Journal of Business Economics and Agribusiness, Volume 2, Number 4, 2025, *Page*: *1-13*

The Effect of Storage Conditions and Periods on The Laboratory and Field Efficacy of Some Insecticides

Omer Hammoud Abdullah*, Saddam Muwaffaq Hassan

Plant Protection Department, Agriculture and Forestry College, Mosul University, Mosul, Iraq

*Correspondence: Omer Hammoud Abdullah
Email: omer.23agp57@student.uomosul.edu.iq

Received: 25-06-2025
Accepted: 25-07-2025
Published: 25-08-2025

Abstract: This study investigates the impact of storage temperature on the physical stability and insecticidal efficacy of selected pesticide emulsions. Laboratory results revealed a consistent increase in the separation layer thickness of pesticide formulations stored under both high (50°C) and low (-5°C) temperatures. The impact was more severe at elevated temperature, where the thickness exceeded the permissible limit of 2 cm for thiamethoxam and abamectin after three months of storage, and for lambda-cyhalothrin after two and three months. In contrast, cold storage at -5°C maintained the separation layer within acceptable specifications for all tested pesticides. A strong negative correlation was observed between separation layer thickness and insecticidal efficacy, with longer storage durations leading to greater physical degradation. These findings suggest that high temperatures accelerate chemical degradation or alter the target insect's response, ultimately reducing pesticide performance. This outcome aligns with previous research by Bajwa and Sandhu (2014), Laskowski et al. (2017), and Scott & Georghiou (1986), who reported that elevated storage temperatures induce physical changes—such as increased viscosity and phase separation—which directly affect the pesticide's stability and bioefficacy. Although cold storage also caused physical changes, its impact on efficacy was less pronounced. Prior studies (University of Minnesota Extension, 2020) (Guo et al, 2018) confirm that temperatures below 5°C may lead to phase separation, crystallization of active ingredients, and increased viscosity, which could reduce pesticide uniformity and effectiveness upon application. In conclusion, while both high and low temperatures influence the physical properties of pesticide formulations, elevated temperature poses a greater risk to their stability and efficacy, highlighting the critical importance of optimal storage conditions.

Keywords: Pesticides, Chemical Pesticides, Pesticide Effectiveness, Pesticide Thiamethoxam, Pesticide Abamectin, Lambda-Cyhalothrin, Neonicotinoid, Pyrethroid

Introduction

The agricultural sector is currently facing significant challenges as a result of ongoing climate change and rapid population growth. These factors necessitate the enhancement of agricultural productivity to ensure global food security. According to Carvalho (2017), the global population is projected to reach 9 billion by the year 2050, which will require a substantial increase in food production to meet the growing demand. To achieve this, modern agriculture relies heavily on the use of pesticides to control pests. The application of chemical and biological pesticides has become one of the primary strategies for sustaining agricultural output and minimizing losses caused by pest infestations (Khamis et al, 2023).

Among the various categories of pesticides, insecticides are among the most widely used due to their effectiveness in controlling insect pests that attack agricultural crops. However, the efficacy of insecticides is highly influenced by storage conditions. Improper storage, especially under extreme temperature fluctuations, can lead to the degradation or decomposition of the active ingredients, thereby reducing their effectiveness or even increasing their toxicity. Previous studies have indicated that high temperatures can accelerate the breakdown of active compounds, while low temperatures may cause changes in emulsifier properties or alter the chemical structure of formulations, ultimately diminishing their pest control performance (Naglaa & Olfat, 2021; Hanan et al., 2016).

Iraq is one of the countries that significantly relies on importing insecticides, with hundreds of tons being imported annually for agricultural pest control. However, storage conditions in Iraq are often suboptimal, as the country experiences extreme temperature variations—exceeding 50°C during the summer and dropping below 0°C in winter. Plant protection products, including insecticides, are typically formulated to remain stable under proper storage conditions. Manufacturers routinely conduct storage stability tests at elevated and reduced temperatures, as well as under ambient conditions, to assess the durability and integrity of their products. In fact, the submission of stability data from such storage tests is a prerequisite for pesticide registration (CLI-SE, 2021).

Storage and transportation conditions can significantly affect the physical properties and chemical stability of insecticides, including the integrity of active ingredients. Moreover, climate change exerts a broader impact on ecosystems, leading to increased crop vulnerability to pests and diseases (FAO, 2015). Changes in weather patterns also hinder effective pest control, as certain insect species adapt and develop resistance to commonly used insecticides. Consequently, there is a pressing need to diversify pest management strategies by incorporating different classes of insecticides to maintain effective pest suppression (Akowuah et al, 2018) (Babarinde et al, 2020).

