Study on physiobiological features of grain and contemporary storage methods

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Abstract. Grains are an important food that provides important nutrients. Due to the seasonality of grain crops, humanity has always looked for options for preserving grain. Proper grain storage is critical to maintaining grain quality, preventing spoilage and ensuring food security. The centuries-old experience of farmers shows that grain storage is a complex process that requires careful planning and management. Proper grain storage has several benefits. First, it helps prevent crop losses due to spoilage, pests and diseases. Secondly, it preserves the quality of the grain, ensuring its suitability for human and animal consumption. Thirdly, it allows you to regulate the supply of grain throughout the year, ensuring its availability even during periods of low harvest. As science and technology have advanced, new, efficient, and cost-effective techniques for storing grains have been put forth. Nevertheless, the issue of product quantity and quality safety during storage remains pertinent. This page gives a general overview of the different ways that grains can be stored, such as in warehouses, silos, and polyethylene sleeves. Each approach is discussed together with its benefits and drawbacks. Gaining an understanding of these procedures would enable stakeholders to design efficient storage plans and make well-informed decisions to guarantee grain supply and quality.

1. Introduction

Grains and seeds are regarded as important sources of nourishment and raw materials for humankind. Due to the periodicity of grain production, there is a necessity to store grain reserves for their use for various needs throughout the year. Humanity has known for millennia that maintaining grain reserves requires a lot of work since grain condition directly affects storage conditions, which in turn impact the quality of the harvest or the finished product made from grain goods [1, 2, 3]. The weight and quality of grain can be significantly lost during improper storage [4] (annual losses of grain products during storage range from 10% to 15%). This results in additional financial losses for the manufacturer, who already bears additional costs associated with planting, harvesting, and transporting grain. If the product is not properly stored, undesirable processes occur in the cells of grain crops: for example, at high temperatures, many of them may germinate; high humidity can lead to the action of microorganisms or insects; and improper warehouse design can result in quantity loss due to the appearance of various rodents in the spaces between items. Food grain loss during storage can be caused by a variety of factors, including the storage structure, grain storage method, environmental factors (warehouse temperature, grain humidity, pH of the environment), and biological factors (insects, pests, microorganisms, and rodents) [5, 6]. Reducing product losses to a minimum is only feasible with knowledge of the product's nature and operations, as well as the availability and proper operation of the technological base.

In general, proper grain crop storage should include the following aspects: storage of the seed fund with minimal weight loss and without reducing quality; preservation of product and seed material quality during storage by using the appropriate modes and technological methods; and financial sustainability of storage. With the advancement of technology and science, new and cost-effective ways for grain storage are emerging. Regardless, the issue of product

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quantity and quality safety during storage remains relevant. To improve the effectiveness of employing a certain storage method, it is necessary to consider the characteristics of the chosen method and product.

2. Grain crops ripening

A seed is a reproductive organ that helps plants reproduce and disperse. A developed seed consists of an embryo, a seed coat, and storage tissue (endosperm and perisperm) (Figure 1). The embryo is the main part of the seed; it represents the germ of a new plant. The embryo differentiates into a primary axis (hypocotyl and embryonic root), leaf cotyledons and embryonic bud. On the outer surface, the embryo and endosperm are covered with a seed coat, which serves as a barrier to microbe penetration, mechanical damage, embryo drying out, and premature germination [7].

The entire process of growth of grain crops consists of several stages, characterized by qualitative changes in biochemical reactions, physiological functions [8, 9, 10] and organoformational processes (Figure 1). Throughout the life cycle of a plant, the duration of interphase periods changes dynamically. In addition, the duration of interphase periods undergoes changes under the influence of environmental factors such as temperature, precipitation, light intensity and duration.

Fig. 1. Grain structure and growth phase

Following the heading stage, from the moment the grain (seeds) are formed, various phases of grain maturity are distinguished: milky, waxy, hard, as well as post-harvest and full.

The grain growth phase begins with grain formation. It begins at fertilization and is defined by the production of the grain's constituent elements: embryo, endosperm, and shell. The grain comprises between 82 and 80% water, and the contents are liquid milk mass. During this time, the grain reaches its full length.

The milky ripening period occurs when the grain has completed its development, its moisture content drops to 70-50%, and an intensive influx of dry substances to the grain continues.

The next prestage is pasty ripeness, characterized by intensive accumulation of dry matter and a decrease in humidity to 50–42%.

