# SENSING ALLIED TO MONITORING THE CONSERVATION OF STORED GRAINS

# SENSORIAMENTO ALIADO AO MONITORAMENTO DA CONSERVAÇÃO DE GRÃOS ARMAZENADOS

# DETECCIÓN ALIADA AL MONITOREO DE LA CONSERVACIÓN DE GRANOS ALMACENADOS

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## ABSTRACT

Grain production in Brazil presents quantitatively and qualitatively irregular harvests, highlighting the need for knowledge about the dynamics of bottlenecks and post-harvest strategies due to loss rates, a reflection of cultural problems and historical deficiencies in the country's agricultural policy. With difficulties in establishing processing units and storage structures on properties, there has been a regional centralization of warehouse locations, which requires planning for logistics operations to flow production. Thus, the objective of this research was to demonstrate the importance of monitoring the temperature and relative humidity of soybean (Glycine max L.) grain mass during storage and the influence of Sitophilus zeamais infestation on the temperature and relative humidity parameters of corn (Zea mays) grain mass. The tests were conducted in the Agricultural Products Postharvest Technology Laboratory at the State University of Maringá (UEM), main campus in Maringá, Paraná. To monitor the evaluated parameters (temperature and relative humidity) of the intergranular air and storage environment, a Data Logger, model RC-61 Elitech®, was used. Soybeans were stored in a prototype metal silo under uncontrolled conditions, and corn grains were stored in polyethylene bags at a constant temperature, with two treatments (with and without Sitophilus zeamais infestation). The use of digital sensors proved efficient for monitoring the temperature and relative humidity of the air in the granular mass, representing a viable and applicable tool in this segment, enabling the adoption of preventive measures aimed at better preserving the physical and chemical quality of stored grains.

**Keywords:** *Glycine max L.* Postharvest Bottlenecks. Microecosystem. *Sitophilus zeamais. Zea mays.*

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## RESUMO

A produção de grãos no Brasil apresenta safras quantitativas e qualitativamente irregulares, evidenciando a necessidade de conhecimentos sobre a dinâmica de gargalos e estratégias pós-colheita em decorrência dos índices de perdas, reflexo de problemas culturais e de deficiências históricas na política agrícola do país. Com dificuldades na implantação de unidades beneficiadoras e de estruturas de armazenagem em propriedades, houve uma centralização regional de pontos de armazéns, o que requere planejamento para operações de logística de escoamento da produção. Assim, o objetivo desta pesquisa foi demonstrar a importância de monitoramento dos fatores temperatura e umidade relativa da massa de grãos de soja (Glycine max L.) durante o tempo de armazenagem e da influência da infestação de Sitophilus zeamais sobre os parâmetros temperatura e umidade relativa da massa de grãos de milho (Zea mays). Os testes foram realizados no laboratório de Tecnologia de Pós-Colheita de Produtos Agrícolas, na Universidade Estadual de Maringá (UEM), campus sede em Maringá-PR. Para o monitoramento dos parâmetros avaliados (temperatura e umidade relativa) do ar intergranular e ambiente de armazenamento foi utilizado equipamento Data Logger, modelo RC-61 Elitech®, utilizando grãos de soja em protótipo de silo metálico em condições não controladas; e grãos de milho acondicionados em embalagens de polietileno, mantidos em temperatura constante, com dois tratamentos (com infestação de Sitophilus zeamais e sem infestação). O uso de sensores digitais se mostrou eficiente para o monitoramento da temperatura de umidade relativa do ar na massa granular, sendo uma ferramenta viável e aplicável neste segmento, possibilitando adoção de medidas preventivas visando melhor conservação da qualidade físico-química de grãos armazenados.

