



Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)

<https://dergipark.org.tr/en/pub/yyutbd>



ISSN: 1308-7576

e-ISSN: 1308-7584

Research Article

Population Growth and Damage Potential of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on Gluten-Free Commodities

Yunus Emre ALTUNÇ*¹

¹Ordu University, Agriculture Faculty, Plant Protection Department, 52200, Ordu, Türkiye

¹<https://orcid.org/0000-0001-5539-552X>

*Corresponding author e-mail: yunusemrealtunc@odu.edu.tr

Article Info

Received: 08.01.2026

Accepted: 22.04.2026

Online published: 02.06.2026

DOI: 10.29133/yyutbd.1859015

Keywords

Chia,
Khapra beetle,
Linseed,
Postharvest,
Quinoa

Abstract: *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is recognized as one of the most damaging quarantine insects on stored grains. However, with the increasing international trade of gluten-free products, it is important to increase our current level of knowledge to better understand their potential susceptibility to infestation by this quarantine insects. For this, the study examined the development potential of *T. granarium* on three internationally traded gluten-free products, quinoa, chia, and linseed, when subjected to whole and flour forms of these products. The adults of *T. granarium* were allowed to grow on whole and flour forms of each product, and the progeny development were recorded after 65 days. Results on population growth, frass production and commodity weight loss, differed significantly on different products as well as their forms. Progeny development, egg production, and pupal weight of *T. granarium* as well as frass production and commodity weight loss, were found to be significantly higher in quinoa, especially in flour, compared to other products. Chia seeds, both in whole and flour form, recorded the lowest results on above parameters. Linseed was found to be support highest insect pupal weight as well as frass production. These results demonstrate that both the commodity itself and physical form strongly affect *T. granarium* population dynamics and damage. The findings point out quinoa flour as a high-risk commodity for infestation and highlight the need to incorporate emerging gluten-free commodities into postharvest risk assessment programs.

To Cite: Altunç, Y E, 2026. Population Growth and Damage Potential of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on Gluten-Free Commodities. *Yuzuncu Yil University Journal of Agricultural Sciences*, (1): 1859015. DOI: <https://doi.org/10.29133/yyutbd.1859015>

1. Introduction

Trogoderma granarium Everts (Coleoptera: Dermestidae) known as khapra beetle, has been recognized as one of the most destructive pests of stored commodities worldwide (Lowe et al., 2000; Lampiri et al., 2022). This pest is native to South Asia but currently reported from many countries. This species also poses threats to world trade and food security due to its capacity to reproduce rapidly in suitable environments, its high tolerance to starvation, and its hiding potential in commodities and structures (Athanasios et al., 2019). Its distribution models based on climatic scenarios also showed re-infestation risk of *T. granarium* to North America and Europe, where it has been eradicated (Harman et al., 2025). The larvae can survive long periods in diapause (Burgess, 1963) and dozens of phosphine resistant populations are already been reported (Machuca-Mesa et al., 2024). *Trogoderma granarium* is

thus one of the insect species regulated as a quarantine pest by the European Union, the United States, Australia, and several other countries (EPPO, 2013).

Reproduction and development of *T. granarium* depends on the nature and chemical composition of the food substrate. Numerous studies have established that food quality such as protein, lipid, and carbohydrate along with content of secondary metabolites and anti-nutritional factors, significantly influences larval mortality, development period, and fecundity (Musa et al., 2010; Barzin et al., 2019; Awadalla et al., 2024). Physical quality of a commodity also matters; early larvae usually develop best on ground, milled, or ground-up material compared to whole seeds or whole grains. Thus, nutritional content and physical form of the food substrate are key determinants of the population growth potential of stored-product insects such as *T. granarium* (Athanassiou et al., 2016).

Currently, there has been considerable global consumption of healthcare and gluten-free foods such as quinoa (*Chenopodium quinoa* Willd.), chia (*Salvia hispanica* L.), and linseed/flaxseed (*Linum usitatissimum* L.), which has increased remarkably (Woomer and Adediji, 2021). The crops are also documented to have high protein, amino, and unsaturated fatty acid contents, in addition to high fiber and phytochemical levels, which might have a potential impact on resistance to infestation by storage insects (Cominelli et al., 2020; Abdel-Hameid and Ibrahim, 2023). Although they have increased commercial utilization and are widely being traded, reports relevant to their susceptibility to important storage product insects, especially *T. granarium*, are still lacking.

Estimating the potential of such alternative commodities for developing pests is crucial for postharvest risk assessment. Therefore, the current study examined the population growth of *T. granarium* on three gluten-free commodities, quinoa, chia, and linseed, investigated in two physical forms, flour and whole seed. In addition to progeny production of *T. granarium*, damage parameters such as commodity weight loss and pest frass production were also evaluated.