Despite the critical importance of this issue, studies investigating the impact of storage conditions on the stability and efficacy of insecticides remain limited, particularly concerning **neonicotinoid**, pyrethroid, and biopesticide formulations. In this context, the present study aims to evaluate the effect of varying storage conditions on selected insecticides formulated in different types, focusing on **emulsion stability** and **adherence percentage**. Furthermore, the study seeks to assess how storage periods and temperature variations influence the insecticidal efficacy against *Callosobruchus maculatus* under laboratory conditions and aphid species in the field.

Among the primary objectives of the research are:

1. To study the effect of elevated temperatures on certain technical specifications of the selected pesticides, such as suspension rate and emulsion stability.
2. To investigate the impact of low storage temperatures and storage duration on the physical and chemical properties of the pesticides.

Research Method

Insecticides Used:

Thiamethoxam, Lambda-cyhalothrin, and Abamectin were selected as representative compounds from different chemical classes for the study.

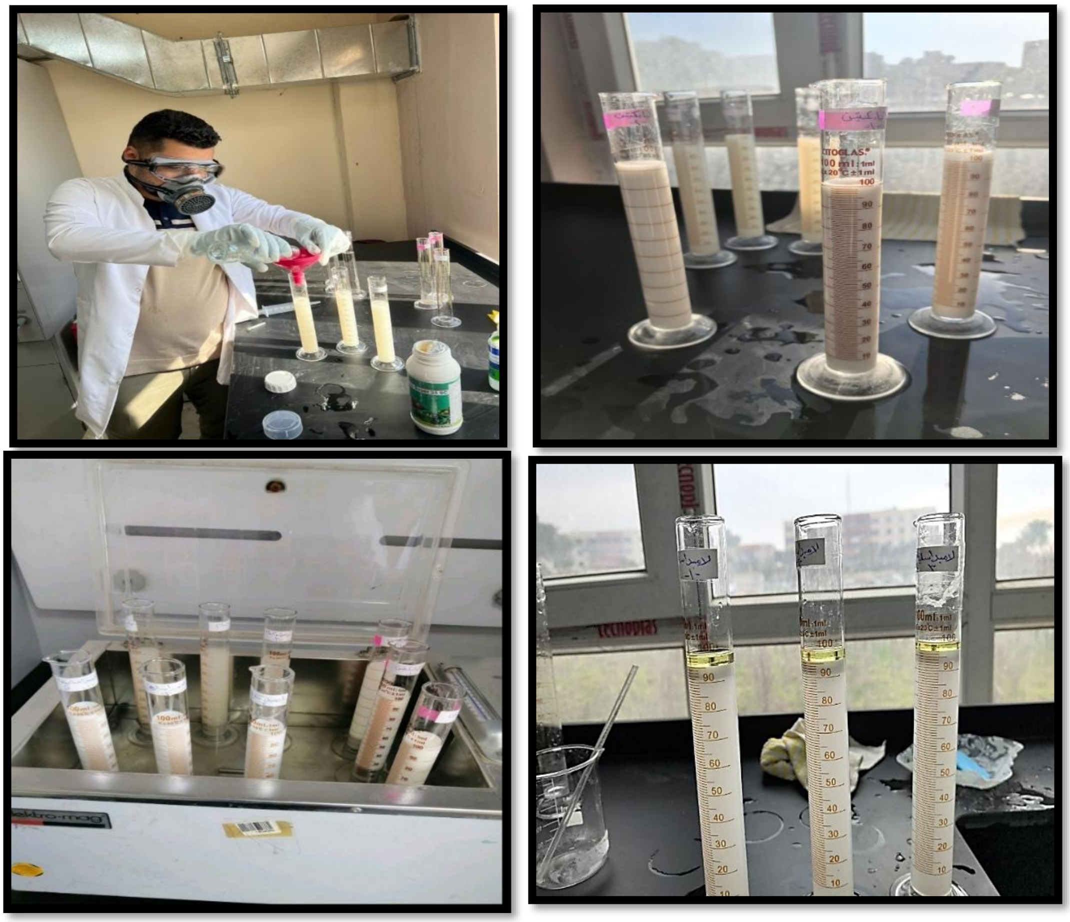
Emulsion Stability Test:

The emulsion stability of the above insecticides was evaluated according to the methodology described in the Iraqi Standard Specification No. (6/8/0/1) of 1984, which serves as the national reference for assessing the emulsification efficiency of emulsifiable concentrate (EC) formulations. According to this standard, an emulsion is considered acceptable if the surface separation layer does not exceed 2 mm after 24 hours of preparation.

For each treatment, 5 mL of insecticide formulation was taken and mixed with 95 mL of tap water in a 100 mL graduated cylinder. The mixture was then transferred to a tightly sealed 250 mL glass cylinder and manually inverted 8 to 10 times through 180° rotations to ensure thorough mixing and homogenization of the emulsion.

After mixing, the solution was returned to the original graduated cylinder and incubated in a water bath maintained at 30 ± 1 °C for 24 hours (see Figure 1). After the incubation period, the thickness of the surface separation layer was measured to assess the emulsion stability in accordance with the specified standard.