**Palavras-chave:** *Glycine max L*. Gargalos Pós-colheita. Microecossistema. *Sitophilus zeamais*. *Zea mays.*

## RESUMEN

La producción de granos en Brasil presenta cosechas irregulares, tanto cuantitativa como cualitativamente, lo que resalta la necesidad de conocer la dinámica de los cuellos de botella y las estrategias poscosecha debido a las tasas de pérdidas, reflejo de problemas culturales y deficiencias históricas en la política agrícola del país. Ante las dificultades para establecer unidades de procesamiento y estructuras de almacenamiento en las propiedades, se ha producido una centralización regional de las ubicaciones de los almacenes, lo que requiere la planificación de las operaciones logísticas para optimizar la producción. Por lo tanto, el objetivo de esta investigación fue demostrar la importancia del monitoreo de la temperatura y la humedad relativa de la masa de grano de soja (Glycine max L.) durante el almacenamiento y la influencia de la infestación por Sitophilus zeamais en los parámetros de temperatura y humedad relativa de la masa de grano de maíz (Zea mays). Las pruebas se realizaron en el Laboratorio de Tecnología de Poscosecha de Productos Agropecuarios de la Universidad Estatal de Maringá (UEM), campus principal en Maringá, Paraná. Para monitorear los parámetros evaluados (temperatura y humedad relativa) del aire intergranular y del ambiente de almacenamiento, se utilizó un registrador de datos, modelo RC-61 Elitech®. La soja se almacenó en un silo metálico prototipo en condiciones no controladas, y los granos de maíz se almacenaron en bolsas de polietileno a temperatura constante, con dos tratamientos (con y sin infestación de Sitophilus zeamais). El uso de sensores digitales resultó eficaz para monitorear la temperatura y la humedad relativa del aire en la masa granular, lo que representa una herramienta viable y aplicable en este segmento, permitiendo la adopción de medidas preventivas para preservar mejor la calidad física y química de los granos almacenados.

**Palabras clave:** *Glycine max L.* Cuellos de Botella Poscosecha. Microecosistema. *Sitophilus zeamais. Zea mays.*

## 1 INTRODUCTION

Driven by the growing global population demand, Brazilian grain production has achieved high productivity numbers year after year, with emphasis on soybean and corn crops, the main agricultural products in the country. The projections for the coming years (2024/2034) are that grain production in Brazil will increase corresponding to a growth rate of 2.2% per year, reaching 379 million tons and with an increase of 15.5% in the area growing grains between this period, from 79.8 million hectares in 2023/24 to 92.2 million in 2033/34, as pointed out in the projections of the Secretariat of Agricultural Policy in partnership with EMBRAPA in the 2023 survey.

Grain production is a highlight among agricultural activities, with high production volumes and monetary values achieved, however, the post-harvest period has been a determining factor in the final profitability of producers (Ramos & Ramos, 2022).

In a country with continental dimensions such as Brazil, logistics is one of the pillars in the development of agricultural activities, but there are limiting factors, such as means of transport that cause lower losses during the journey to the destination, require better flow plans for less waiting time for the product stopped in the cargo (Caixeta Filho, 2018). Factors that include risk management and maintenance of product quality must be linked to investment and planning of better infrastructures of processing and drying units, as well as ports and storage units, as these directly compromise the qualitative and quantitative losses of the product (Fassio, 2018).

Although the corrections/mitigations in scale and spatial distribution are notorious, in storage the availability/need ratio is below the growth of agricultural production (Ramos & Ramos, 2022).

The grain storage process is one of the components of the Agricultural Policy, coordinated by the Ministry of Agriculture, Livestock and Supply (MAPA). Storage is a post-harvest stage, being a pillar for the balance of supply and demand and the basis for the execution of production flow planning in time and space, contributing to the reduction of price and market volatility and ensuring long-term food security (Santana et al., 2014; Frederico, 2010; Vieira Filho & Ribeiro, 2025).

Although Brazilian agriculture shows increases in grain production year after year, on the other hand, logistics and static storage capacity are moving slowly. The stages carried out in the post-harvest period are responsible for maintaining the conservation of the grains, aiming to reduce quantitative and qualitative losses, through cleaning, phytosanitary treatment and drying operations in the processing and storage units. According to data from the National Supply Company (CONAB, 2025), Brazilian grain production in the 2024/25 harvest is estimated at 345.2 million tons, 47.7 million tons higher than the 2023/24 cycle.

On the other hand, Brazil has approximately 210.1 million tons of static capacity, that is, it does not have space for stock compatible with overproduction, resulting in a storage deficit that impacts the resources generated in production, and investment in the construction of warehouses and modernization for better performance of existing processing units is a way to minimize this problem (Silva et al., 2024; CONAB, 2023; Teles et al., 2025; Lermen et al., 2020).

In the agricultural post-harvest sector, grain storage procedures are responsible for more than 50% of agricultural losses (Pimentel et al., 2024). Therefore, a constant concern whose complex challenge demands strategies for the management and maintenance of stored grain. There are several factors that interfere with the quality of the grains during this period, such as the temperature and humidity of the grains and the atmosphere of the environment to which they are exposed, the amount of broken grains, foreign matter and impurities, attack by insects, mites and microorganisms, and temperature is the main factor that affects the conservation of grains (Nunes et al., 2021; Costa et al., 2024; Ramachandran, 2022).

The presence of insects, such as the corn weevil (*Sitophilus zeamays*), the red flour beetle (*Tribolium castaneum*) and the lesser grain storage borer (*Rhyzopertha dominica*), are the most common. The action of these insects not only causes quantitative losses, but due to the generation of biological waste, they contaminate the product and reduce its quality (Mortazavi et al., 2025).