The waxy ripening phase starts off at the end of the influx of dry substances from the plant to the grain; the grain has a waxy consistency, turns yellow (green persists along the groove), and the humidity level rises to 22-30 percent. At this humidity level, grain harvesting takes place. Due to the fact that when harvested separately, the grain in the windrows also loses moisture.

The solid phase is distinguished by increased moisture loss from the grain, which lessens the intensity of respiration and makes it better suited for storage.

The post-harvest phase occurs on the farm and in grain storage facilities. The processes of converting basic organic compounds into more complex ones continue, respiration intensity is lowered to a minimum, and seeds become biologically mature with high germination rates.

Full ripening phase: the grain contains up to 10-15% moisture, has a firm consistency, a strong germination potential, and is excellent for storage.

The phases of grain ripeness are closely related to the technological properties of grain. Crop readiness for harvesting is evaluated taking into consideration all the dynamics of grain ripening. Early grain harvesting exposes the current to a highly humid grain mass and increases the physiological activity of the grains, which is primarily manifested in intense breathing [9, 11]. Preparing such a grain mass for storage presents certain difficulties, and the grain may have reduced technological properties. The most effective grain products for processing and storage are typically achieved

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through harvesting grains at an appropriate time, taking into consideration the stages of grain development and maturation [12].

3. Features of grain stock storage

Firstly, when storing grain, be mindful of the fact that crops are biological systems with inherent properties for respiration, post-harvest ripening, self-warming, and germination. Physiological processes are those that occur as a result of the vital activity of its living components (grains, weed seeds, insects, mites, and microbes) [13]. Understanding the essence of physiological processes enables control over these activities in the grain mass and ensures the reliable preservation of grain and seeds.

Grain respiration

For grains and seeds, which are autonomous living systems, respiration plays an essential role in their vital functions. Grains, like other organisms, require a systematic supply of energy to maintain life. The intensity of the respiration process is influenced by such factors as the moisture content of the grain and grain mass, their temperature, botanical characteristics, grain maturity, grain size, and the presence of injured and sprouted grains [14, 15, 16]. When grains and seeds have sufficient air, aerobic respiration takes over and releases carbon dioxide, water, and energy. If the air in the inter-granular gaps is not replaced, carbon dioxide produced during breathing accumulates there. Under such conditions, the grain undergoes anaerobic respiration [17, 18]. The type and rate of respiration play an integral part in the process of storing grains and seeds. Since they measure the amount of CO_2 present [19] in the inter-grain gaps, the amount of dry matter lost, the amount of grain moisture, and the temperature increase.

Post-harvest ripening

To prepare for post-harvest ripening, grain must be cleaned and disinfected before storage. Post-harvest ripening is a progressive reduction in enzyme activity and grain respiration rate. This process occurs between one and a half and two months following harvesting. To speed up post-harvest ripening, it is recommended to dry the grain or subject it to active ventilation with dry air, since humidity above the critical level creates favorable conditions for the enzymatic hydrolysis of organic substances used in the respiration process. Upon reaching full physiological maturity, the respiration rate decreases and germination increases to its maximum value and the grain in this condition is well stored.

Foci of grain masses

Self-heating is defined as an increase in grain mass temperature caused by a combination of intensive physiological processes, the spontaneous disintegration of grain reserve components, and the extremely low thermal conductivity of the grain mass. Consisting of autonomous living systems, the grain mass breathes intensely when the humidity is above critical, releasing an enormous amount of heat during aerobic respiration. The growth of self-warming and an increase in grain temperature to 50–55 °C result in the self-destruction of thermosensitive bacteria, which are replaced by thermophilic ones. As a result of their vital activity, the heated grain masses reach temperatures of 65–70 °C. With the achievement of such temperatures, reactions of non-biological, thermal oxidation of organic substances in the grain begin to occur. Because of the high temperatures, grain respiration slows and finally stops completely. The organic matter of the grain begins to decompose, and it darkens to the point of complete blackening. The reasons for self-heating can be gross violations of the technology of storing grain and seeds and a lack of proper control over their condition, especially in freshly harvested batches of grain that have not passed the post-harvest ripening period and are in an active physiological state. Self-heating requires immediate measures (drying, cooling, or selling heated batches of grain).

