-filled traps can be attributed to the attractive properties of this liquid, likely related to its characteristic smell, which may stimulate the locomotor activity of certain carabid beetles. Several studies (Scheller, 1984; Woodcock, 2005; McCravy & Willand, 2007) have demonstrated that strong volatile compounds, such as those emitted by vinegar, promote increased capture of carabid beetles compared to odourless solutions. This chemical attraction/repulsion, based on semiochemical perception essential for many insects, may thus explain the observed disparities. In contrast, brine, due to its reduced preservative capacity and rapid evaporation, may generate decaying odours that, in turn, repel certain carabid beetles (Schmidt et al., 2006). It is important to note, however, that our aim was to best assess carabid populations, not artificially increase the number of individuals captured. Therefore, a liquid whose attractive effect enhances capture could bias the estimation of true abundance by overestimating certain species sensitive to this attractant, at the expense of less responsive species or those repelled by the stimulus. Our GLMM and IndVal analyses clearly illustrate these interspecific disparities: for example, *Poecilus cupreus* and *Pterostichus melanarius* seem to prefer vinegar, while *Phyla obtusa* and *Ocydromus tetracolus* are favoured by propylene glycol, whose lower volatility might reduce the attractive effect of the liquid. These findings support previous work highlighting that the nature of the preservation liquid can alter the relative representation of species (Luff, 1975; Topping, 1993; Kwon et al., 2022).

While the strong odour of vinegar might be expected to attract not only carabids but also non-target vertebrates such as wild boar, foxes, or large birds, our data did not support this concern. Trap loss rates remained low overall (5.29%) and, in both comparisons, vinegar traps showed lower loss rates than the alternative liquids (1.71% vs 3.40% for propylene glycol in 2023; 9.18% vs 11.0% for brine in 2024), with no statistically significant differences detected. This suggests that, in our agricultural context, vinegar did not result in increased disturbance by wildlife and therefore did not introduce a differential bias in abundance or composition estimates between liquid types. While these results may not generalise to all environments, they are reassuring for the use of vinegar as a preservation liquid in similar agroecosystems.

Table 4. Number of individuals captured of selected species in Barber traps containing vinegar or brine for the months of April and July. The *P*-values are derived from IndVal and GLMM analyses. Significant *P*-values ($P < 0.05$), indicating a difference between the liquids for a given species, are highlighted in bold.

Vinegar-brine comparison	Species	Individuals captured in vinegar	Individuals captured in propylene	*P*-value IndVal	GLMM *P*-value
April	*Loricera pilicornis*	90	21	0.04	2.10e-04
	Metallina properans	29	7	0.02	0.01
	Nebria brevicollis	38	13	0.015	0.01
	Nebria salina	76	46	0.072	0.14
	Poecilus cupreus	545	117	0.005	5.83e-08
July	*Anchomenus dorsalis*	144	91	0.01	0.01
	Notiophilus biguttatus	0	9	0.009	0.9
	Poecilus cupreus	641	431	0.065	0.1
	Pterostichus melanarius	4264	2947	0.08	0.1
	Trechus quadristriatus	48	14	0.004	0.04

Seasonal variability and capture efficiency

The absence of significant differences in terms of abundance in April and August, contrasting with those observed in July, suggests that the efficiency and attractiveness of preservation liquids interact with the seasonal cycles of carabid beetles. The July period, often marked by increased activity and specific behaviours related to reproduction or foraging, may amplify the attractive or repulsive effects of vinegar. Moreover, the higher temperatures during this period favour evaporation, which could reduce the effectiveness of more volatile liquids such as brine, thus facilitating beetle escape (Schmidt et al., 2006). Furthermore, the attractive or repulsive orientation induced by preservatives appears to vary depending on sex (Adis, 1976), season (Dethier, 1947; Adis & Kramer, 1975; Adis, 1976), and environmental context (Koivula et al., 2003). In our study, this phenomenon is evident in the vinegar–propylene comparison conducted in 2023, where only the July period showed a significantly higher capture rate for vinegar traps. In contrast, in the vinegar–brine comparison, all periods except July showed significant differences, which may be explained by an unusually rainy summer in 2024. Additionally, brine, due to its lesser ability to kill quickly and its high buoyancy, would allow larger beetles to escape (McCravy & Willand, 2007). This is consistent with the fact that the majority of indicator species for vinegar in the brine comparison are larger species (e.g., *Nebria salina*, *Poecilus cupreus*, *Pterostichus melanarius*). In contrast, propylene glycol and acetic acid, due to their ability to kill quickly and their higher density, seem to provide comparable results (Santos et al., 2007), as evidenced by the absence of a marked distinction between assemblages captured with these two liquids.