In addition to biotic factors, the process of operations aimed at maintaining the quality of the stored product is a crucial factor to minimize losses. Performing ventilation/aeration incorrectly can result in an increase in the temperature of the grain mass, consequently raising respiratory rates, reducing weight and creating a favorable atmosphere for the proliferation of fungi, such as aflatoxins or mycotoxins, which pose health risks when ingested by humans or animals (Mafra & Christian, 2024; Baena et al., 2019; Mutalov et al., 2025).

Modern approaches to grain management during the storage period require detailed knowledge about the composition of the product, the conditions of the environment to which it is exposed, and the interaction between both. The use of sensors in all post-harvest stages has been consolidated as the main tool for efficient product monitoring. Being easy to handle for collecting and forming a data set, this equipment helps to understand the dynamics of the grain mass and to choose the appropriate management to be adopted, ensuring greater conservation (Bica et al., 2021; Carvalho & Rodrigues, 2023; Zeymer et al., 2021)

Research using digital monitoring to visualize the dynamics of grain mass characteristics during the storage period is essential to combine technology with quality conservation and loss reduction. Thus, the research developed in two stages should monitor during the storage time the temperature and relative humidity of the soybean grain mass (*Glycine max* L.) and evaluate the influence of *the Sitophilus zeamais* infestation on the temperature and relative humidity of the air of the corn grain mass (*Zea mays*).

## 2 MATERIAL AND METHODS

The tests were carried out in the laboratory of Post-harvest Technology of Agricultural Products, at the State University of Maringá (UEM), headquarters campus in Maringá-PR.

**Step 1: Digital monitoring of soybean mass during storage**

The experiment was installed in a prototype of a cylindrical silo, built with dimensions of 0.54 m diameter and 0.58 m height, in sheet metal material (Figure 1). It was loaded with soybeans, and the grain mass was kept stored in uncontrolled environment conditions, in a greenhouse at the Technical Irrigation Center of the State University of Maringá, in Maringá-PR.

**Figure 1**

*Assembly of the prototype for data collection on the mass of grains stored in a metal silo*

To monitor the temperature and relative humidity of the air, Data Logger equipment, model RC-61 Elitech® (Figure 1), was used. The equipment had calibration certification with a tolerance of ±3 % for relative humidity between 20 and 80 %, and ± 0.5 °C for temperature in a monitoring range ranging from -20 to 40 °C.

In order to obtain data and evaluate the dynamics of the grain mass, the sensors of temperature and relative humidity of the air were installed inside and on the surface of the grain mass, which synchronized to record environmental information at intervals of 15 minutes for a period of 600 hours.

The sensors connected to the monitor transmitted the data to the equipment's internal memory, which was exported to the computer. The temperature and relative humidity of the intergranular air were monitored at different points and the parameters were compared according to the position of the sensors in the grain mass.

**Step II: Evaluation of the influence of *Sitophilus zeamais* on temperature and relative humidity in maize grains during storage**

The corn lot, from cultivation carried out at the Technical Irrigation Center, Maringá-PR, with approximate humidity of 12 %bs (dry basis) was divided into two subplots and stored under uncontrolled conditions of temperature and relative humidity to evaluate the infestation of *S. zeamais* on physical parameters of the grains.

The grains were subjected to two storage conditions, with weevil infestation (10 individuals of *S. zeamais*) and no infestation. The storage was carried out using polyethylene packages containing 2 kg of grains, kept in a Biochemical Oxygen Demand (BOD) chamber, at a constant temperature of 25° C ± 1 °C. Adult individuals of *S. zeamais* were used for infestation. Sensors to record the temperature and relative humidity of the air were installed inside the grain mass.

To monitor the temperature and relative humidity of the air, a Data Logger equipment, model RC-61 (Elitech®), was used. The equipment had calibration certification with a tolerance of ± 3 % for relative humidity between 20 and 80 %, and ± 0.5 °C for temperature in a monitoring range ranging from -20 to 40 °C. The readings were performed at one-minute intervals

The sensors connected to the monitor transmit the data to the equipment whose reading inside the mass of the grains was at one-minute intervals, and the equipment is synchronized at the beginning of storage. For data collection, monitoring was carried out for 560 minutes, and the data were recorded in the equipment's internal memory and exported to the computer. In the interpretation of the information, the temperature and relative humidity of the grain mass were compared for the conditions with and without *S. zeamais* infestation over the storage time.

