

Article

Preference of Major Stored Product Insects in Fortified Rice with Basil

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Abstract: As the world's population grows, the needs for feeding it follow the same path. Considering these conditions, ensuring the quantity and quality of raw materials, such as cereals, seems imperative. Stored product insects are responsible for significant losses in the post-harvest stages of agricultural products and the available chemical methods for their control are decreasing, due to their negative impact on the environment and humans. To this end, the evaluation of the efficacy of non-chemical methods for the management of storage insects is crucial. In the present study, we conducted two trials of choice tests based on rice fortified with basil to determine its potential as a non-chemical repellent of stored product insects. In the first trial, we evaluated the repellent activity of rice enriched with basil on adults of *Sitophilus oryzae*, *Rhyzopertha dominica*, *Tribolium castaneum* and *Oryzaephilus surinamensis*, as well as on *T. castaneum* larvae. In the second trial, the same procedure was followed with deltamethrin-treated rice fortified with basil. The results of the first trial showed that for most of the insect species tested, the rice fortified with basil was moderately repellent, while for *O. surinamensis*, it was attractive. Surprisingly, in the second trial, the deltamethrin-treated rice fortified with basil showed a repellent effect on *O. surinamensis* adults and *T. castaneum* larvae, while no repellency was observed for the rest of insect species examined. Observation time was not significant for any of the insect species, combinations and trials, with the exception of the rice fortified with basil vs. Blanc combination in *O. surinamensis*. Our findings suggest that the use of deltamethrin-treated rice fortified with basil was effective as a repellent for *O. surinamensis* adults and *T. castaneum* larvae.

Keywords: repellency; stored product insects; fortified rice; basil; deltamethrin



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1. Introduction

The expected increase in the world's population requires up to a 50% increase in food availability [1–3]. Cereals have been the main source of human nutrition for centuries [4]. At a time when more than 690 million people are undernourished, the need for grain quality and quantity insurance is considered imperative [3,5]. Stored product insects are primarily responsible for post-harvest losses occurring during storage [4]. Specifically, grain losses during the storage period in India are estimated at USD 1 billion [6,7], of which, USD 364 million are losses due to insect infestation [8]. However, this amount increases dramatically, reaching up to 20% of production, as far as developing countries are concerned [9].

Oryza sativa L., commonly known as rice, belongs to the Poaceae family and is one of the most nutritious and widely consumed staple foods [10]. Indeed, according to the Food and Agricultural Organization of the United Nations (FAO) in 2019, rice came third in the global ranking of the most produced agricultural grains, while the upward growth of rice production continued in 2021–2022, when 509.87 million metric tons of rice were consumed worldwide [11]. China is the largest producer and consumer of rice worldwide and its

government maintains a state reserve to ensure food self-sufficiency [12]. In Bangladesh, one of the major rice-growing regions, most of the production is stored by farmers for at least one growing year, thus exposing the rice for a long time to the unpredictable conditions prevailing in the storage facilities, such as warehouses, etc. [13]. In another rice-producing country, India, the annual rate of rice storage losses is 3.51%, most of which is due to the insect infestation [14,15]. Apart from losses, insect infestation in rice can lead to a non-normal appearance, unwanted changes both in the biochemical composition and in the glycemic values, but also a lack of digestibility [15].

The most effective controlling methods for stored product insects include the use of chemical contact insecticides, as well as gaseous insecticides, such as fumigants [16,17]. The most commonly used fumigant is phosphine, which can efficiently protect stored commodities from a wide range of stored product insects and mites. Nevertheless, the incorrect practices that have been repeatedly followed for decades during the application of insecticides, the multiple undesirable effects on human health, and the development of insect resistance to various active ingredients, including phosphine, have oriented the scientific community to the research of new, alternative, environmentally friendly methods of insect control [4,18,19].

The plant kingdom includes 2121 species of aromatic and medicinal plants that could be helpful in pest management, of which 297 have demonstrated insect repellent properties [20]. A repellent can generally be described as a substance that can be used “to cause movement away from stimuli to be repulsed” or “an agent of action as in any stimulus which elicits an avoiding reaction” [21]. *Ocimum basilicum* (L.) (Lamiales: Lamiaceae) is an industrial aromatic and medicinal plant native to Africa and India but widespread in many parts of the world [22–24]. Extensive research in *O. basilicum* extracts has shown that it has antimicrobial, antioxidant [25], antiviral [26], anti-inflammatory [27], insecticidal, and repellent properties, especially against mosquitoes [28–31]. There is an abundance of published work highlighting the effectiveness of *O. basilicum* as a grain protectant either through its insecticidal or repellent activity [22,32–41]. For instance, Al-Harbi et al. [40] found that *O. basilicum* essential oils caused a 100% mortality of the adult stage of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). In the same study, *O. basilicum* essential oils had the highest repellent activity against *S. oryzae*, compared to the essential oils of black caraway, *Nigella sativa* (L.) (Ranunculales: Ranunculaceae), seeds and lavender, *Lavandula angustifolia* Mill. (Lamiales: Lamiaceae), flowers.

Agrafioti et al. [41] were the first that evaluated the development of stored product insects in rice fortified with basil and found that fortification generally reduced the infestation level from *S. oryzae*, the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae), while the insect population growth was also reduced compared to the unfortified rice. However, no information is available on the repellent effect of rice fortified with basil against stored product insects. To close this gap, in the first series of trials, choice tests were conducted to determine the repellent effect of rice fortified with basil against major stored product insects, while in the second series of trials, choice tests were carried out with deltamethrin-treated rice fortified with basil, in light of the fact that the spraying with contact insecticides is, on the one hand, one of the most widespread methods of insect control during the postharvest stages and on the other hand, to evaluate the behavior of stored product insects after their exposure to the combination of an active substance and basil.