The emulsion stability test is a key physical assessment used to determine the quality and stability of EC formulations. It indicates the formulation's ability to form a uniform and stable emulsion upon dilution, which is essential for effective field application and safe usage.



Figures 1. The attached series of images illustrate the experimental steps followed to assess the emulsion stability of various insecticide formulations.

Result and Discussion

1. Effect of Storage Periods at High (50 °C) and Low (-5 °C) Temperatures on the Separation Layer Thickness (cm) of Pesticide Emulsions After Three Months of Exposure

A. Thiamethoxam Emulsifiable Concentrate:

The statistical analysis results presented in Table (1) demonstrate the impact of storage duration under high (50 °C) and low (-5 °C) temperatures on the separation layer thickness (cm) of thiamethoxam emulsion after three months of exposure. The findings reveal that storage at the elevated temperature (50 °C) led to a gradual increase in the separation layer thickness over time. Specifically, the thickness measured 0.48 cm in the first month, rose to 0.97 cm in the second month, and reached its highest value of 2.12 cm in the third month—exceeding the permissible limit specified by standard technical specifications (≤2 cm). This deterioration indicates a loss of the physical homogeneity of the emulsion due to prolonged heat exposure and possible alteration of its chemical constituents, which may negatively affect its efficacy and stability upon application.

In contrast, the results under cold storage conditions (-5 °C) displayed a more stable pattern. The separation layer thickness measured 0.47 cm in the first month, increased slightly to 0.98 cm in the second month, and reached 1.07 cm in the third month. Despite the gradual increase, all values remained within the acceptable limits of the standard specifications, suggesting that low temperatures contribute to maintaining the physical stability of the emulsion during extended storage periods.

A comparison across storage durations shows that the third month represents the most critical phase in terms of separation layer thickness increase, under both high and low temperature conditions. However, the effect was more pronounced and concerning at 50 °C, where the thickness exceeded the standard limit, whereas it remained within the acceptable range at -5 °C. These findings indicate that storage duration—particularly beyond two months—is a decisive factor influencing emulsion stability, especially under suboptimal thermal conditions.

An analysis of the average effect of the two temperature levels over the entire study period reveals that the mean separation layer thickness was 1.19 cm at high temperature, compared to 0.84 cm at low temperature. This data indicates a statistically significant difference, highlighting the negative impact of high-temperature storage on emulsion stability. The observed increase suggests that elevated temperatures accelerate phase separation between the emulsion's components (continuous and dispersed phases), potentially leading to sedimentation of the active ingredient and a loss of physical uniformity.

Considering the LSD (Least Significant Difference) values at a 0.01 probability level, the differences in separation layer thickness among storage months and temperatures were statistically significant, particularly in the third month at 50 °C, where the differences exceeded the minimum threshold for significance (T*M = 0.068). This supports the conclusion that there is a clear interaction between storage duration and temperature in affecting emulsion stability.

Table 1. Effect of Storage Periods at High (50 °C) and Low (-5 °C) Temperatures on the Separation Layer Thickness (cm) of Thiamethoxam Emulsifiable Concentrate After Three Months of Exposure

Mean Temperature	**Storage Duration (Months)**			**Before exposure to storage conditions**	**Temperature**
	Month3	**Month2**	**Month1**		
1.19a	**2.12a**	**0.97c**	**0.48d**	**0.32**	**50°C**
0.84b	**1.07b**	**0.98c**	**0.47d**	**0.32**	**- 5°C**
-	**1.59a**	**0.98b**	**0.47c**	**0.32**	**Monthly Mean**
T = 0.039, M = 0.048, T*M = 0.068, CV= 2.7%				**LSD $_{0.01}$**	

The increase percentage in the separation layer thickness of thiamethoxam after storage at high and low temperatures reached (48.96% and 47.50%) after one month, and (202.08% and 210.15%) after two months, respectively. The differences in the rates of increase during these two periods were not statistically significant. However, after three months, the increase rates became significant, reaching (561.46% and 236.97%) at high and low temperatures, respectively (Figure 2).