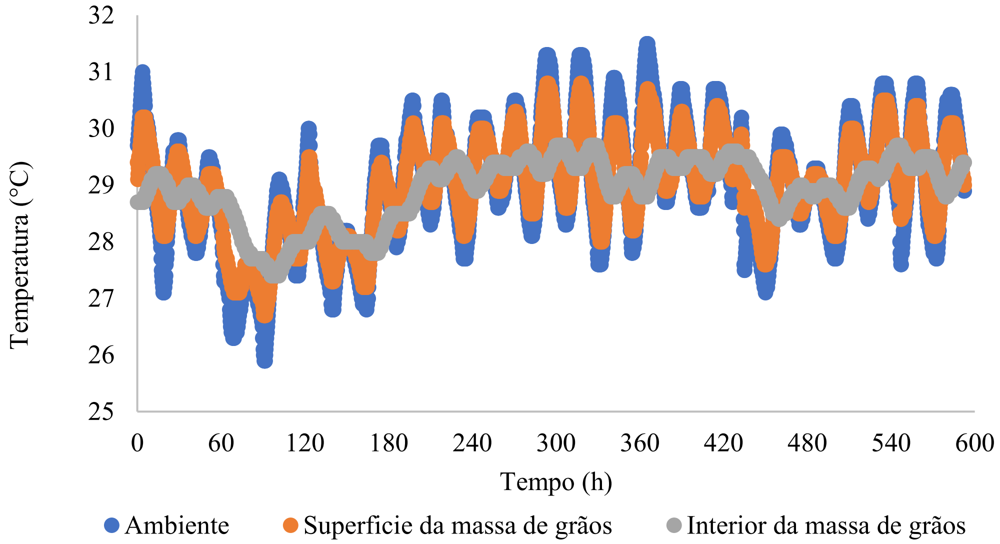
## 3 RESULTS AND DISCUSSION

### 3.1 MONITORING OF THE MASS OF SOYBEANS STORED IN A PROTOTYPE METAL SILO

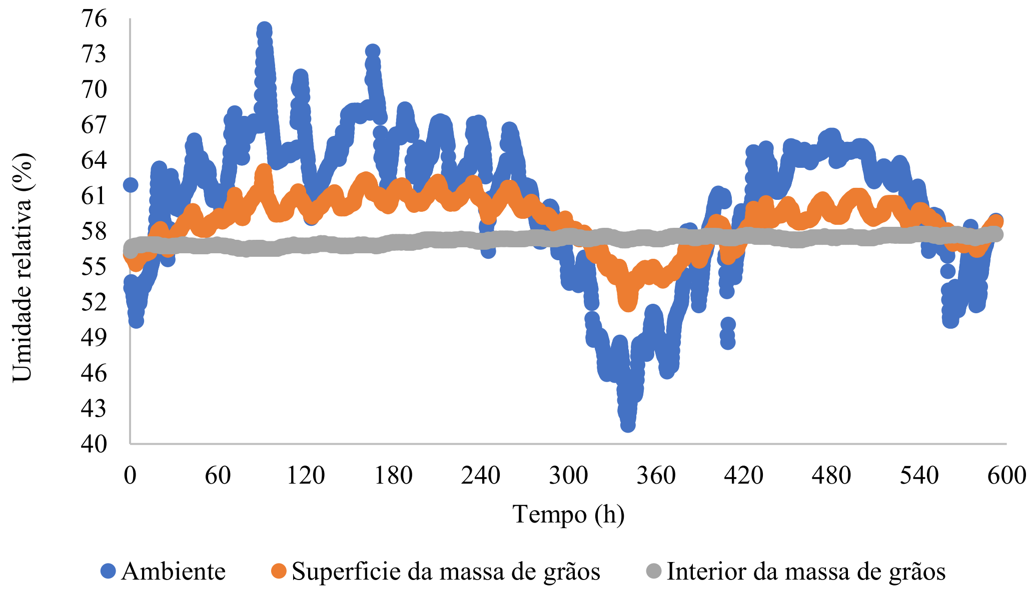
Under the conditions of the experimental unit, the monitoring of the temperature of the granular mass showed homogeneous behavior as a function of the position where the measurements occur. The variations in temperature and relative humidity (Figure 2) are due to the permanence of the silo prototype under uncontrolled environment conditions, suffering maximum and minimum temperature peaks during the day.