2. Materials and Methods

2.1. Insects

Adults of *S. oryzae*, *R. dominica*, *O. surinamensis*, and the red flour beetle, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae), as well as larvae of *T. castaneum* were used for experimentation. All species were reared at the Laboratory of Entomology and Agricultural Zoology (LEAZ), Department of Agriculture, Crop Production, and Rural

Environment, University of Thessaly, at 25 °C, 65% relative humidity (r.h.), and continuous darkness. *Sitophilus oryzae* and *R. dominica* were reared on whole wheat kernels, *T. castaneum* on wheat flour, and *O. surinamensis* on oat flakes. Adult beetles <1 month-old and larvae of last instar were used in the tests. All rearings of the abovementioned insect species have been kept under laboratory conditions for more than 20 years.

2.2. Rice Fortification

White milled long grain rice (“nychaki”) obtained from the Arnaoutelis S.A. rice industry (Lamia, Fthiotida, Greece) was used in our trials. For the rice fortification with basil, we followed the procedure recommended by Igoumenidis et al. [42] and Agrafioti et al. [41]. Briefly, dry basil leaves (50 g) were soaked and remained fully immersed for 10 min in double-heated deionized water (3.5 L). After soaking and cooling down to room temperature, the basil aqueous extract (3 L) was heated again to boiling temperature using a conventional cooker and 200 g of white milled rice was added and cooked for 20 min under continuous stirring. After cooking, the fortified rice with basil was strained and freeze-dried (Telstar Cryodos, Terrassa, Spain). Unfortified white milled, long-grain rice (“nychaki”), afterwards referred as conventional rice, served as control.

2.3. Insecticidal Application

A commercial formulation of deltamethrin (K-Othrine 25 SC, 2.5% w/w active ingredient (a.i.), Bayer Hellas, Attiki, Greece) was used in the experiments. The label dose of deltamethrin (9.7 mg of grain/m²) was utilized and applied in uninfested and insecticide-free fortified rice with basil. Insecticide spraying solutions were prepared by diluting the appropriate amount of the insecticide in 50 mL of distilled water. Afterwards, 1 mL of the spraying solution was sprayed on 110 g of rice fortified with basil, using a specialized airbrush (Badger 100, Kyoto BD-183 K Grapho-tech, Kyoto, Japan). Then, the grains were placed in a glass jar and shaken manually for 2 min to ensure the equal distribution of the insecticide in the entire grain mass.

2.4. Choice Tests

2.4.1. Test 1—Untreated Choice Tests

The tests were conducted inside plastic Petri dishes (90 mm diameter, 15 mm high) with 63.61 cm² bottom surface (Greiner Bio-One, Carl Roth GmbH + Co. KG, Karlsruhe, Germany), which were divided into two equal parts. For the one-choice tests, 0.5 g of conventional rice (C) or fortified rice with basil (F) was placed in one part of the dish, whereas the other part was left empty and served as blank (B) (control area). For the two choice-tests, 0.5 g of fortified rice (F) was placed in one part of the dish and 0.5 g of conventional rice (C) was placed in the other part (control area). One unsexed individual of each insect species was released in the center of the dish, with different Petri dishes for each insect species. The insect presence on the treated and untreated area or in the middle of the Petri dish was recorded 5, 10, 15, 30, and 60 min after exposure. There were 20 dish replicates for each insect species and life stage.

2.4.2. Test 2—Treated Choice Tests

The same experimental procedure described for Test 1 was also followed in Test 2, in which we evaluated the insect response to deltamethrin-treated rice. For this reason, 0.5 g of deltamethrin-treated conventional rice or deltamethrin-treated fortified rice with basil (CD and FD, respectively) (please refer to Section 2.3 for deltamethrin application) was placed in one part of the dish (treated area), whereas in the other part, 0.5 g of conventional rice or rice fortified with basil was placed (untreated area). More specifically, we tested four different combinations: (i) deltamethrin-treated fortified rice with basil vs. conventional rice (FD vs. C), (ii) deltamethrin-treated conventional rice vs. basil fortified-rice (CD vs. F), (iii) deltamethrin-treated fortified rice with basil vs. basil fortified-rice (FD vs. F),

(iv) deltamethrin-treated conventional rice vs. conventional rice (CD vs. C). Each treatment was replicated 20 times for each insect species and life stage.

2.5. Statistical Analysis

Prior to analysis, all data were tested for normalization and homogeneity using the Shapiro–Wilk test. Since the required assumptions for parametric tests were not met, nonparametric analyses were performed. For both choice tests (Test 1 and 2), for each treatment and insect species tested, the data were analyzed separately with a generalized linear model framework, with observation time as the response variable. To determine the effect of each treatment on insect choice, the average number of insects present in each part of the Petri dish for each observation time was subjected to Wilcoxon signed-rank test ($p < 0.05$). A Friedman’s test was used to detect differences between treatments ($p < 0.05$), when there was a number of insects that chose to stand in the middle of the Petri dish. All data were analyzed using SPSS 29.0 (IBM Corporation, Armonk, NY, USA).

3. Results

3.1. Test 1—Untreated Choice Tests

For all insect species examined, the observation time did not play a significant role in the insects’ choice, with the exception of *O. surinamensis* and the combination of F vs. B (Table 1). Most *S. oryzae* adults (60%) opted for F in the combination F vs. B; however, no significant differences were detected either in this combination or in the rest of the combinations tested (F vs. C and C vs. B) (Figure 1).

Table 1. Chi-square parameters of the untreated choice tests (Conventional vs. Fortified (C vs. F), Fortified vs. Blanc (F vs. B) and Conventional vs. Blanc (C vs. B)) for the different observation intervals (5, 10, 15, 30, and 60 min), in all cases $df = 4$.