Germination of grains and seeds

Having gone through a complex path of ontogenetic development, grains are in a state of rest, but under favorable conditions, viable seeds begin to germinate; that is, they emerge from the state of anabiosis and the transition of the seed embryo to further development. Grain germination and seeds lead to the intensification of physiological processes [20, 21] in the grain masses, the loss of dry substances [22, 23], the release of energy, the danger of self-heating of the grain [24], and, finally, the loss of sowing and commercial advantages of grain lots. Sprouted grain is not suitable for long-term storage. Rapid development of microflora is observed on sprouted grain, and storage molds make the grain mass unsuitable for use. Seed germination is possible only when they are moistened with droplet-liquid moisture, which appears as a result of poor waterproofing of storage facilities and condensation of water vapor in the intergrain spaces of the grain mass. It is necessary to store grain and seeds in conditions that prevent droplets of liquid moisture from entering them and to systematically monitor the condition of the grain.

4. Methods of storing grain masses

The method of storing grain masses is primarily determined by their physical and physiological features, as well as the modes of preservation chosen. Storage modes are the conditions that must be established to ensure the safety of grain masses. Traditionally, there are three storage modes that account for physiological processes in wheat grain mass: dry storage, refrigerated storage, and oxygen-free storage.

Grain crops are mainly stored in special storage facilities. Granaries are categorized based on a wide range of factors, including the length of time they are kept in storage, their structural characteristics (sheds, warehouses, elevators, etc.), the kinds of operations they perform (storage only or storage and processing), their level of mechanization, and the kind of active seed ventilation installations that are available [25]. Grain mass storage of any kind needs to be set up to avoid both mass loss (apart from biological) and quality deterioration.

Currently, the most prevalent techniques of grain storage include: storage in a one-story grain warehouse; grain storage in riots; grain storage in silos; grain storage in an elevator; and grain storage in sealed flexible polyethylene sleeves. When placing grain for long-term storage in bulk storage facilities, it is necessary to calculate the storage capacity and the required number of warehouses to accommodate a given batch of grain.

Storage in a grain warehouse

Grain warehouses are single-story buildings with a gable roof. The walls are 3-3.5 m high, and upper and lower galleries can be found inside. Such warehouses store grain in bulk on the floor. Grain warehouses cover a huge area and can store up to several thousand tons of products and can be automated or non-mechanized. Elevator towers are attached to mechanized warehouses; loading and unloading equipment, conveyors, etc. are located inside. In non-mechanized warehouses, only simple self-propelled and mobile mechanisms are used. *Grain storage in an elevator*

Elevators are the most advanced sort of granaries, with items placed in vertical concrete silos. They represent a whole complex of a working tower, silo buildings and mechanisms that provide reception, pre-cleaning, drying, and mixing of the grain mass during storage. There are galleries and tunnels between the work building and the silos. Inside the silos, optimal temperature and humidity are maintained, preventing the development of fungi and bacteria [26, 27]. The hermetically sealed design reliably protects supplies from rodents and various weather and climatic influences. Despite all the many advantages, even storing grain in elevators has its difficulties: elevator machinery must be continually cleaned of spills and product residues; grain can attach to the inside walls of silos while in storage; and high financial charges (Figure 2).

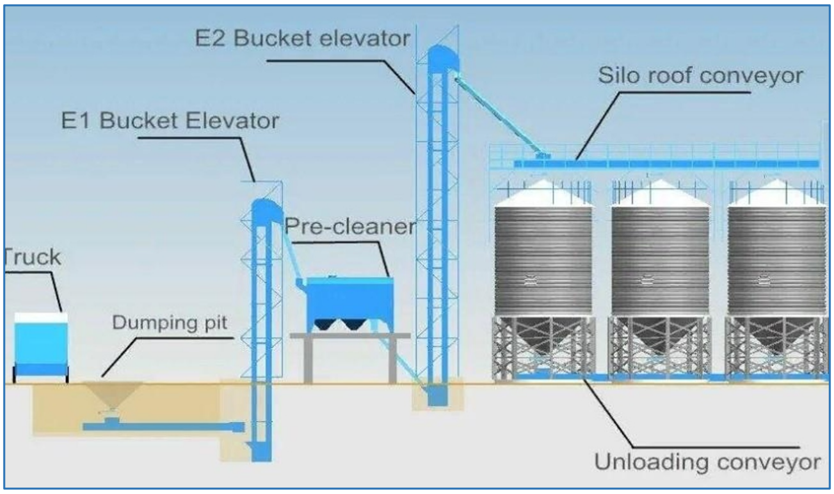

Fig. 2. Elevator mechanisms

Metal silos

Fig. 3. Metal silos storage

Metal silos are a more mobile and easier-to-install structure than concrete elevators. Silo bodies are made of steel, aluminum or alloys. The base of such granaries can be either conical or horizontal. In the latter case, the procedure for installing the structure is significantly simplified, since construction will only require a concrete platform for a supporting metal base. Metal silos reliably protect grain from rodents. They are easy to clean and disinfect, but thermoregulation is their weak point (Figure 3).