Methodological perspectives

The performance of vinegar as an economical alternative to conventional liquids, such as propylene glycol, aligns with the conclusions of recent studies (Aristophanous, 2010; Gardarin & Valantin-Morison, 2021) suggesting that less costly solutions can be used without compromising sampling quality. Although some differences remain, notably due to the smell of vinegar, our data show that the composition of the assemblages, as well as their diversity and abundance, remain generally comparable across most sampling periods. However, it is important to acknowledge that our experimental design did not allow direct comparison of all three liquids within the same experiment, year, or cropping system, which limits cross-context interpretation of these findings. While the differences between liquids may seem marginal within each specific comparison (vinegar vs. propylene glycol in sugar beet; vinegar vs. brine in cereals), it is important to note that, in a broader context of comparisons between studies conducted under varied conditions, the use of different liquids could introduce subtle discrepancies, thereby influencing the results obtained. Therefore, it is crucial to account for these variations to ensure comparability in large-scale studies.

On the other hand, brine stands out due to more contrasting results, particularly because of its variable performance depending on environmental conditions. For instance, during particularly wet years, such as 2024, a high number of slugs were captured in brine traps. These slugs produced a substantial amount of mucus upon contact with the salt, resulting in the formation of a solid mucus block inside the trap. This phenomenon not only limited the capture of other invertebrates but also made the identification of certain individuals more difficult.

The literature also highlights that the composition of the preservation liquid can influence not only capture efficiency but also the morphological and molecular preservation of specimens (Moreau et al., 2013; Nakamura et al., 2020; Graux et al., 2024). In the future, with the growing accessibility of genetic analysis and sequencing, it will be essential to prioritise liquids that ensure optimal DNA preservation. For such applications, propylene glycol may prove more suitable than vinegar, offering better long-term genetic conservation (Weigand et al., 2021).

CONCLUSION

The primary objective of this study was to assess the effectiveness of vinegar as an alternative to conventional preservation liquids – propylene glycol and brine – used in Barber traps to sample carabid beetle populations within agroecosystems. By comparing vinegar with propylene glycol in sugar beet and vinegar with brine in cereals at different stages of the growing cycle, we sought to determine whether vinegar, as a more affordable option, could offer equivalent performance in terms of abundance, diversity, and composition of carabid assemblages.

Our results indicate that, overall, vinegar and propylene glycol yield similar surveys. Both liquids capture a comparable number of individuals and yield species assemblages with equivalent diversity indices. In contrast, brine is distinguished by significantly lower efficiency, likely due to its reduced ability to kill quickly and its buoyancy, which favours beetle escape. These results confirm that brine should be avoided for carabid surveys within the studied context. However, it is important to note that despite overall similarities, interspecific differences persist. Indeed, certain species appear to be particularly attracted or repelled by vinegar. These disparities could introduce biases in the census of certain communities, particularly in environments or crop systems with differing dynamics. Future investigations conducted in more diverse environments or in less intensive crops could reveal more marked differences between the performance of these preservation liquids, thus providing a better understanding of the attraction or repulsion mechanisms related to the chemical properties of each.

Furthermore, in a context where DNA analysis is becoming increasingly prominent in community ecology, the preservation of genetic integrity is a critical criterion. Although vinegar offers promising performance for morphological surveys, propylene glycol may represent a more suitable option for studies requiring optimal DNA conservation over the long term. This reflection on the future of analysis methods underscores the importance of tailoring the choice of preservation liquid to the specific objectives of each research.

In conclusion, given our results and those reported by other studies, and considering the substantial price difference between vinegar and propylene glycol, it is difficult to dismiss vinegar as a viable alternative. This cost-effective solution demonstrates comparable performance for carabid beetle population surveys and should not be ruled out for entomological surveys. However, the choice of preservation liquid should align with the study's objectives, whether for accurate population quantification or for specimen preservation for genetic analysis.

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