Combinations	Adults						Larvae			
	<i>Sitophilus oryzae</i>		<i>Rhyzopertha dominica</i>		<i>Tribolium castaneum</i>		<i>Oryzaephilus surinamensis</i>		<i>Tribolium castaneum</i>	
	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
C vs. F	2.161	0.706	11.830	0.159	1.642	0.990	5.330	0.255	0.657	0.957
F vs. B	2.083	0.720	1.765	0.987	1.634	0.990	13.388	0.010	0.579	0.965
C vs. B	1.761	0.780	8.255	0.409	3.406	0.906	1.042	0.903	1.616	0.806

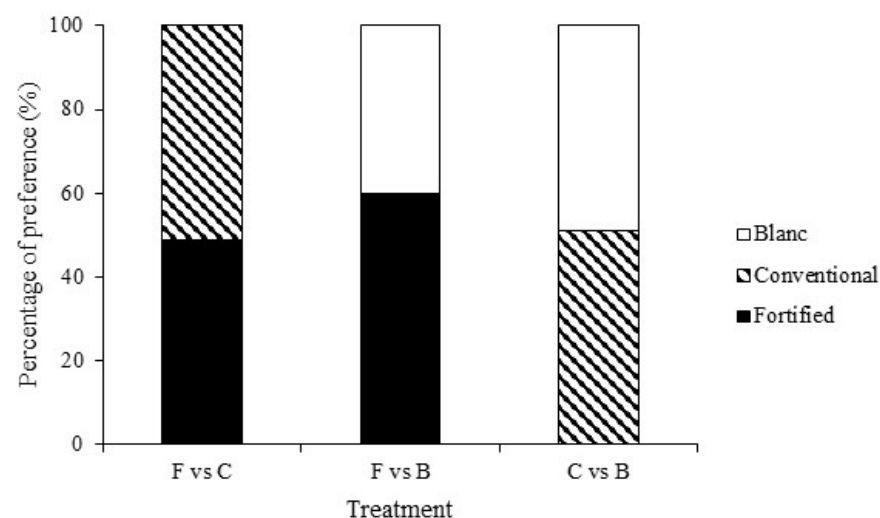


Figure 1. Average choice rate (%) of *Sitophilus oryzae* adults for each of the three following combinations: Conventional vs. Fortified rice (C vs. F), Fortified rice vs. Blanc (F vs. B), and Conventional rice vs. Blanc (C vs. B).

Regarding *R. dominica* adults, a percentage of 13–15% remained in the middle of the Petri dish for all the combinations examined (F vs. C, F vs. B, and C vs. B). This specific percentage of *R. dominica* individuals differed significantly compared to C, F, and B in the combinations F vs. C, F vs. B, C vs. B, respectively (Figure 2). Overall, twice as many individuals of *R. dominica* selected C compared to F, 1.2 more individuals selected F compared to B, and 1.5 more individuals were detected in the B compared to C. Nevertheless, no significant difference was recorded in the mean number of *R. dominica* that chose one of the two options (F or C, F or B, and C or B) in all the combinations evaluated (Figure 2).

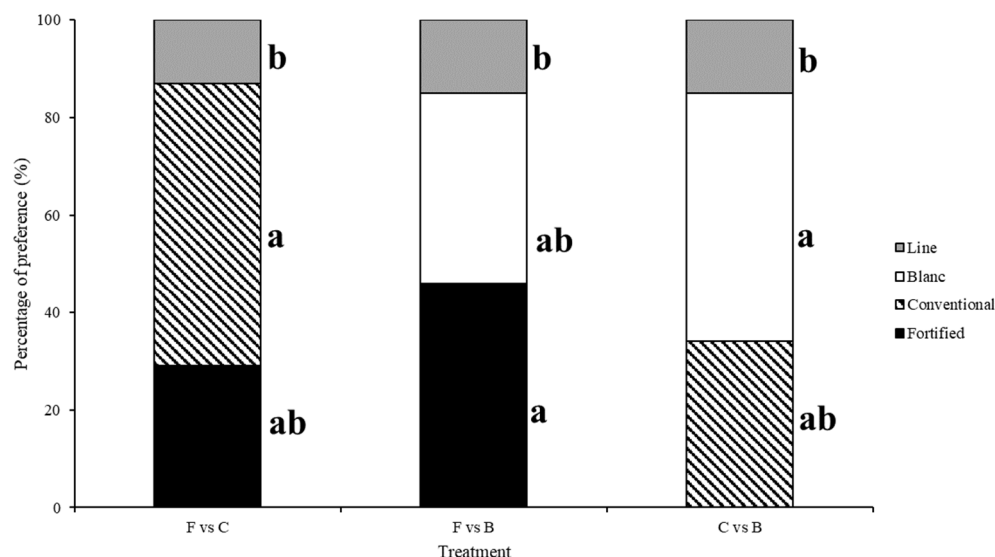


Figure 2. Average choice rate (%) of *Rhyzopertha dominica* adults for each of the three following combinations: Conventional vs. Fortified rice (C vs. F), Fortified rice vs. Blanc (F vs. B), and Conventional rice vs. Blanc (C vs. B). The percentage (%) of insects that chose to stand in the line in the middle of Petri dish, represented as “Line”. For each combination, means followed by the same lowercase letter are not significantly different, according to chi-square test at 0.05; where no letters exist, no significant differences were noted. Chi-square parameters for the F vs. C combination were: $\chi^2 = 8.4$, $df = 2$, $p = 0.015$, for the F vs. B were: $\chi^2 = 8.3$, $df = 2$, $p = 0.016$, for the B vs. C were: $\chi^2 = 10.00$, $df = 2$, $p < 0.001$.

The percentage of *T. castaneum* adults that remained on the line in the center of the Petri dish fluctuated at smaller levels (6–7%) in relation to the respective *R. dominica* figures (Figure 3). In the combination, F vs. C, 55% of the insects chose C, while the percentage of individuals that chose F was 67% in the combination F vs. B. Finally, in the combination C vs. B, the number of *T. castaneum* adults was equally distributed in the two dish parts (Figure 3). In the case of *O. surinamensis* adults, the preference for F was stronger compared to C and B, while in the combination C vs. B, no statistically significant differences were detected (Figure 4). In the F vs. C and F vs. B combinations, the highest number of *T. castaneum* larvae chose for F (58 and 59%, respectively), while in the C vs. B combination 54% of the larvae chose C and 46% B (Figure 5). However, no statistical differences were detected for any of the combinations examined (Figure 5).