**Figure 2**

*Monitoring of the temperature (a) and relative humidity (b) conditions of the intergranular air of soybean grain mass during storage in a prototype metal silo*




a)




b)

The variation in the temperature of the external air had a direct influence on the values observed on the surface and in the intergranular air, with very similar variations on the surface of the grain mass and in its interior, but with greater amplitudes in the external environment (Figure 2a). The mass of grains in the storage environment constitutes a dynamic ecosystem, formed by biotic and abiotic elements that are affected both chemically and biologically by several factors. The heterogeneity of the temperature observed at the three data collection points (Figure 2a) demonstrates the presence of a thermal gradient in the grain mass, in the direction of the warmer region to the colder region. Grains located closer to the surface of the silo wall have a greater influence of the conditions of the external environment (Figure 2). The increase in the water content of intergranular air associated with high temperatures leads to an increase in respiratory rates, consequent loss of dry matter and quality, favoring the development of microorganisms (BICA et al., 2021; JAQUES et al., 2018).

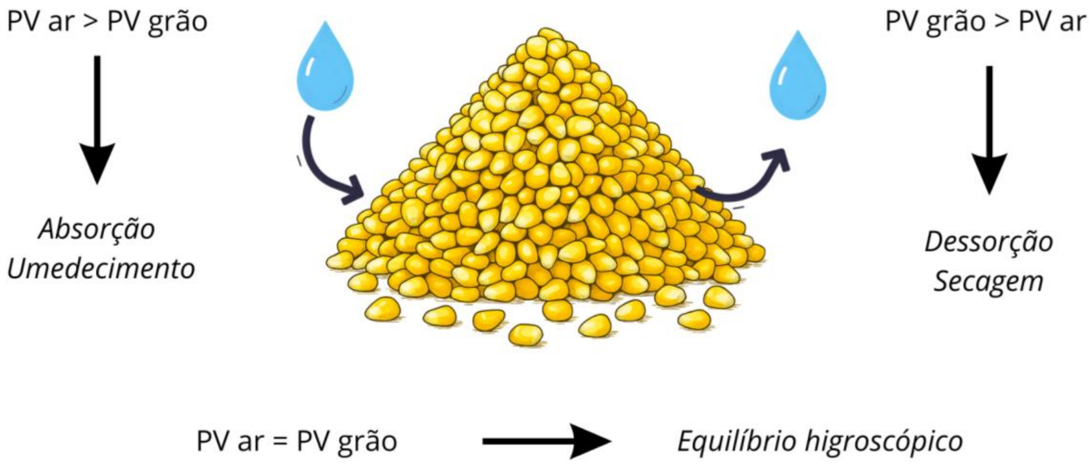
It is observed that the maintenance of the water content of the grains is a function of the environmental conditions. As well as temperature, the relative humidity of the external environment showed greater amplitudes, mainly influencing the grains in the peripheral region (Figure 2b). During this period, there was a change in the grain mass in the peripheral part of the silo, which led to heterogeneity between the water content of the grains over the days.

Due to the hygroscopic characteristics of the grains (absorption and desorption), due to the difference in vapor pressure between ambient air and the product, there are exchanges until the grain reaches equilibrium moisture, keeping its water content constant according to the psychrometric conditions of the air (NUNES et al., 2021). In the study, the intergranular air inside the grain mass did not show variations with the amplitude obtained in the environment outside the silo (42 to 76%), while peripheral regions such as the grain surface showed oscillation in time (Figure 2), with a possible effect on equilibrium moisture and metabolic activity. According to Ferreira Júnior et al. (2024a), a heating in the grain mass in the central part of the silo caused heterogeneity between the water content of the grains over the days.

To adopt a management aimed at maintaining and conserving the physical quality of grains, it is necessary to understand the interactions between the environment and the grain mass. The intergranular air has its psychrometric properties governed by the grain mass, and can establish, when interacting in the air mass, gradients and convective air currents that promote heat and mass exchange (water vapor) in the grain mass, naturally inducing the moisture migration process, thus increases in the water content of the grains and the water activity in the intergranular space. The process of moving water molecules from the interior of the grain to the air occurs in the form of steam and through the difference in vapor pressure between them (Figure 3), as a function of the thermodynamic conditions of the intergranular air.

**Figure 3**

*Illustration of the dynamics of the sorption process between grains and ambient air*




Aeration, through the technique of blowing air through the intergranular spaces, is a fundamental technique to avoid the formation of convective air currents and inhibit the anaerobic process inside the mass. In metal silos, when the external temperature is higher, or if there is an increase in temperature inside the structure on hot days, the grains near the walls heat up more than those near the center of the silo, as well as the intergranular air that is close to and in contact with the walls, this causes its density to decrease and updrafts of air to be formed near the walls,  on the other hand, the air molecules in the center of the silo form a downdraft of cold air (Lopes et al., 2006; Elias et al., 2017; Plumier & Maier, 2021).