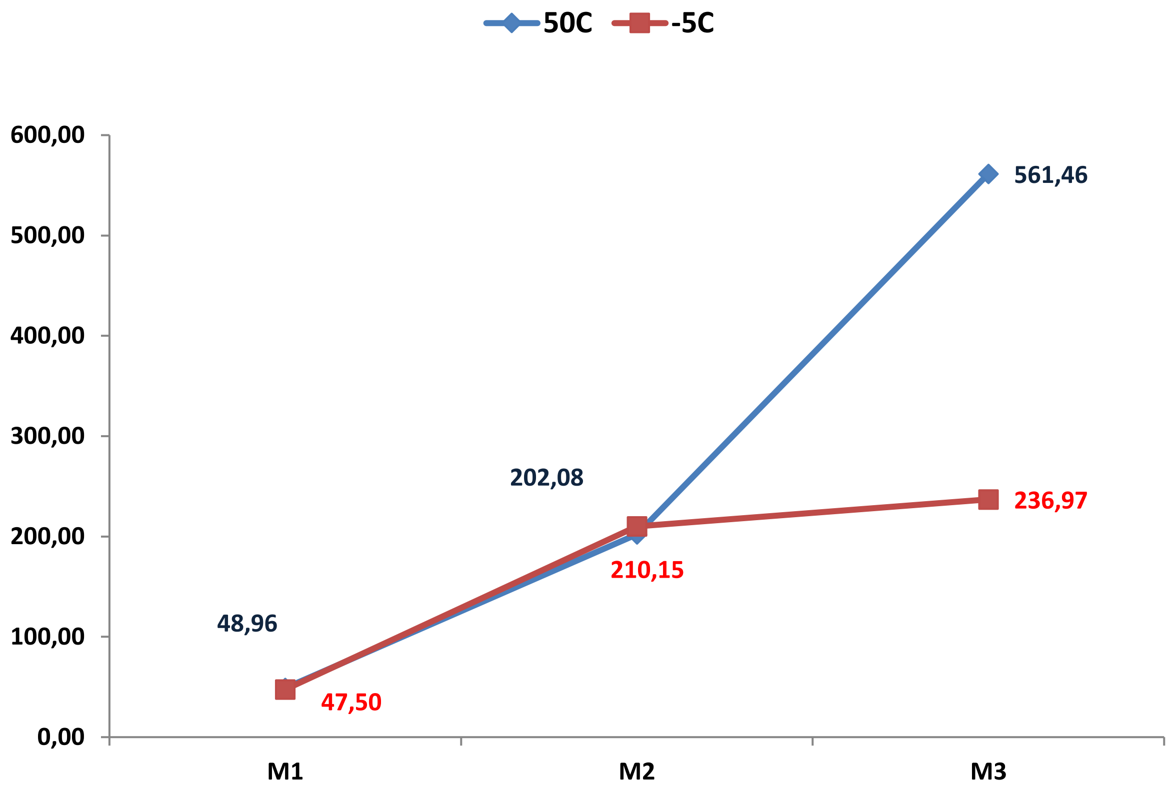


Figure 2. Percentage increase rates (%) in the separation layer thickness of thiamethoxam emulsifiable concentrate stored at high (50 °C) and low (-5 °C) temperatures for three months compared to the pre-exposure period.

B. Lambda-Cyhalothrin Emulsifiable Concentrate:

The statistical analysis results presented in Table (2) illustrate the effect of storage duration at high (50 °C) and low (-5 °C) temperatures on the separation layer thickness (cm) of the lambda-cyhalothrin emulsion after three months of exposure. The data show that storage at the elevated temperature (50 °C) resulted in a noticeable gradual increase in the separation layer thickness over time. Specifically, the thickness measured 0.96 cm in the first month, increased to 3.12 cm in the second month, and reached its highest value of 3.48 cm in the third month. These increases clearly exceeded the permissible limit specified by standard technical specifications (≤2 cm) in both the second and third months. This degradation indicates a loss of physical homogeneity in the emulsion due to prolonged exposure to high temperatures, which may adversely affect its effectiveness and stability during application.

In contrast, the results under cold storage conditions (-5 °C) exhibited a more stable trend. The separation layer thickness was 0.59 cm in the first month, increased to 1.47 cm in the second month, and reached 1.73 cm in the third month. Despite the gradual increase, all values remained within the permissible limits of standard specifications, indicating that low temperatures effectively contribute to preserving the physical stability of the emulsion during extended storage periods.

A comparative analysis across storage durations reveals that the third month represents the most critical phase regarding the increase in separation layer thickness, under both high and low temperature conditions. However, the difference was more pronounced and critical at 50 °C, where the separation layer thickness reached 3.48 cm, surpassing the standard limit, while remaining within the acceptable range (1.73 cm) at -5 °C. These results suggest that storage duration—especially beyond two months—is a crucial factor affecting emulsion stability, particularly under unfavorable thermal conditions.

An analysis of the average effect of the two temperature levels throughout the study period shows that the mean separation layer thickness was 2.52 cm under high-temperature storage, compared to 1.26 cm under low-temperature storage. This data reflects a clear and significant difference, highlighting the detrimental impact of high-temperature storage on emulsion stability. The observed increase suggests that elevated temperatures accelerate phase separation between the emulsion's components (continuous and dispersed phases), potentially resulting in the sedimentation of the active ingredient and a loss of physical uniformity in composition.

Considering the LSD (Least Significant Difference) values at the 0.01 probability level, the differences in separation layer thickness among storage months and temperature levels were statistically significant, particularly in the second and third months at 50 °C, where the differences exceeded the minimum threshold for significance (T*M = 0.170). This supports the conclusion that a clear interaction exists between storage duration and temperature in influencing emulsion stability.