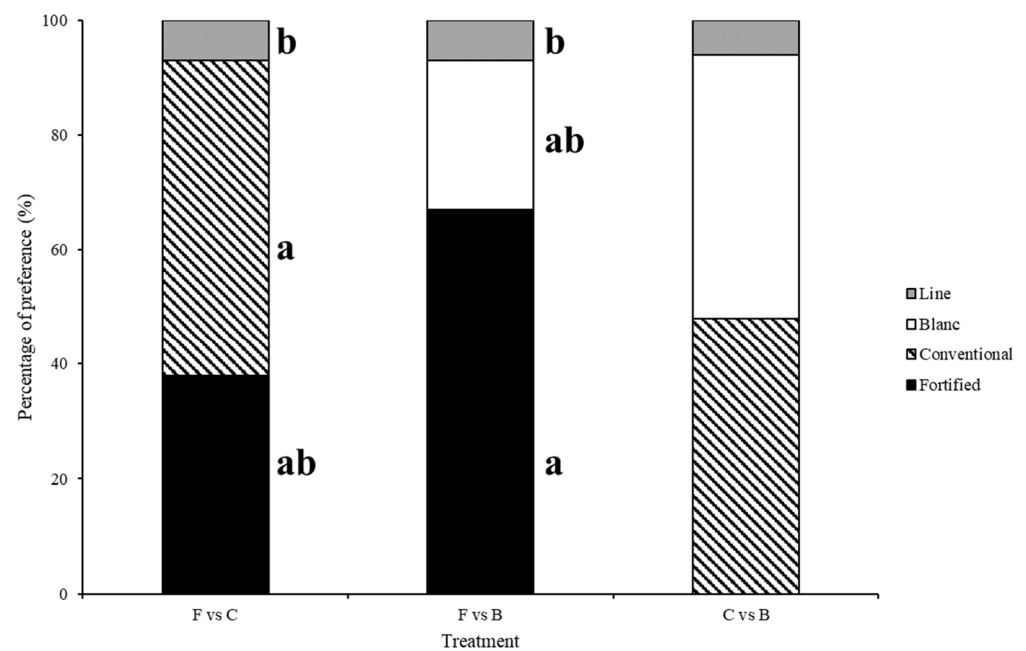


Figure 3. Average choice rate (%) of *Tribolium castaneum* adults for each of the three following combinations: Conventional vs. Fortified rice (C vs. F), Fortified rice vs. Blanc (F vs. B), and Conventional rice vs. Blanc (C vs. B). The percentage (%) of insects stand in the line in the middle of Petri dish, presented as “Line”. For each combination, means followed by the same lowercase letter are not significantly different, according to chi-square test at 0.05, where no letters exist, no significant differences were noted. Chi-square parameters for the F vs. C combination were $\chi^2 = 10.0$, $df = 2$, $p < 0.001$, for the F vs. B were $\chi^2 = 10.0$, $df = 2$, $p < 0.001$.

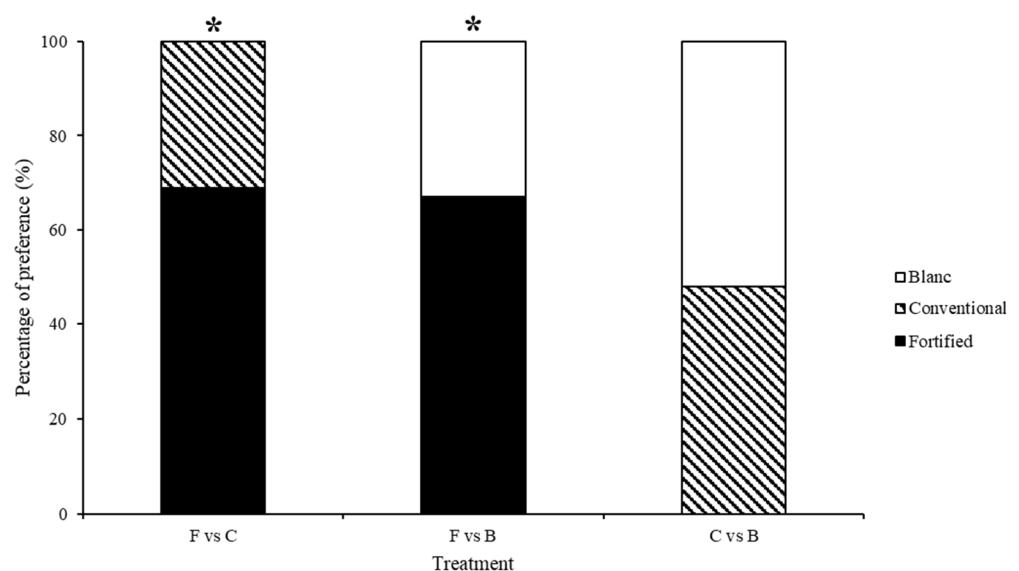


Figure 4. Average choice rate (%) of *Oryzaephilus surinamensis* adults for each of the three following combinations: Conventional vs. Fortified rice (C vs. F), Fortified rice vs. Blanc (F vs. B), and Conventional rice vs. Blanc (C vs. B). For each combination, means with asterisks (*) indicate significant differences between the two choices, according to Wilcoxon signed-rank test at $p < 0.05$ (in all cases $df = 4$). Where no asterisk (*) exists, no significant differences were found. Wilcoxon’s signed-rank test parameters for F vs. C were: $z = -2.0$, $df = 1$, $p = 0.046$, for F vs. B were: $z = -2.0$, $df = 1$, $p = 0.041$.