2. Materials and Methods

2.1. Insect maintaining and commodities

Laboratory population of *T. granarium* was reared in 370 cc (diameter 71.9 mm, height 121.6 mm) glass jars for over eight years. Cracked wheat (60 g) was added to the jars for food supply. Three paper towel strips were placed on food media for serving as oviposition and hiding sites. The jars were covered with muslin and rubber bands to prevent insect escape and ensure aeration. Mass production continued throughout the trials. Mass-reared insects were stored in incubators (Nüve EN 120, Türkiye) set at 29 ± 2 °C, $60 \pm 5\%$ relative humidity, and constant darkness. The gluten-free raw whole seed and flour products of quinoa, chia, and linseed were obtained from a local gluten-free product supplier, Ingro Food (Konya, Türkiye). The products were kept in +4 °C until start of trials and just before the experiments, products were stored in a refrigerator at -18 °C for 24h to prevent initial insect contamination. The moisture content of products was not measured.

2.2. Experimental design

Laboratory trials began in August 2025. Prior to the experiments, all existing adults in the jars were removed using a brush to ensure that only newly eclosed adults of the laboratory cultures would be used. Jars containing only pre-adult stages were placed back into the incubator and waited for one week for adult emergence. At the end of one week, the collected 0-7 d old adults were sexed for use in the experiments. Sexing was determined based on differences in antennae between male and female adults according to Bousquet (1990). For each product of quinoa, chia, and linseed, 20 grams of whole seed or flour forms were separately weighed using an analytical balance (Shimadzu, Japan) and transferred to 105 cc glass jars. Ten adults (5 females + 5 males) aged 0-7 d were transferred into each jar, and the jars were covered with muslin. The trials were conducted with five replications. The prepared jars were kept in the incubator for 65 days to allow insect development (Altunç et al., 2023). At the end of the period, the jars were opened, and the contents were passed through #10, #20, #40, and #60 mesh analysis sieves (Loyka, Türkiye), and the seed/flour, adults, larvae, pupae, egg, along with the frass were separated from each other. The life stages were counted under a stereo microscope (Leica S8APO, Germany). All the pupae were weighed using a four-digit analytical balance. At the end of the trials, the frass obtained from the jars of whole seed treatments was weighed. The final weights of the whole seed

or flour fractions were recorded to determine the seed weight loss, by subtracting from the initial weights of seed in the respective jars.

2.3. Data analysis

Progeny production data (adults, larvae, pupae, and eggs, except for the ten parental adults) were analyzed using generalized linear models (GLM) with the negative binomial distribution. Significance of the fixed factors (i.e., product type and form) was assessed by Wald χ^2 test. Adult mortality was analyzed using binomial distribution (dead - alive) with a logit link function. The weight data, such as weight loss, frass amount, and pupal weight data were analyzed using GLM with Gaussian distribution and the F test. If significant differences were found, post-hoc pairwise comparisons were applied using contrast on estimated marginal means with false discovery rate (FDR) adjustment ($P < 0.05$). Statistical analyzes were performed using R software (R Core Team, 2025) with the ‘car’ (Fox and Weisberg, 2019), the ‘emmeans’ (Lenth, 2022), and the ‘multcomp’ (Hothorn et al., 2008) packages.

3. Results

3.1. Progeny growth of *Trogoderma granarium* on gluten-free commodities

The population growth of *T. granarium* were markedly influenced by the type and physical form of the gluten-free commodities tested. Egg production differed significantly among grains ($\chi^2=36.39$, $df=2$, $P < 0.001$). The highest number of eggs at the end of the experiments was on quinoa flour, with a mean of 106.2 ± 50.58 , whereas the number of eggs chia and linseed, regardless of their form, was comparatively low (Figure 1A). For quinoa, flour supported higher number of eggs than the whole seeds (38.8 ± 12.85), though the difference was not significant ($\chi^2=1.984$, $df=1$, $P=0.159$).