The air molecules that circulate are unsaturated, being able to absorb water vapor as they pass through hot regions. By absorbing water vapor and heat, its enthalpy increases, intensifying its ability to exchange thermal energy with water molecules from the grains it passes through. In the central region of the lower third of the silo (near the base), where the point of lowest temperature of the grain mass is located, after the occurrence of convective currents, water condensation occurs when it reaches the dew point. The grains located in this region have high humidity, affecting their quality. Similarly, when the ambient temperature is lower, on colder days or hours, the air near the wall of the structure cools down and a descending convective current is formed, causing an ascending convective current in the center of the grain mass, which results in condensation in the central region of the cone (upper part) of the silo (Lopes and Neto,  2019; Ziegler et al., 2021).

The use of technology for post-harvest grain management, such as digital monitoring of temperature and humidity, is a viable and applicable option for monitoring grain mass. Monitoring enables the adoption of preventive measures that ensure better conservation of the physiological quality of the grain, reducing losses (qualitative and quantitative) and reducing economic losses.

The maintenance of the quality of the stored grains is based on the knowledge of climatic information and control of humidity and temperature inside the stored mass. In this scenario, the use of digital temperature and relative humidity sensors proved to be efficient for temperature control and monitoring and for the automated management of aeration in soybeans (Ferreira Júnior et al., 2024b).

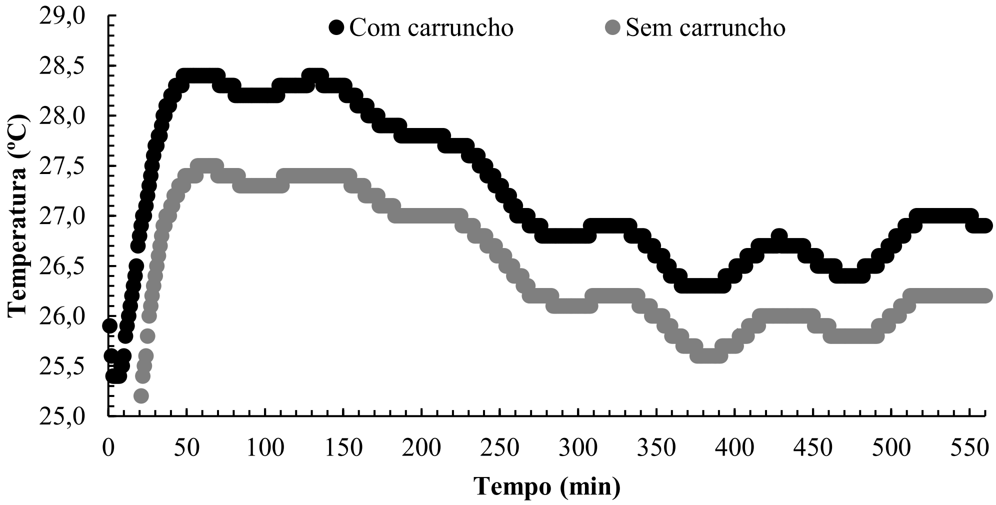
The use of technology for post-harvest grain management, such as digital monitoring of temperature and humidity, is a viable and applicable option for monitoring grain mass. Monitoring enables the adoption of preventive measures that ensure better conservation of the physiological quality of the grain, reducing losses (qualitative and quantitative) and reducing economic losses.

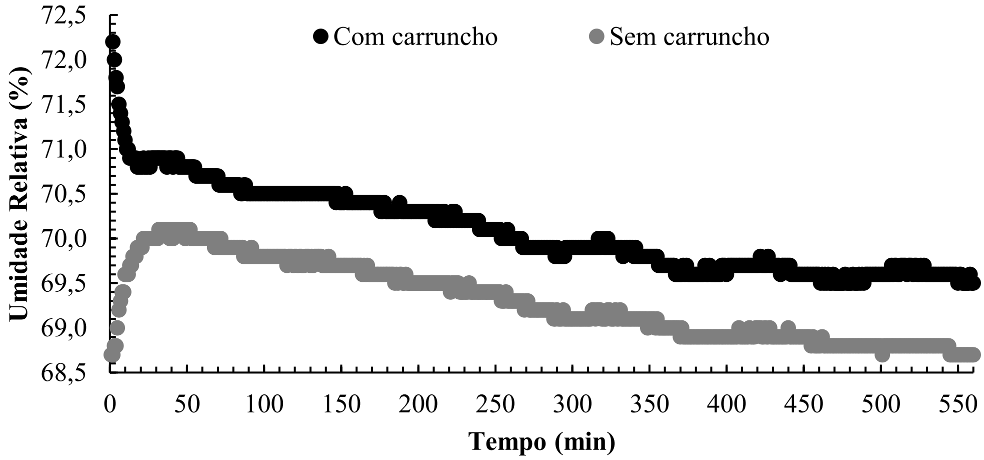
### 3.2 MONITORING OF GRAINS INFESTED AND KEPT AT CONSTANT TEMPERATURE