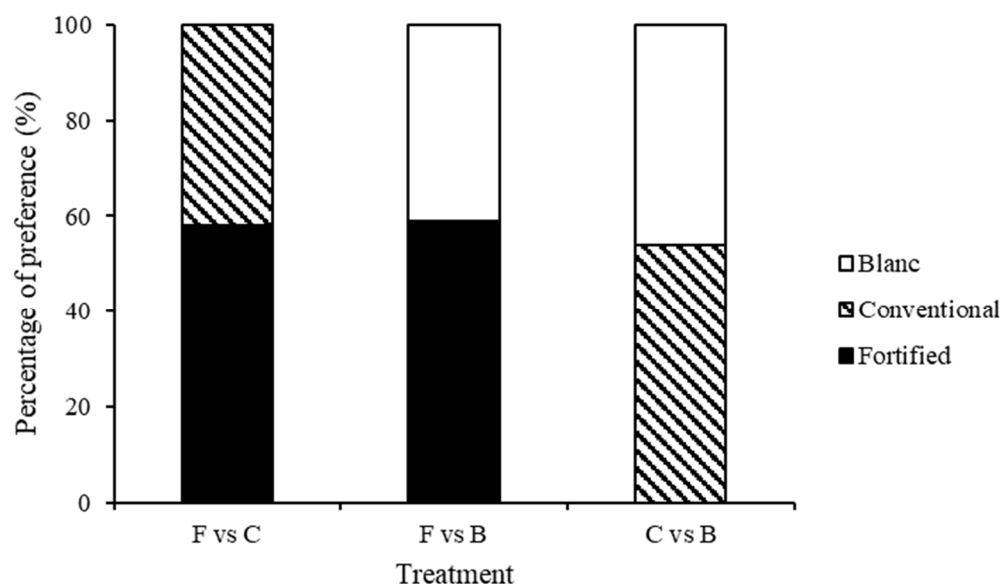


Figure 5. Average choice rate (%) of *Tribolium castaneum* larvae for each of the three following combinations: Conventional vs. Fortified rice (C vs. F), Fortified rice vs. Blanc (F vs. B), and Conventional rice vs. Blanc (C vs. B)..

3.2. Test 2—Treated Choice Tests

Observation time did not affect the selection of any of insect species and treated combinations tested (Table 2). For the majority of the combinations tested, deltamethrin-treated rice, either fortified with basil or conventional, collected the highest percentage of *S. oryzae* adults. More specifically, 59% chose the FD in the FD vs. C combination, 55% chose the CD in the F vs. CD combination, and 59% chose the CD in the CD vs. C combination (Figure 6). An exception was the combination of FD vs. F, where F collected 53% of *S. oryzae* individuals compared to FD, which collected 47%. However, no differences were detected in this combination or in the others evaluated (Figure 6). In the case of *R. dominica*, statistically significant differences were presented only in the combination CD vs. C, where CD collected two times more adults compared to C (Figure 7). The other combinations collected a similar mean number of *R. dominica* adults in both options (Figure 7).

Table 2. Chi-square parameters of the treated choice tests (Fortified with deltamethrin vs. Conventional (FD vs. C), Fortified vs. Conventional with deltamethrin (F vs. CD), Fortified with deltamethrin vs. Fortified (FD vs. F), and Conventional with deltamethrin vs. Conventional (CD vs. C) for the different observation intervals (5, 10, 15, 30, and 60 min), in all cases $df = 4$.

Combinations	Adults						Larvae			
	<i>Sitophilus oryzae</i>		<i>Rhyzopertha dominica</i>		<i>Tribolium castaneum</i>		<i>Oryzaephilus surinamensis</i>		<i>Tribolium castaneum</i>	
	X ²	p	X ²	p	X ²	p	X ²	p	X ²	p
FD vs. C	3.473	0.482	2.576	0.631	0.568	0.967	3.125	0.537	0.624	0.960
F vs. CD	0.404	0.982	1.067	0.899	1.445	0.836	0.879	0.928	1.104	0.894
FD vs. F	1.044	0.903	1.761	0.780	1.952	0.745	4.835	0.305	1.250	0.870
CD vs. C	3.059	0.548	3.890	0.421	0.624	0.960	4.948	0.293	1.515	0.824

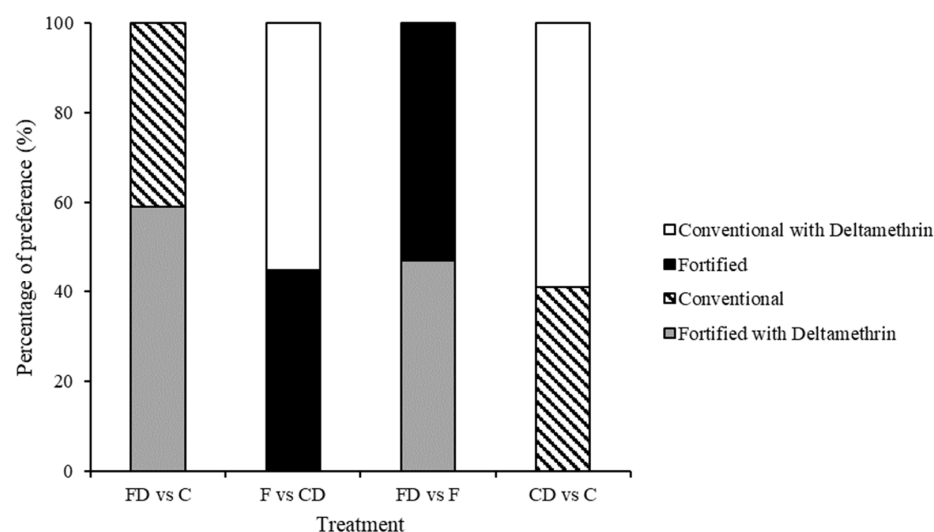


Figure 6. Average choice rate (%) of *Sitophilus oryzae* adults for each of the three following combinations: Fortified with deltamethrin vs. Conventional rice (FD vs. C), Fortified vs. Conventional with deltamethrin rice (F vs. CD), Fortified with deltamethrin vs. Fortified rice (FD vs. F), and Conventional with deltamethrin vs. Conventional rice (CD vs. C).