Table 2. Effect of storage periods at high (50 °C) and low (-5 °C) temperatures on the separation layer thickness (cm) of lambda-cyhalothrin emulsifiable concentrate after a three-month exposure period

Mean Temperature	**Storage Duration (Months)**			**Before exposure to storage conditions**	**Temperature**
	Month3	**Month2**	**Month1**		
2.52a	3.48a	3.12b	0.96e	0.46	**50°C**
1.26b	1.73c	1.47d	0.59f	0.46	**- 5°C**
-	2.61a	2.30b	0.78c	0.46	**Monthly Mean**
T = 0.098, M = 0.120, T*M = 0.170, CV= 3.6%				**LSD $_{0.01}$**	

The percentage increase in the separation layer thickness of lambda-cyhalothrin emulsifiable concentrate upon storage at high and low temperatures reached 111.94% and 28.63% after one month, 586.62% and 221.17% after two months, and 666.44% and 280.18% after three months, respectively. The differences in the rates of increase were consistently statistically significant at the high temperature compared to the low temperature across all storage periods (Figure 2).

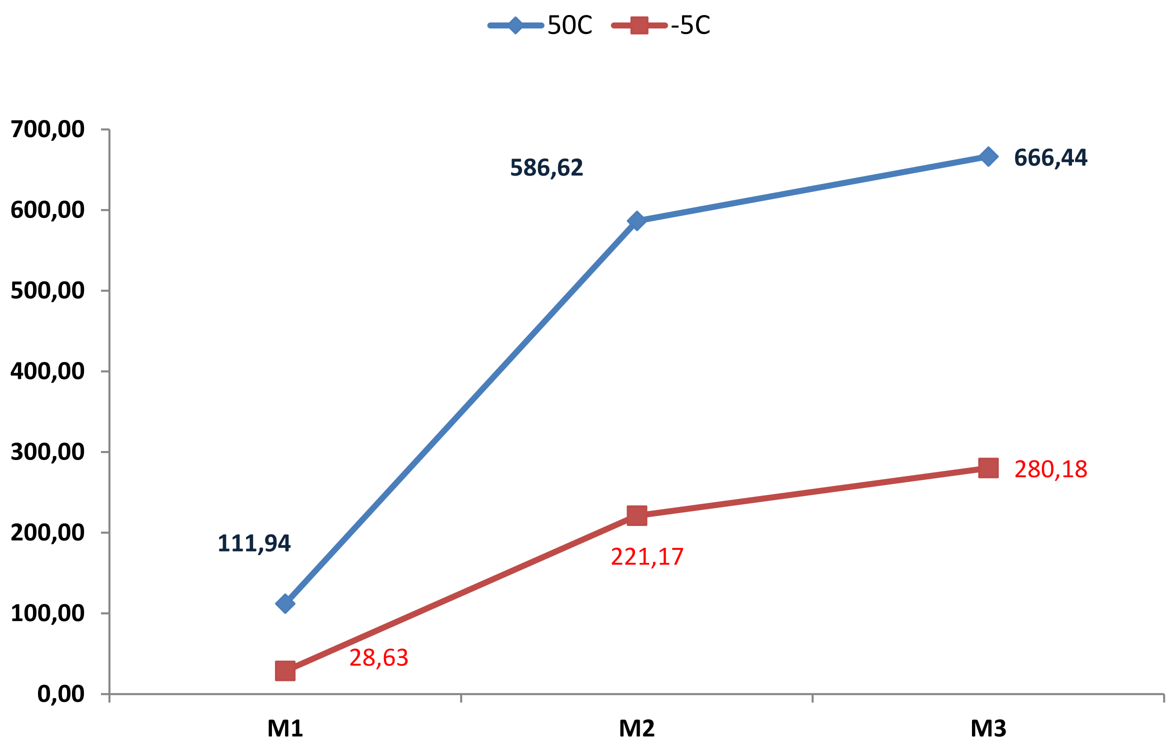


Figure 3. Percentage increase in the separation layer thickness of lambda-cyhalothrin emulsifiable concentrate stored at high (50 °C) and low (-5 °C) temperatures for three months, compared to the pre-storage (baseline) value

C. Abamectin Emulsifiable Concentrate:

The statistical analysis results presented in Table (3) demonstrate the effect of storage duration under high (50 °C) and low (-5 °C) temperatures on the separation layer thickness (cm) of the abamectin emulsion over a three-month exposure period. The initial measurement, prior to any storage treatment, showed a separation layer thickness of 0.41 cm, serving as the baseline reference for comparison.