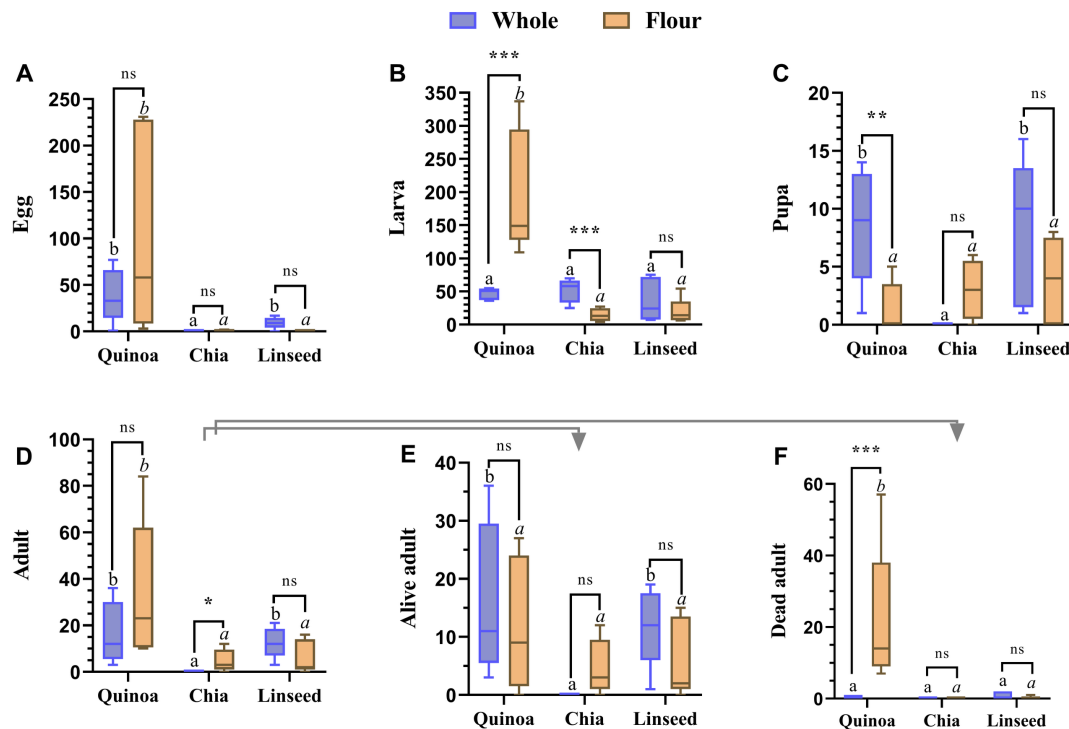


Figure 1. Total number of eggs (A), larvae (B), pupae (C), adults (D), alive adults (E), and dead adults (F) in the progeny of *Trogoderma granarium* in whole grains and flour of quinoa, chia, and linseed after 65 d of infestation. Lines indicate differences between grain physical forms; regular letters (whole grain) and italicized letters (flour) indicate differences among commodities within each physical form (GLM, negative binomial distribution, Wald χ^2 test with FDR-adjusted pairwise contrast, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns: not significant).

Larval development followed a similar result (Figure 1B). The mean number of larvae counted on quinoa flour (198.8 ± 41.93) was approximately fourfold greater than on whole quinoa (46.8 ± 4.07), making quinoa flour the most suitable substrate for larval survival and development ($\chi^2=47.20$, $df=1$, $P<0.001$). Conversely, larval counts were significantly reduced on chia flour compared with its grain form ($\chi^2=16.82$, $df=1$, $P<0.001$), while no significant difference was observed between whole and flour forms of linseed ($\chi^2=1.41$, $df=1$, $P=0.236$).

Number of pupae varied significantly across commodities (Figure 1C). At the end of the 65d period, more pupae were recorded on whole quinoa than quinoa flour ($\chi^2=8.50$, $df=1$, $P=0.004$), whereas pupation on chia was minimal in both forms. Linseed whole seeds had slightly more pupae (8.0 ± 2.85) than the flour (3.8 ± 1.69), but it was not significant ($\chi^2=1.32$, $df=1$, $P=0.251$).

The number of total adults was greatest on quinoa flour (33.6 ± 13.7), followed by whole quinoa seeds (16.6 ± 5.96). No additional adults were found beyond parental ones from whole chia, and moderate numbers were recorded from linseed, with no significant difference between its two forms ($\chi^2=1.55$, $df=1$, $P=0.214$) (Figure 1D). The number of alive adults (Figure 1E) showed a similar result, with the highest density on quinoa substrates, although differences between forms were not statistically significant ($\chi^2=0.24$, $df=2$, $P=0.622$). Notably, number of dead adults (Figure 1F) was significantly higher on quinoa flour than on its whole seeds ($\chi^2=23.07$, $df=1$, $P<0.001$), whereas no dead adults were counted in chia and linseed, except the ten parental adults that died during the experiments. The adult mortality rate (%) of *T. granarium* grown on gluten free commodities was significantly changed by both type of food ($\chi^2=16.60$, $df=1$, $P<0.001$), and its physical form ($\chi^2=34.60$, $df=1$, $P<0.001$). The highest adult mortality rate was observed in flour form of quinoa as 69.25 ± 8.64 % and nearly in whole form of linseed (Figure 2).