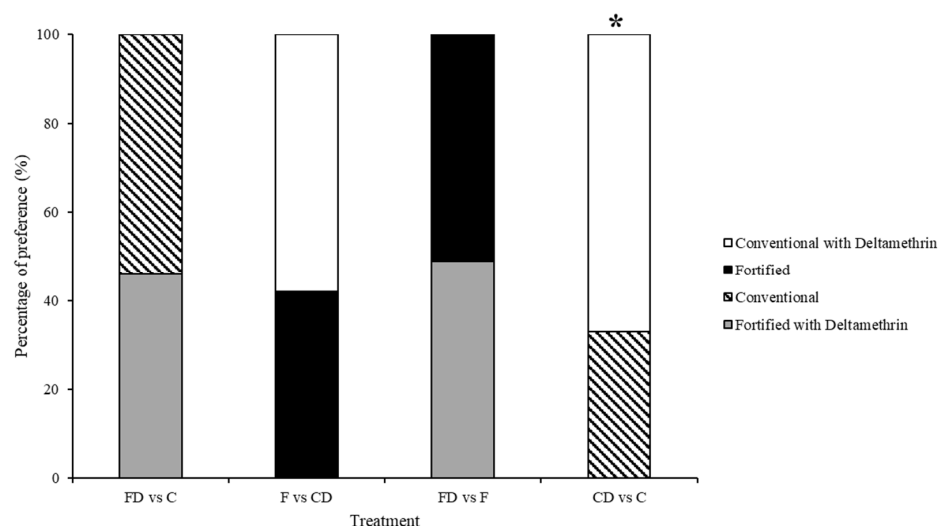


Figure 7. Average choice rate (%) of *Rhyzopertha dominica* adults for each of the three following combinations: Fortified with deltamethrin vs. Conventional rice (FD vs. C), Fortified vs. Conventional with deltamethrin rice (F vs. CD), Fortified with deltamethrin vs. Fortified rice (FD vs. F), and Conventional with deltamethrin vs. Conventional rice (CD vs. C). For each combination, means with asterisks (*) indicate significant differences between the two choices, according to Wilcoxon signed-rank test at $p < 0.05$ (in all cases $df = 4$). Where no asterisk (*) exists, no significant differences were found. Wilcoxon's signed-rank test parameters for CD vs. C were $z = -2.0$, $df = 1$, $p = 0.043$.

Adults of *T. castaneum* showed a completely different preference for the combinations examined compared to the previous two insect species (Figures 6–8). In this case, for most of the combinations examined, untreated rice (without deltamethrin), either F or C, collected the highest number of individuals, except for the F vs. CD combination (Figure 8). Among the treatments, a significantly higher number of *T. castaneum* adults were detected in C (66%) compared to CD (34%) (Figure 8).

The repellent effect of deltamethrin was strongly demonstrated in the case of *O. surinamensis*. In particular, only 1/5 of *O. surinamensis* adults chose FD in the combination, FD vs. C, while correspondingly, in the rest of the combinations the higher percentage of individuals chose F or C compared to FD or CD (Figure 9). Nevertheless, significant

differences between the two options were shown in three out of four combinations tested (Figure 9). A similar behavior to *O. surinamensis* was also observed in the larvae of *T. castaneum* (Figures 9 and 10). In all combinations evaluated, the percentage of larvae that chose the deltamethrin-treated rice (FD or CD) was significantly lower than the percentage that chose the untreated rice (F or C) (Figure 10). In addition, the highest percentage of preference was 66% and observed in C both in the combination, FD vs. C, and in CD vs. C (Figure 10).

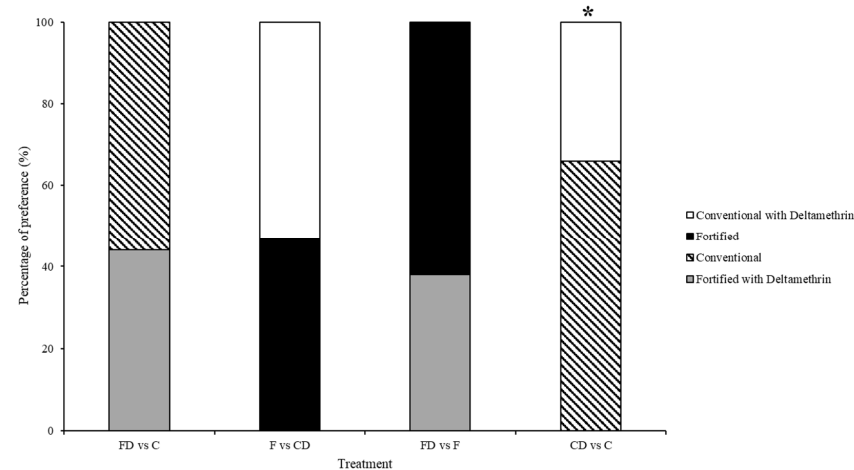


Figure 8. Average choice rate (%) of *Tribolium castaneum* adults for each of the three following combinations: Fortified with deltamethrin vs. Conventional rice (FD vs. C), Fortified vs. Conventional with deltamethrin rice (F vs. CD), Fortified with deltamethrin vs. Fortified rice (FD vs. F), and Conventional with deltamethrin vs. Conventional rice (CD vs. C). For each combination, means with asterisks (*) indicate significant differences between the two choices, according to Wilcoxon signed-rank test at $p < 0.05$ (in all cases $df = 4$). Where no asterisk (*) exists, no significant differences were found. Wilcoxon's signed-rank test parameters for CD vs. C were $z = -2.0$, $df = 1$, $p = 0.041$.