Under elevated temperature conditions (50 °C), the emulsion exhibited a gradual increase in separation layer thickness over time. It measured 0.96 cm in the first month, rose to 1.17 cm in the second month, and reached its peak value of 2.14 cm in the third month. This final value exceeded the maximum allowable limit according to standard technical specifications for pesticide emulsions (≤2 cm), indicating the onset of physical instability in the formulation after prolonged exposure to high temperatures. Nonetheless, the average separation layer thickness at this temperature was 1.42 cm, reflecting a relative stability until the third month.

In contrast, under low-temperature storage conditions (-5 °C), a similar gradual increase in separation layer thickness was observed. The thickness measured 0.98 cm in the first month, increased to 1.67 cm in the second month, and reached 1.73 cm in the third month. Although these values were comparable to those observed under high-temperature storage, they remained within the permissible range, suggesting that low temperatures contributed to minimizing phase separation and preserving the physical stability of the emulsion throughout the storage period.

A comparison across storage durations indicates that the third month was the most critical in terms of increased separation layer thickness at both temperatures. However, the increase was more severe under the 50 °C condition, where the thickness exceeded the acceptable limit (2.14 cm), while it remained within specification (1.73 cm) under cold storage. These findings indicate that storage duration—especially beyond two months—is a decisive factor influencing emulsion stability, with a more detrimental cumulative effect observed under high-temperature conditions.

Analyzing the average effect of temperature across the entire study period revealed a mean separation layer thickness of 1.42 cm under high-temperature storage, compared to 1.46 cm under low-temperature storage. Despite their closeness, the differences between these means were not statistically significant, based on the LSD value for the temperature factor (T = 0.078 NS), indicating that temperature alone did not significantly affect the outcome. However, its interaction with storage duration proved to be important.

When examining the interaction between temperature and storage duration, the data showed no significant differences in the first month at either temperature (0.96 and 0.98 cm, respectively). However, after two months, statistically significant differences emerged, with the emulsion stored at -5 °C showing a greater separation thickness (1.67 cm) compared to that at 50 °C (1.17 cm). By the third month, this trend reversed, and the separation layer thickness at 50 °C exceeded the permissible limit, indicating a clear interaction between temperature and storage duration (T*M = 0.136), as supported by the LSD test at the 0.01 probability level.

Table 3. Effect of storage periods at high (50 °C) and low (-5 °C) temperatures on the separation layer thickness (cm) of abamectin emulsifiable concentrate after three months of exposure.

Mean Temperature	Storage Duration (Months)			Before exposure to storage conditions	Temperature
	Month3	Month2	Month1		
1.42a	**2.14a**	**1.17c**	**0.96d**	**0.41**	**50°C**
1.46a	**1.73b**	**1.67b**	**0.98d**	**0.41**	**- 5°C**
-	**1.94a**	**1.42b**	**0.97c**	**0.41**	**Monthly Mean**
T = 0.078 NS, M = 0.096, T*M = 0.136, CV= 3.8%				**LSD** $_{0.01}$	

The percentage increase in the separation layer thickness of lambda-cyhalothrin emulsifiable concentrate during storage at high and low temperatures reached (135.05% and 138.29%) after one month, and (184.57% and 306.66%) after two months, respectively. After three months, the increase reached (421.34% and 322.74%) under high and low temperature storage, respectively. The differences in the increase rates were not statistically significant after one month; however, they became significant between the second and third months (Figure 4).