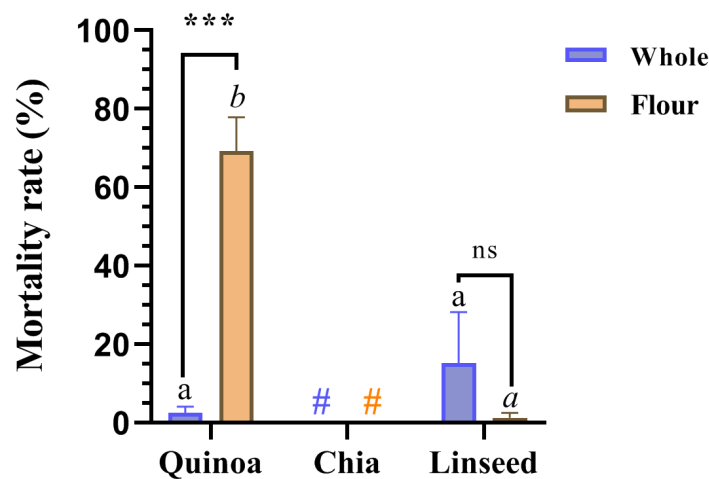


Figure 2. Adult mortality rate of *Trogoderma granarium* in whole and flour forms of quinoa, chia, and linseed after 65 d of infestation. Lines indicate differences between grain form and flour; letters (whole grains) and italicized letters (flour) indicate differences among commodities within each physical form (GLM, binomial distribution, Wald χ^2 test with FDR-adjusted pairwise contrast, *** $P<0.001$, ns: not significant, # no mortality observed).

The overall progeny production (sum of all developmental stages) of *T. granarium* was significantly affected by the commodity $\times$ form factor ($\chi^2=24.79$, $df=2$, $P<0.001$) (Figure 3). The greatest total progeny was observed on quinoa flour (340.0 ± 87.69), followed by quinoa whole seeds (120.8 ± 20.47). This difference was highly significant ($\chi^2=15.43$, $df=1$, $P<0.001$). On chia, progeny numbers were comparatively low, with flour (22.8 ± 3.01) yielding significantly less individuals than whole chia (51.4 ± 8.15) ($\chi^2=16.22$, $df=1$, $P<0.001$). Linseed supported moderate progeny production (whole; 66.2 ± 18.72 , flour; 29.6 ± 10.02) with a slight but insignificant decline in the flour form ($\chi^2=3.42$, $df=1$, $P=0.064$).

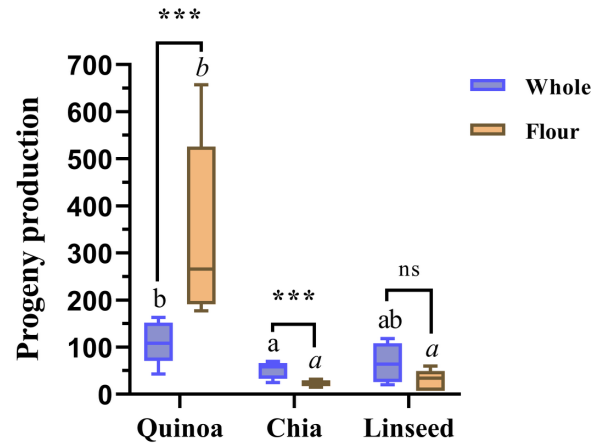


Figure 3. Total progeny production of *Trogoderma granarium* in whole grains and flour of quinoa, chia, and linseed after 65 d of infestation. Lines indicate differences between grain forms; letters (whole grains) and italicized letters (flour) indicate differences among commodities within each physical form (GLM, negative binomial distribution, Wald χ^2 test with FDR-adjusted pairwise contrast, *** $P < 0.001$, ns: not significant).

3.2. Commodity damage and pupal weight

Differences among commodities were also reflected in the physical indicators of infestation. Weight loss of the commodities regardless of their form was highest in quinoa ($1027.4 \text{ mg} \pm 175.13$) and linseed ($651.5 \text{ mg} \pm 125.40$), while chia showed minimal losses ($356.2 \text{ mg} \pm 43.77$). No significant difference was found between whole grains and flour across all tested commodities ($F_{1,24}=2.46$, $P=0.130$) (Figure 4a).

Frass weight in whole seeds was substantial in quinoa ($337.0 \text{ mg} \pm 54.44$) and linseed ($282.4 \text{ mg} \pm 81.13$), but negligible in chia ($5.4 \text{ mg} \pm 0.22$) ($F_{1,12}=9.93$, $P=0.003$) (Figure 4b).

Pupal weight differed significantly among treatments (Figure 4c). It was significantly higher in quinoa flour than in whole quinoa ($F_{1,43}=8.99$, $P=0.049$) and highest of all in linseed flour ($5.42 \text{ mg} \pm 0.54$), whereas it was significantly lower in chia flour ($3.11 \text{ mg} \pm 0.36$) and pupae were absent in whole seeds.