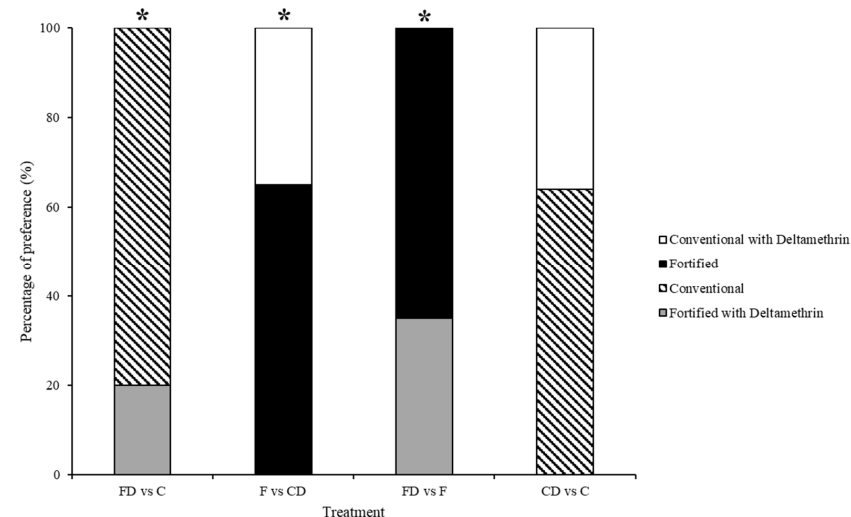


Figure 9. Average choice rate (%) of *Oryzaephilus surinamensis* adults for each of the three following combinations: Fortified with deltamethrin vs. Conventional rice (FD vs. C), Fortified vs. Conventional with deltamethrin rice (F vs. CD), Fortified with deltamethrin vs. Fortified rice (FD vs. F), and Conventional with deltamethrin vs. Conventional rice (CD vs. C). For each combination, means with asterisks (*) indicated significant differences between the two choices, according to Wilcoxon signed-rank test at $p < 0.05$ (in all cases $df = 4$). Where no asterisk (*) exists, no significant differences were found. Wilcoxon's signed-rank test parameters for FD vs. C were $z = -2.0$, $df = 1$, $p = 0.043$, for F vs. CD were: $z = -2.0$, $df = 1$, $p = 0.041$, for FD vs. F were: $z = -2.0$, $df = 1$, $p = 0.042$.

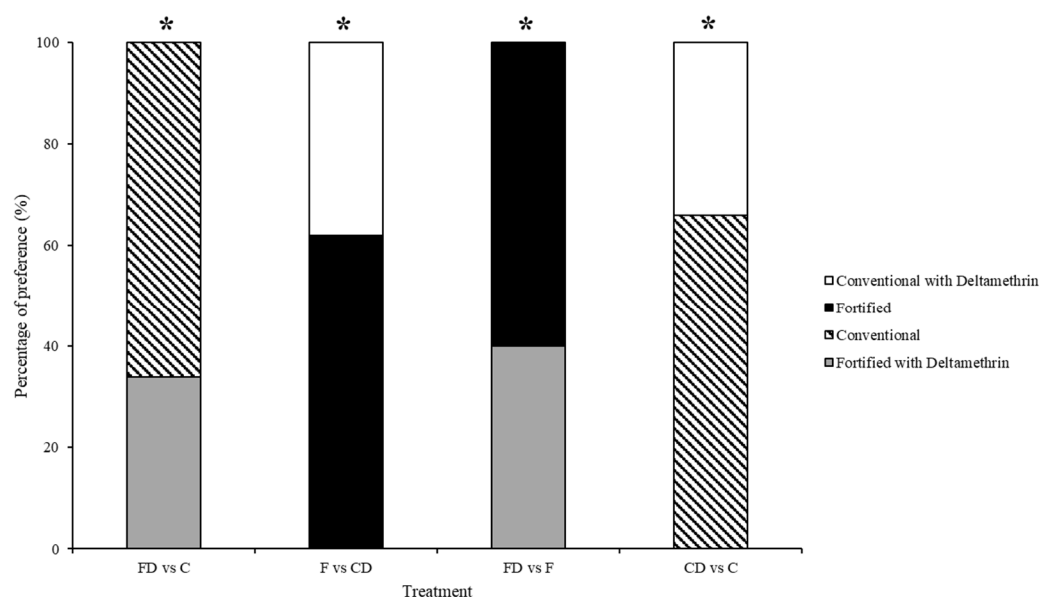


Figure 10. Average choice rate (%) of *Tribolium castaneum* larvae for each of the three following combinations: Fortified with deltamethrin vs. Conventional rice (FD vs. C), Fortified vs. Conventional with deltamethrin rice (F vs. CD), Fortified with deltamethrin vs. Fortified rice (FD vs. F), and Conventional with deltamethrin vs. Conventional rice (CD vs. C). For each combination, means with asterisks (*) indicated significant differences between the two choices, according to Wilcoxon signed-rank test at $p < 0.05$ (in all cases $df = 4$). Wilcoxon's signed-rank test parameters for FD vs. C were $z = -2.0$, $df = 1$, $p = 0.041$, for F vs. CD were: $z = -2.0$, $df = 1$, $p = 0.042$, for FD vs. F were: $z = -2.0$, $df = 1$, $p = 0.041$, for CD vs. C were: $z = -2.0$, $df = 1$, $p = 0.042$.

4. Discussion

There are several published works that confirm the repellency of *Ocimum* species against stored product insects [33,34,36,40,43–48]. For example, Al-Ghamdi and Wong [35] evaluated the efficacy of *O. basilicum* and the screw pine, *Pandanus tectorius* Parkinson (Pandanales: Pandanaceae), powders against *T. castaneum* with satisfactory results. However, all these papers involved essential oils, extracts, or dried plant materials. Agrafioti et al. [41] in an experiment conducted on fortified rice with basil and spearmint found that the level of infestation of *R. dominica*, *S. oryzae*, and *O. surinamensis* was reduced compared to conventional rice. This is the first paper that evaluates the repellent effect of basil as a fortifying material on rice either alone or in combination with deltamethrin.