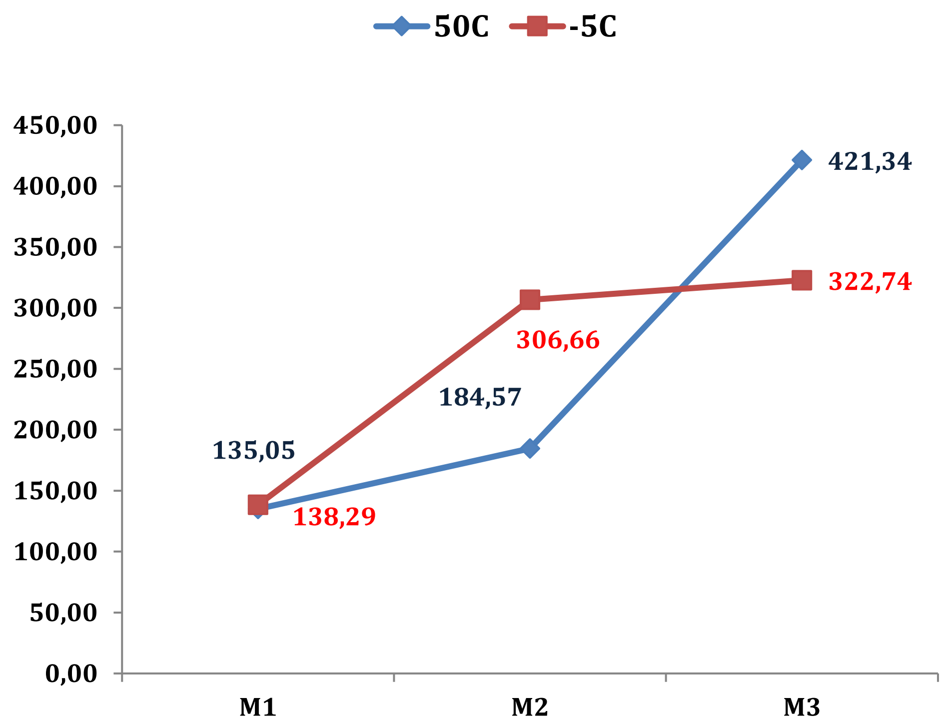


Figure 4. Percentage increase in the separation layer thickness of abamectin emulsifiable concentrate stored at high (50 °C) and low (-5 °C) temperatures for three months compared to the pre-storage baseline.

Conclusion

Scientific Conclusions:

Effect of Storage Temperature and Duration on the Physical Stability of Emulsifiable Concentrate Pesticides

The physical stability of the emulsifiable concentrate (EC) pesticide formulations under investigation was found to be significantly influenced by storage temperature. Elevated temperatures (50 °C) led to a marked increase in the thickness of the separation layer compared to cold storage conditions (-5 °C), indicating pronounced destabilization of the formulations under thermal stress. This trend was consistent across all tested formulations.

Furthermore, storage duration proved to be a critical factor in the degradation of physical stability. All tested samples exhibited a progressive increase in the separation layer thickness over time, reflecting the gradual separation of active ingredients, solvents, or surfactants. Such phase separation suggests ongoing degradation or physicochemical incompatibility among the formulation components as storage time increases.

Individual Evaluation of Pesticide Stability

1. Thiamethoxam (Thiamethoxam EC)

Thiamethoxam EC exhibited moderate sensitivity to elevated storage temperatures. After three months at 50 °C, the separation layer reached a thickness of 2.12 cm, thereby exceeding the maximum allowable limit (2.00 cm) set by technical standards for EC formulations. This exceedance indicates emulsion breakdown and compromised physical stability under thermal stress.

In contrast, storage at -5 °C maintained acceptable physical stability, with the separation layer measuring 1.07 cm after the same storage period.

The percentage increase in the separation layer was markedly higher at elevated temperature (561.46%) compared to low temperature (236.97%), highlighting the adverse effect of prolonged heat exposure. These findings indicate that although thiamethoxam possesses a degree of thermal resilience, its long-term stability is substantially compromised under high-temperature storage conditions.

2. Lambda-Cyhalothrin (Lambda-Cyhalothrin EC)

Among all tested formulations, lambda-cyhalothrin EC exhibited the highest degree of physical degradation under elevated temperatures. After three months at 50 °C, the separation layer thickness reached 3.48 cm—well beyond the permissible technical threshold—indicating severe instability and heightened thermal sensitivity.

Conversely, under cold storage conditions, the formulation showed relatively good performance, with a separation layer thickness of 1.73 cm. This result underscores the importance of low-temperature storage for maintaining the physical integrity of the formulation.

Furthermore, the rate of increase in separation layer thickness remained consistently high under thermal stress throughout the entire storage period and was statistically significant. These observations confirm that lambda-cyhalothrin EC is the least physically stable of the three tested formulations when subjected to elevated storage temperatures.

3. Abamectin (Abamectin EC):

Abamectin EC demonstrated a distinct stability pattern compared to the previous two formulations. During the first month of storage, no significant differences were observed in separation layer thickness between high and low temperature conditions, suggesting initial physical stability regardless of temperature.

However, by the third month, significant differences emerged. At 50 °C, the separation layer increased to 2.14 cm, exceeding the acceptable technical limit, while remaining within permissible boundaries (1.73 cm) under low-temperature storage. This indicates that extended exposure to high temperatures ultimately impairs the stability of abamectin EC.

Interestingly, during the first two months, the percentage increase in the separation layer was greater under cold conditions compared to hot ones, possibly indicating early-stage physicochemical changes unrelated to temperature. Nonetheless, by the third month, the thermal effect became dominant and statistically significant in destabilizing the formulation.

These findings suggest that abamectin EC exhibits relatively greater physical stability than lambda-cyhalothrin EC, particularly under moderate storage conditions. Nevertheless, it remains susceptible to degradation upon prolonged thermal exposure, highlighting the necessity for appropriate temperature-controlled storage and handling to ensure product quality.