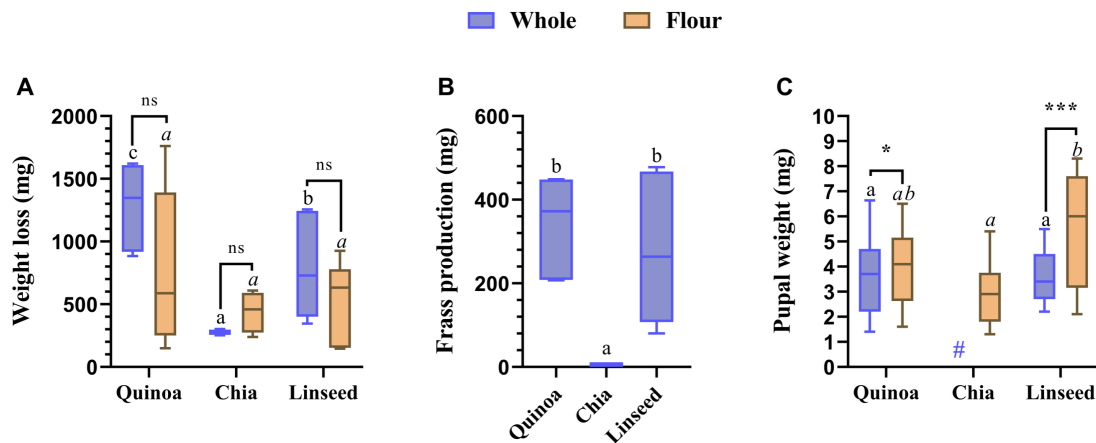


Figure 4. Commodity weight loss (A), pest frass production (B) (only for whole seeds), and pupal weight (C) of *Trogoderma granarium* in whole seeds and flour of quinoa, chia, and linseed after 65 d of infestation. Lines indicate differences between physical forms; regular letters (whole) and italicized letters (flour) indicate differences among commodities within each physical form (GLM, Gaussian distribution, F test with FDR-adjusted pairwise contrasts, * $P < 0.05$, *** $P < 0.001$, ns: not significant, # no pupae were counted).

4. Discussion

Findings showed that the population growth and damage potential of *T. granarium* were strongly dependent on both the type of gluten-free commodity and its physical form, with quinoa, particularly in flour form, provided the most suitable substrate for development. In contrast, chia and linseed demonstrated varying degrees of susceptibility, highlighting substantial differences in their suitability as hosts for *T. granarium*.

Consistent with the general observations on *T. granarium*, which has a broad host range including cereals, pulses, and most dried plant products (Hagstrum et al., 2013), this species has been shown the ability of building a population on tested gluten-free commodities quinoa, chia, and linseed. However, *T. granarium* known to exhibit differential population growth on different grain types (Kavallieratos et al., 2019). Quinoa flour supported significantly higher progeny and larval abundance compared to whole seed and the other commodities tested in the present study. This is coherent with the findings in the larvae of *T. granarium*, which generally prefer nutritionally rich and physically accessible substrates, that are important for their rapid development (Athanassiou et al., 2016; Hashem et al., 2025).

Other researchs on different stored grains has also indicated that the type of host could play a very important role in affecting the life history parameters of *T. granarium*. For example, developmental time and survival of *T. granarium* differed among sorghum varieties, directly affecting final population size and damage metrics and highlighting commodity as a main factor of pest progeny (Gourgouta et al., 2021; Lampiri et al., 2021). Similarly, the work carried out on wheat varieties revealed that the both developmental duration and reproductive output of the pest can vary substantially with cultivar, indicating that intrinsic grain quality is a key driver of infestation success (Golizadeh and Abedi, 2016).

In contrast to quinoa, chia and linseed showed minimal support for *T. granarium* growth, especially in flour form of both. This may be because of secondary metabolites and physical properties of these commodities that may reduce feeding efficiency. Chia seeds contain high levels of dietary fiber, including mucilage-forming soluble fractions, as well as phenolic compounds (Arioglu-Tuncil, 2025). High fiber content has been associated with reduced nutrient availability and lower insect growth, while phenolic compounds are defence mechanisms of plants to stressors such as insect infestation (Rodríguez et al., 2022). Similarly, linseed contains substantial amounts of lignans and diverse phenolic acids, which play a defensive role against insect feeding (Harmatha and Dinan, 2003), alongside anti-nutritional compounds such as cyanogenic glycosides (Kajla et al., 2015). Although direct studies on both chias' and linseeds' resistance mechanisms are lacking, similar host resistance traits have been reported in other seeds where proximate properties and phenolic compounds correlate with reduced pest growth (Nietupski et al., 2017; Naseri and Majd-Marani, 2022).