In storage, the mass of grains results in a dynamic ecosystem, consisting of biotic (grains, insects and microorganisms) and abiotic (foreign materials, intergranular air, water vapor and the storage structure) elements, whose interactions are influenced by environmental conditions (temperatures and relative humidity). It was observed that the temperature inside the mass of corn grains showed oscillations throughout the storage period, related to sorption dynamics, interaction of grains with the environment, and insect action (SILVA et al., 2021), with the temperature being higher in infested grains (Figure 4a). Monitoring the temperature of the grain mass is an important parameter for quality control and storage safety, avoiding the heating of the grain mass and maintaining its integrity (BICA et al., 2021).

**Figure 4**

*Monitoring of temperature (A) and relative humidity (B) inside the mass of corn grains stored with and without the presence of Sitophilus zeamais*




The increase in temperature (Figure 4a) caused by the presence of insects causes the heating of the dough, which can cause losses because there is an increase in the weight loss of the product by accelerating metabolic processes, intensifying the respiratory activity of the stored grain (Neves et al., 2017).

Considering that the temperature range between 27 and 31°C is optimal for *S. zeamais*, the conditions of 25 to 28.8°C recorded (Figure 4a) favor the metabolic activity and reproduction of the insects, enhancing losses in quantitative and qualitative terms. Conditions of high temperature and relative humidity (Figure 4) favor the presence of insects and the development of pathogens, promoting grain deterioration, as demonstrated by Jaques et al. (2018), in which corn grains stored with 18 % water content and a temperature of 35 °C showed a greater reduction in quality. The high temperatures together with high relative humidity provide favorable conditions for fungal development, which concomitant with the attack of insects establish themselves more easily in the grains.

Regarding relative humidity, as shown in Figure 4b, in the initial storage period there was an inversely proportional behavior between infested and non-infested grains, mainly related to the adjustment of the equilibrium moisture of the grains to storage conditions. The process of equilibrium of grain moisture occurs with water vapor exchanges between the material and the environment, being influenced by the chemical composition of the product, the difference in water vapor pressure in the air and temperature, so that when the vapor pressure of the grains is higher than that of the surrounding air, the desorption phenomenon occurs, with water vapor transfer to the air and reducing the moisture of the grain ( AMARAL et al., 2019; Silva et al., 1995). Considering that the temperature was influenced by the infestation condition (Figure 4a), there are changes in the isothermal properties and consequently in the equilibrium humidity.

The increase in temperature caused by the presence of insects intensifies the respiratory process of the grain mass, which leads to increases in losses. This process occurs through the consumption of $O_2$ (oxygen) and the release of CO2 (carbon dioxide) through gas exchange, intensified due to the attack of insects or the installation of pathogenic fungi, these processes induce the release of ethylene, resulting in an increase in the consumption of reserve tissues, reducing the nutritional quality of the grains and even making them unfeasible for consumption or processing.

According to Wen, 2024 evaluating chestnut grains with fungal infestation during storage, demonstrates that the desorption process, that is, water loss, induces an increase in the activity of the enzyme α-amylase, accelerating starch hydrolysis and increasing the levels of reducing sugar, favoring the development of microorganisms and the decomposition of nuts. In the case of corn grains, the endosperm represents approximately 83% of the weight of the dry grain, being formed mainly of starch (88%), while in the endosperm there are reserve proteins (8%) of the prolaminas, called zeins, in the germ (11% of the grain) almost all lipids (oil and vitamin E), minerals, other proteins and sugars are concentrated, the pericarp represents about 5% of the grain and is responsible for protecting the other structures from the oscillation of humidity in the environment, attack by insects and microorganisms, composed of polysaccharides of the hemicellulose and cellulose types (Paes et al., 2006).

The concentration of CO2 is a factor that can be monitored and assist in monitoring quality, since temperature and relative humidity sensors are punctual, not allowing to accurately characterize the changes that occur in the entire grain mass. In relation to temperature, this is aggravated by the fact that the grains are good thermal insulators and there is no monitoring between the intergranular spaces, allowing the formation of heating and respiration foci of the product to go unnoticed (Barreto et al., 2017; Zeymer et al., 2021).