References

Ahmad, A. S. (2025). Combined effects of pulsed electric field and soursop leaf extract treatment and modified atmosphere packaging on melanosis inhibition and shelf-life elongation of Pacific white shrimp during refrigerated storage. *Innovative Food Science and Emerging Technologies*, *100*, ISSN 1466-8564, https://doi.org/10.1016/j.ifset.2024.103903

Akbar, R., Khan, I. A., Alajmi, R. A., Ali, A., Faheem, B., Usman, A., Ahmed, A. M., El-Shazly, M., Farid, A., & Giesy, J. P. (2022). Evaluation of insecticidal potentials of five plant extracts against the stored grain pest, *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Insects*, *13*, 1047. https://doi.org/10.3390/insects13111047

Araújo, R. S. (2023). Effect of Pesticides and a Long-Life Inoculant on Nodulation Process and Soybean Seed Quality during Storage. *Agronomy*, *13*(9), ISSN 2073-4395, https://doi.org/10.3390/agronomy13092322

Augustine, N., & Balikai, R. A. (2019). Biology of pulse beetle, *Callosobruchus chinensis* (Linnaeus) on cowpea variety DC-15. *Journal of Entomology and Zoology Studies*, *7*(1), 513–516.

Butt, Z. I. (2024). MHD slip flow through nanofluids for thermal energy storage in solar collectors using radiation and conductivity effects: A novel design sequential quadratic programming-based neuro-evolutionary approach. *Modern Physics Letters B*, ISSN 0217-9849, https://doi.org/10.1142/S0217984925500757

Carvalho, F. P. (2017). Pesticides, environment, and food safety. *Food and Energy Security*, *6*, 48–60. https://doi.org/10.1002/fes3.108

CLI-SE. (2021). *Guidelines for specifying and managing shelf life and expiry date of crop protection product* (Technical Monograph No. 17, 3rd ed., 20 pp.). CropLife International.

FAO/WHO. (2016). *Manual on development and use of FAO and WHO specifications for pesticides* (3rd rev. ed., 228 pp.). Rome: FAO Plant Production and Protection.

Fernández-Alba, A. R., & García-Reyes, J. F. (2008). Large-scale multi-residue methods for pesticides and their degradation products in food by advanced LC-MS. *Trends in Analytical Chemistry*, *27*(11), 973–990.

Fishel, F. M. (2016). *Pesticide toxicity profile: Neonicotinoid pesticides*. University of Florida. Accessed from http://edis.ifas.ufl.edu/pi117

Hamza, A. M. (2017). Natural products for controlling sitophilus oryzae with respect to the effect of storage conditions and grain type. *Egyptian Journal of Biological Pest Control*, *27*(2), 245-253, ISSN 1110-1768, https://www.scopus.com/inward/record.uri?partnerID=HzOxMe3b&scp=85025658800&origin=inward

Hanan, S. T., Naglaa, K. Y., & Olfat, A. R. (2016). Effect of storage on the stability and biological effectiveness of some insecticides. *Journal of Biological Chemistry and Environmental Science*, *11*(2), 265–282.

Khamis, W. M., El-Sabrout, A. M., Shahin, R., & others. (2023). Field efficacy, sub-lethal, and biochemical effects of certain biorational insecticides against the new intruder, *Spodoptera frugiperda* in Bani-Suef, Upper Egypt. *Neotropical Entomology, 52*, 963–973. https://doi.org/10.1007/s13744-023-01064-y

Mrda, J. (2010). Effect of storage period and chemical treatment on sunflower seed germination. *Helia*, *33*(53), 199-206, ISSN 1018-1806, https://doi.org/10.2298/HEL1053199M

Naglaa, K. Y., & Olfat, A. R. (2021). Effect of storage temperature conditions on the stability and biological effectiveness of insecticide formulation. *Egyptian Journal of Plant Protection Research Institute, 4*(3), 426–431.

Rivera, P. (2014). Effect of vacuum storage on shelf life of a grain protector based on Peumus boldus molina foliage powder and lime against Sitophilus zeamais motschulsky. *Chilean Journal of Agricultural Research*, *74*(1), 49-54, ISSN 0718-5820, https://doi.org/10.4067/S0718-58392014000100008

Roberts, J. R., & Karr, J. C. (2012). Pesticide exposure in children. *Pediatrics, 130*(6), e1765–e1788. https://doi.org/10.1542/peds.2012-2758

Shinde, P. (2024). Effect of Modified Atmosphere Storage Conditions on Seed Quality and Longevity of Kabuli Chickpea Varieties. *Indian Journal of Agricultural Research*, *58*(4), 566-575, ISSN 0367-8245, https://doi.org/10.18805/IJARe.A-5785

Stejskal, V. (2021). Sensitivity of polyphagous (Plodia interpunctella) and stenophagous (Ephestia kuehniella) storage moths to residual insecticides: effect of formulation and larval age. *Insect Science*, *28*(6), 1734-1744, ISSN 1672-9609, https://doi.org/10.1111/1744-7917.12889

World Health Organization (WHO). (2003). *Guidelines on the management of public health pesticides*. Geneva: WHO.

Zhao, J. (2024). Experimental study on effect of an active solar heating soil heat storage system on the thermal environment in Gobi solar greenhouses. *Energy and Buildings*, *325*, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2024.115055