The influence of physical form of commodities on insect infestation highlights the complexity of stored product pest dynamics. Flour forms create homogeneous substrates that are easily infested by early instar larvae of *T. granarium*, without requiring them to penetrate intact seeds. This phenomenon is well documented in stored product pests, where for many species like *T. granarium*, cracked, milled, or processed grains are more susceptible to infestation than intact kernels due to increased surface area, and improved feeding access (Locatelli et al., 2008; Athanassiou et al., 2010 and 2016; Kavallieratos et al., 2012; Kyrgiakakis et al., 2024; Hashem et al., 2025).

The significantly higher pest frass production and weight loss in quinoa and linseed also have practical implications. High frass levels not only represent direct weight loss but also lead to increased contamination by secondary pests, higher moisture retention, and potential microbial growth, thereby amplifying real postharvest losses (Adams, 1976; Arthur et al., 2007; Shah et al., 2020).

From an applied perspective, the findings showed that commodity type and its physical form must be factored into risk assessments and management strategies for *T. granarium*. Flour products and finely milled grains should be considered high-risk substrates in surveillance and quarantine programs due to their propensity to support rapid pest population growth.

The expansion of gluten-free foods in global markets has increased the diversity of stored commodities and introduced new stored-product pest risks. Studies on alternative flours and grains show that gluten-free products differ widely in their capacity to support insect survival and reproduction (Cominelli et al., 2020). Some substrates, such as teff and millet, can sustain pest populations at levels comparable to or exceeding those observed in wheat-based products (Cominelli et al., 2020; Gerken and Campbell, 2020). As gluten-free grains and flours become more common in storage, processing, and

trade, their susceptibility to major stored-product pests warrants targeted evaluation to inform effective postharvest management and quarantine risk assessment.

Conclusion

This study demonstrated that both commodity type and physical form significantly affects the population growth and damage potential of *T. granarium*. Quinoa flour was found as a highly favorable substrate for progeny production, whereas chia and linseed exhibited lower susceptibility to infestation, which shows the opportunities to integrate host traits into risk modeling and pest management. Future research should aim to examine the biochemical and physiological mechanisms underlying host resistance and to quantify how processing and storage practices modulate *T. granarium* infestation potential.

Ethical Statement

Ethical approval was not required as the study involved only invertebrate insect species.

Conflict of Interest

The author declares that there are no conflict of interest.

Artificial Intelligence Declaration

During the preparation of this manuscript, the author used ChatGPT-4 in order to copyedit the text only. After using this tool, the author reviewed and edited the content as needed. The author take full responsibility for the content of the article.

Funding Statement

No funding was received for this study.

Author Contributions

The sole author of this paper has made all contributions to the research process, including investigation, data analysis, writing, and editing.

Acknowledgements

The author acknowledges the anonymous reviewers for their contribution to the submitted work and expresses gratitude to Prof. Dr. Ali Güncan (Ordu University, Faculty of Agriculture) for his pre-review and suggestions.

References

- Abdel-Hameid, N. F., & Ibrahim, S. T. (2023). Quinoa (*Chenopodium quinoa* Willd.) seeds storage in relation to insect pests' infestation and some biological information. *Egyptian Academic Journal of Biological Sciences A, Entomology*, 16(2), 29-37. <https://doi.org/10.21608/eajbsa.2023.297323>
- Adams, J. M. (1976). Weight loss caused by development of *Sitophilus zeamais* Motsch. in maize. *Journal of Stored Products Research*, 12(4), 269-272. [https://doi.org/10.1016/0022-474X\(76\)90043-6](https://doi.org/10.1016/0022-474X(76)90043-6)
- Altunç, Y. E., Agraftoti, P., Lampiri, E., Güncan, A., Tsialtas, I. T., & Athanassiou, C. G. (2023). Population growth of *Prostephanus truncatus* and *Sitophilus zeamais* and infestation patterns in three maize hybrids. *Journal of Stored Products Research*, 101, 102091. <https://doi.org/10.1016/j.jspr.2023.102091>