Storing grain in sealed flexible polyethylene sleeves

Grain "sleeves" are three-layer polymer bags 60-75 m long and with a capacity of 65-300 tons, which are filled with grain by a special grain packaging machine - a bagger (AG BAG). The hoses are made using a special additive - metallocin (mLL), which gives the hose material the greatest strength and elasticity. The structure of the sleeve material is three-layer. The three layers are inseparable; each layer is made from different polymers with different additives and stabilizers. Ultraviolet additives in the material of the sleeves prevent the harmful effects of the UV spectrum on stored products. Advantages: allows you to avoid the process of forced stoppage of harvesting, which often occurs due to the lack of free space on the currents, storage of dry grain or grain with high humidity; no need to transport grain to the elevator; release of automobile and other agricultural equipment; storage of sorted grain and so on. Disadvantages: probability of damage during storage of seed material by products of anaerobic activity; short hose life (Figure 4).

Fig. 4. Polyethylene sleeve storage

Storage of grain in riots

During the harvest season, it is not always possible to place grain in grain storage facilities. In this case, temporary storage of grain is organized in open asphalt areas, in so-called riots. The riot can be formed in the form of a cone, pyramid or other shape. For temporary storage in a bund, it is necessary to cool the grain mass to at least + 8°C and below. The cooled riot is covered with a tarpaulin. It is strictly forbidden to cover the bunk with uncooled and wet grain mass, as this contributes to its self-heating. It is not allowed to store seed grain for a long time in bungalows.

Among the above, we can draw the following conclusion: elevators are able to ensure the safety of the quantity and quality of grain, but the high cost of storage is a serious argument not in favor of this storage method; storage in metal silos and polyethylene sleeves reduces losses in the quantity and quality of grain.

5. Modern Storage Technologies

Controlled Atmosphere Storage

Nitrogen controlled storage is a technology that can slow down the change in grain quality by increasing the amount of nitrogen in the air from 78% to 97-99%, and reducing oxygen (O_2) from 21% to 1-3%. The positive effect of a nitrogen-based controlled atmosphere during grain storage is that the lack of oxygen in the intergrain space of the mound suppresses the intensity of respiration, water generation, and the vital activity of aerobic microorganisms (bacteria and fungi), insects [28] and mites, which are the main cause of grain spoilage. This technology uses the properties of inert gas as a natural inhibitor of redox processes in the body. Long-term storage of grain in a nitrogen atmosphere prevents re-infestation by pests [29]. Nitrogen does not form harmful residual substances in the grain.

Aeration and grain refrigerating

Grain refrigerating is the most commonly used method of grain aeration. One of the main tasks of aeration is cooling the grain in order to reduce the biological activity of the grain mass and, first of all, harmful insects and mites. In most granaries, without cooling the grain mass during storage, the number of insects quickly increases, which leads to a decrease in the quality of the grain material and the cost of such grain is significantly reduced. Thus, cooling grain through aeration has a dual purpose: lowering the temperature of the grain below the limit of insect reproduction and cooling the grain quickly enough so that an egg laid by a wandering female insect on the first day of grain storage does not develop into a mature individual [30]. At grain temperatures below 15°C, the development of all types of insects is usually suspended, which practically prevents damage from insects in the grain mass.

Ozone treatment of grain material

When drying grain using an ozone-air mixture, the oxygen ion formed during the decay of ozone acts as an adsorbent, i.e. a particle that absorbs another substance. In this case, the gas itself enters into a chemical reaction with the material being dried and water. Afterwards, the gas itself enters into a chemical reaction with the material being dried and water. The use of the ozonation process will improve the efficiency of moisture transfer, disinfect the heap, increase the safe storage period, while maintaining quality indicators [31, 32]. For ozonation of seeds, conical silos mounted on supports should be used, because Ozone is heavier than air and after treatment is stopped, the gas will move downwards, which can lead to its accumulation in the silo galleries of flat-bottomed options.

6. Conclusion

In summary, grain crop storage is a complex task that requires an understanding of the specifics involved. The use of scientifically based storage methods in production, the modernization of existing granaries, equipment and complexes for working with grain masses, increasing the level of qualifications of technologists and service personnel create completely objective prerequisites for preserving the entire grown crop.

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