As it is a living organism, the monitoring of intergranular variables of the grain mass can help to precede the dynamics of respiratory activity of the grain mass, being a tool to avoid losses over time. Studies such as de Leal *et al.*, 2023, monitoring temperature, relative humidity and carbon dioxide concentration in the mass of wheat grains stored in silos, demonstrates efficiency in indirect and early determination of quality change in grains, characterizing the loss of dry matter and reduction of product weight even with it remaining in hygroscopic equilibrium with grain water content close to 12 % (bu). Similarly, Nunes et al., 2017, using canola grains, found that the use of high temperature and water content intensifies the loss of dry matter and increases the incidence of moldy grains over the storage time.

The chemical composition of the product is a determining factor in the management during the post-harvest, since the relationship of the water content at the equilibrium moisture point characterizes the dynamics of water sorption of the grains as a function of the relative humidity and the temperature of the air that surrounds them. Therefore, for hygroscopic products packaged at constant temperature, equilibrium humidity increases as relative humidity increases, whereas under constant relative humidity conditions, equilibrium humidity decreases with increases in temperature (Brooker et al., 1992; Bertolo et al., 2022).

The storage of corn grains can be carried out using sacks or with the product in bulk. In the case of sacks, the material that will be used for storage is a crucial factor in determining the management of the grains, which can be permeable, semi-permeable or impermeable materials, changing the dynamics of sorption with external conditions and protection from insects, however, the initial condition in which the grain will be stored is crucial for the care to be taken in the long term (Sá et al., 2020). In general, bulk storage in metal silos is the most common way to use it, due to the greater use of physical space, reduced labor, greater ease and control in flow and supply, transportation costs, and monitoring through sensors (Ziegler et al., 2021).

Diarra & Amoah, 2019 evaluates the efficiency of airtight systems with controlled atmosphere with corn grains, demonstrating that the reduction of oxygen concentration and relative humidity of the atmosphere causes total mortality of insects in airtight packages in 52 days, with minimal damage to the grains caused by the action of insects. Similarly, Valle et al., 2021 find that modified atmospheres reduced or inhibited microbial growth in stored corn grains, highlighting the balance of the grain's respiration rate and the effective permeability rate of carbon dioxide and oxygen from the storage system in airtight packaging.

The occurrence of *Sitophilus zeamais* attacks (Figure 5a) on stored maize grains is common. The grain mass attacked by insects presents increases in the amount of foreign matter and impurities, generated due to the action of insects on the grains, which leads to an increase in intergranular temperature. This increase favors the reproductive habit and development of insects, so these attacks can be intensified at warmer times of the year, also increasing the defect in the grains (Ferrari Filho et al., 2014; Bihalva et al., 2022). Weevils (Figure 5b) affect the classification of the product at the time of shipments, making it impossible to sell lots.

**Figure 5**

*Occurrence of pest insect attacks: a) Sitophilus zeamais; b) corn grains attacked by S. zeamais*


(a)

(b)

Protecting grains during storage is crucial for maintaining quality and preventing losses caused by pest insect attack. Studies indicate a reduction of 18.3 % in the specific mass of sorghum grains and up to 17 % in corn grains after 70 days of packaging due to the attack of *S. zeamais*. Therefore, for the corn crop, it is essential to carry out treatments with the application of protective insecticides (pyrethroids and organophosphates), as a preventive measure and if a critical level of insect attack on the grains is reached, carry out curative treatment or purge with phosphine (Guedes et al., 2008; Lorini, 2008; Pimentel et al., 2019).

When using products for the treatment of grain mass, interactions between grain and product can reflect on the physical characteristics of the granular mass. Normando *et al.* (2023), found a significant reduction in water content and apparent specific mass in corn grains treated with diatomaceous earth, which is associated with the desiccant action capacity of the insecticide applied, which reduces moisture and normal grain runoff. After fumigation, the residual phosphine concentration in stored grains, based on air/grain equilibrium, can cause contamination and insect resistance of grains (Plumier et al., 2020). In the control of insect pests, the efficiency of the treatments and their interaction with the grain mass (Yin et al., 2025) is associated with the temperature and relative humidity of the storage ecosystem (Ziegler et al., 2021; Yin et al., 2025). Lower temperatures have a higher mortality rate or slower development of *Sitophilus* sp. and lower dry matter intake (Schiavon et al., 2025)

## 4 FINAL THOUGHTS

In the post-harvest processes of grains, in order to reverse weaknesses and gaps, practices to maintain the characteristics of the grain is essential to ensure the commercial and nutritional value of the grain until the moment of commercialization. The use of sensors combined with digital platforms for monitoring the mass of stored grains is an efficient and easy-to-use tool. The collection of a set of data associated with the formation of a database are prerequisites to understand the interactions between the granular mass and the storage environment, aiming at the adoption of management practices to mitigate the quantitative and qualitative losses of the grains and favor better conditions in the maintenance of quality during storage.

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