- Arioglu-Tuncil, S. (2025). A comparative assessment of flaxseed (*Linum usitatissimum* L.) and chia seed (*Salvia hispanica* L.) in modulating fecal microbiota composition and function in vitro. *Food Science & Nutrition*, 13, e70243. <https://doi.org/10.1002/fsn3.70243>
- Arthur, F. H., Bautista, R. C., & Siebenmorgen, T. J. (2007). Influence of growing location and cultivar on *Rhyzopertha dominica* (Coleoptera: Bostrichidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae) infestation of rough rice. *Insect Science*, 14(3), 231-239. <https://doi.org/10.1111/j.1744-7917.2007.00149.x>
- Athanassiou, C. G., Opit, G. P., & Throne, J. E. (2010). Influence of commodity type, percentage of cracked kernels, and wheat class on population growth of stored-product psocids (Psocoptera: Liposcelidae). *Journal of Economic Entomology*, 103(3), 985-990. <https://doi.org/10.1603/EC09280>
- Athanassiou, C. G., Kavallieratos, N. G., & Boukouvala, M. C. (2016). Population growth of the khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on different commodities. *Journal of Stored Products Research*, 69, 72-77. <https://doi.org/10.1016/j.jspr.2016.05.001>
- Athanassiou, C. G., Phillips, T. W., & Wakil, W. (2019). Biology and control of the khapra beetle, *Trogoderma granarium*, a major quarantine threat to global food security. *Annual Review of Entomology*, 64(1), 131-148. <https://doi.org/10.1146/annurev-ento-011118-111804>
- Awadalla, H. S., Abdel-Hady, A. A., Shalaby, M. M., Hashem, A. S., & Ramadan, M. M. (2024). Development, survival, and reproduction of the khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) in response to different stored diets and their chemical composition. *Journal of Plant Protection and Pathology*, 15(9), 271-276. <https://doi.org/10.21608/jppp.2024.318987.1264>
- Barzin, S., Naseri, B., Fathi, S. A. A., Razmjou, J., & Aeinehchi, P. (2019). Feeding efficiency and digestive physiology of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on different rice cultivars. *Journal of Stored Products Research*, 84, 101511. <https://doi.org/10.1016/j.jspr.2019.101511>
- Bousquet, Y. (1990). *Beetles associated with stored products in Canada: An identification guide*. Agriculture and Agri-Food Canada.
- Burges, H. D. (1963). Studies on the Dermestid beetle *Trogoderma granarium* Everts. VI.—Factors inducing diapause. *Bulletin of Entomological Research*, 54(3), 571-587. <https://doi.org/10.1017/S0007485300049026>
- Cominelli, F., Reguzzi, M. C., Aldini, R. N., & Mazzoni, E. (2020). Insect pest susceptibility of grains and seeds recently introduced to the Italian market: An experimental evaluation. *Journal of Stored Products Research*, 89, 101691. <https://doi.org/10.1016/j.jspr.2020.101691>
- European and Mediterranean Plant Protection Organization (EPPO). (2013). Diagnostics: PM 7/13 (2) *Trogoderma granarium*. *EPPO Bulletin*, 43(3), 431-448.
- Fox, J., & Weisberg, S. (2019). *An R companion to applied regression* (3rd ed.). Sage.
- Gerken, A. R., & Campbell, J. F. (2020). Oviposition and development of *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) on different types of flour. *Agronomy*, 10(10), 1593. <https://doi.org/10.3390/agronomy10101593>
- Golizadeh, A., & Abedi, Z. (2016). Comparative performance of the Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on various wheat cultivars. *Journal of Stored Products Research*, 69, 159-165. <https://doi.org/10.1016/j.jspr.2016.08.003>
- Gourgouta, M., Athanassiou, C. G., & Arthur, F. H. (2021). Susceptibility of four different sorghum varieties to infestation by the khapra beetle. *Journal of Economic Entomology*, 114(3), 1373-1379. <https://doi.org/10.1093/jee/toab018>
- Hagstrum, D. W., Klejdysz, T., Subramanyam, B., & Nawrot, J. (2013). *Atlas of stored-product insects and mites*. AACC International Press.
- Harman, R. R., Morrison, W. R., III, Altunç, Y. E., Athanassiou, C. G., & Gerken, A. R. (2025). Increasing global risk of khapra beetle invasion forecasted under projected environmental conditions. *Scientific Reports*, 15(1), 26064. <https://doi.org/10.1038/s41598-025-11690-8>
- Harmatha, J., & Dinan, L. (2003). Biological activities of lignans and stilbenoids associated with plant-insect chemical interactions. *Phytochemistry Reviews*, 2(3), 321-330.
- Hashem, A. S., Amin, H. E., Ramadan, M. M., Abdel-Hady, A. A., Awadalla, H. S., Al-Solami, H. M., Sharawi S. E., Alghamdi A. G., Alkenani N. A., Mahran H. A., & Guedes, R. N. C. (2025).