For most of the insect species tested in the present study fortification with basil had a moderate repellency effect. Indeed, *S. oryzae*, *R. dominica*, and *T. castaneum* adults showed 51 and 40, 58 and 39, and 55 and 26% repellency in fortified rice with basil in F vs. C and F vs. B combinations, respectively. The findings of our research are in line with those of other works concerning the repellent action of both *O. basilicum* [36] and other species of the genus, *Ocimum* [33,43]. Al-Ghamdi and Wong [36] found that 1 h of exposure to plant powders of *O. basilicum* caused 52% and 44% repulsion of *S. oryzae* and *T. castaneum* adults, respectively. Similarly, 1,8 cineole, the main component of *O. kenyense* Ayob. ex A.J.Paton (Lamiales: Lamiaceae), showed a moderate repellent effect even when applied at the highest dose tested (10 μ L/disc) against adults of *T. castaneum* (48% mean percent repellency value) and the larger grain borer, *Prostephanus truncatus* Horn (Coleoptera: Bostrychidae) (50% mean percent repellency value) [33]. In the same research, 1,8 cineole evoked strong repellency against the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), and the granary weevil, *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) [33]. Additionally, Bekele et al. [43] demonstrated a moderate repellent action of dry (10–65%) and ground (28–59%) leaves, and essential oil (35–39%) of *O. Ocimum sauve* Willd (Lamiales: Lamiaceae) against *R. dominica*. For *R. dominica* and *T. castaneum* adults, a percentage of 6 to 15% stayed

on the line in the middle of the Petri dish and essentially did not choose any of the two options. In the case of *R. dominica* adults, this could be attributed to the reduced mobility of this species compared to other stored product insect species [49], while with regard to *T. castaneum* adults, this could be due to the extremely difficult return of its large body to a prone position after being in a supine position.

On the other hand, *O. surinamensis* adults and *T. castaneum* larvae showed the lowest rates of repellence from rice fortified with basil with 31–33 and 41–42%, respectively. In fact, rice fortified with basil had an attractive effect on *O. surinamensis*, as 67 and 69% of individuals were attracted by its presence. Agrafioti et al. [41] showed that progeny production of *O. surinamensis* was enhanced when rice fortified with basil was used as a substrate compared to rice fortified with spearmint. Accordingly, in a field experiment conducted in India in a potato crop, yellow sticky traps baited with basil oil attracted more adults of the winged cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae), than yellow sticky traps baited with lavender, geranium, and tea tree oil [50]. In addition, Moawad and Ebadah [51] observed that *O. basilicum* oil was the most attractive oil to 1st instar larvae of the Indianmeal moth, *Plodia interpunctella* Hübner (Lepidoptera: Pyralidae), compared to the rose geranium, *Pelargonium graveolens* L'Hér. (Geraniales: Geraniaceae), and the clove, *Syzygium aromaticum* (L.) (Myrtales: Myrtaceae), oils. On the other hand, the fact that *O. surinamensis* was attracted to rice with basil may also be due to its ability to infest different types of dried fruit and herbs [52].

The combined action of plant derivatives with chemical or natural insecticides in order to enhance the insecticidal efficacy against stored product insects has been extensively studied [53–62]. For instance, Yang et al. [56] found that the combined application of the essential oil of *Allium sativum* L. (Asparagales: Amaryllidaceae) with diatomaceous earth against *S. oryzae* and the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae), was significantly more effective than the single application of either the essential oil or the diatomaceous earth. The combination of basil with deltamethrin for the management of both agriculture- [63] and public-health-affecting insects [64] has shown satisfactory results. Silva et al. [63] evaluated the combined action of *O. basilicum* essential oil with deltamethrin for the control of the fall armyworm, *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae), and found that the dose of deltamethrin required to kill 50% of the population of *S. frugiperda* was reduced by 80% when applied in combination with *O. basilicum* oil compared to when applied alone. Similarly, in the work of Suwannayoud et al. [64], the mixture of *Ocimum gratissimum* essential oil with deltamethrin had a synergistic effect against the blow flies, *Chrysomya megacephala* (F.) (Diptera: Calliphoridae), *Chrysomya rufifacies* Macquart (Diptera: Calliphoridae), *Lucilia cuprina* Wiedemann (Diptera: Calliphoridae), and the house fly, *Musca domestica* L. (Diptera: Muscidae). Nonetheless, no research is available demonstrating the repellency of plant materials in combination with chemical insecticides with regard to stored product insects. Our results showed that *O. surinamensis* adults and *T. castaneum* larvae were attracted to rice fortified with basil in the first trial. However, when rice fortified with basil was combined with deltamethrin, a strong repellent effect was observed for *O. surinamensis* adults. Indeed, deltamethrin has been found to repel insects [65–68] through contact repellency or irritability, in which an insect is stimulated to leave the immediate toxic environment upon contact with the treated surface [69]. Still, in our study we are not able to determine which type of repellency took place at least in the stored product insects examined here.

5. Conclusions

Our results highlight the preference of major stored product insects in rice fortified with basil. In the untreated trials, most insect species showed moderate repellence from fortified rice with basil, with the exception of *O. surinamensis*, which was attracted to rice fortified with basil. On the contrary, *O. surinamensis* adults and *T. castaneum* larvae were repelled by the deltamethrin treated-rice that was fortified with basil. Integrated pest management in stored products is based on the use of more than one ecologically com-

patible control method. Our data indicate that the combination of techniques, such as the fortification with other chemical compounds of low mammal toxicity and the application of deltamethrin could play an important role in stored product protection. The current work suggests that, under certain circumstances and for specific insect species, the use of rice fortified with basil and treated with deltamethrin is promising for stored rice protection. However, additional experimental work is required towards this direction.

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