- Unraveling grain vulnerability to the khapra beetle (*Trogoderma granarium*): Structure and mineral content. *Journal of Stored Products Research*, 112, 102647. <https://doi.org/10.1016/j.jspr.2025.102647>
- Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal: Journal of Mathematical Methods in Biosciences*, 50(3), 346-363. <https://doi.org/10.1002/bimj.200810425>
- Kajla, P., Sharma, A., & Sood, D. R. (2015). Flaxseed-a potential functional food source. *Journal of Food Science and Technology*, 52(4), 1857-1871. <https://doi.org/10.1007/s13197-014-1293-y>
- Kavallieratos, N. G., Athanassiou, C. G., Arthur, F. H., & Throne, J. E. (2012). Lesser grain borers, *Rhyzopertha dominica*, select rough rice kernels with cracked hulls for reproduction. *Journal of Insect Science*, 12(1), 38. <https://doi.org/10.1673/031.012.3801>
- Kavallieratos, N. G., Athanassiou, C. G., Boukouvala, M. C., & Tsekos, G. T. (2019). Influence of different non-grain commodities on the population growth of *Trogoderma granarium* Everts (Coleoptera: Dermestidae). *Journal of Stored Products Research*, 81, 31-39. <https://doi.org/10.1016/j.jspr.2018.12.001>
- Kyrgiakakis, C., Sakka, M. K., & Athanassiou, C. G. (2024). Population growth of different stored product species on wheat, barley, and tritordeum. *Food Bioscience*, 61, 104698. <https://doi.org/10.1016/j.fbio.2024.104698>
- Lampiri, E., Athanassiou, C. G., & Arthur, F. H. (2021). Population growth and development of the khapra beetle (Coleoptera: Dermestidae), on different sorghum fractions. *Journal of Economic Entomology*, 114(1), 424-429. <https://doi.org/10.1093/jee/toaa235>
- Lampiri, E., Baliota, G. V., Morrison, W. R., Domingue, M. J., & Athanassiou, C. G. (2022). Comparative population growth of the Khapra beetle (Coleoptera: Dermestidae) and the warehouse beetle (Coleoptera: Dermestidae) on wheat and rice. *Journal of Economic Entomology*, 115(1), 344-352. <https://doi.org/10.1093/jee/toab209>
- Lenth, R. V. (2022). *Emmeans: Estimated marginal means, aka least-squares means* (R package version 1.8.1-1) [Computer software]. <https://CRAN.R-project.org/package=emmeans>
- Locatelli, D. P., Limonta, L., & Stampini, M. (2008). Effect of particle size of soft wheat flour on the development of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). *Journal of Stored Products Research*, 44(3), 269-272. <https://doi.org/10.1016/j.jspr.2008.02.004>
- Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the world's worst invasive alien species: A selection from the global invasive species database* (Vol. 12). The Invasive Species Specialist Group (ISSG).
- Machuca-Mesa, L. M., Turchen, L. M., & Guedes, R. N. C. (2024). Phosphine resistance among stored product insect pests: A global meta-analysis-based perspective. *Journal of Pest Science*, 97(3), 1485-1498. <https://doi.org/10.1007/s10340-023-01713-6>
- Musa, A. K., Kalejaiye, D. M., Ismaila, L. E., & Oyerinde, A. A. (2010). Proximate composition of selected groundnut varieties and their susceptibility to *Trogoderma granarium* Everts attack. *Journal of Stored Products and Postharvest Research*, 1, 13-17.
- Naseri, B., & Majd-Marani, S. (2022). Different cereal grains affect demographic traits and digestive enzyme activity of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). *Journal of Stored Products Research*, 95, 101898. <https://doi.org/10.1016/j.jspr.2021.101898>
- Nietupski, M., Kwiatkowski, J., & Kosewska, A. (2017). Physicochemical properties of achenes of buckwheat cultivars affecting the development of grain weevil (*Sitophilus granarius* L.) and lesser grain borer (*Rhyzopertha dominica* F.). *Zemdirbyste-Agriculture*, 104(4), 311-320. <https://doi.org/10.13080/z-a.2017.104.040>
- R Core Team. (2025). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing.
- Rodríguez, A., Beato, M., Usseglio, V. L., Camina, J., Zygodlo, J. A., Dambolena, J. S., & Zunino, M. P. (2022). Phenolic compounds as controllers of *Sitophilus zeamais*: A look at the structure-activity relationship. *Journal of Stored Products Research*, 99, 102038. <https://doi.org/10.1016/j.jspr.2022.102038>
- Shah, J. A., Vendl, T., Aulicky, R., & Stejskal, V. (2020). Frass produced by the primary pest *Rhyzopertha dominica* supports the population growth of the secondary stored product pests

Oryzaephilus surinamensis, *Tribolium castaneum*, and *T. confusum*. *Bulletin of Entomological Research*, 111(2), 153-159. <https://doi.org/10.1017/S0007485320000425>

Woomer, J. S., & Adedeji, A. A. (2021). Current applications of gluten-free grains – a review. *Critical Reviews in Food Science and Nutrition*, 61(1), 14-24. <https://doi.org/10.1080/10408398.2020.1713724>