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Study of the quality and loses of durum wheat (*Triticum durum*) during storage: an overview of traditional storage in Algeria

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ABSTRACT. Wheat is one of the most significant crops commercially because of its growing use. There is a real concern about the safety of grain that has been stored for a long time on a worldwide scale in order to get and retain a supply of high-quality grains. There are numerous methods to store wheat, however, traditional techniques are still used in Algeria. During storage, wheat grains are infested with pests and diverse microbial populations that can cause grain loses and disease. Preharvest, harvest, transportation, storage, and processing are all potential sources of microbial contamination in wheat. Fungi are the most contaminating flora, presenting mycotoxin excretion risk. Whereas lactic acid bacteria represent the fermentation flora. Contrary to what some research has found regarding the decrease in the nutritional value of wheat during storage, the storage in underground pits can enhance the product's nutritional quality. Durum wheat fermentation is primarily a crucial technique that, when done on an industrial scale, might produce new products with improved technological and nutritional qualities. This present review highlights the storage methods available worldwide, different losses of wheat during storage, the effects of the storage conditions and natural fermentation on the quality of the stored wheat.

Keywords: Grains; underground pits; fermentation; microflora; nutritional value

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Introduction

Wheat offers around 20 % of the calories and proteins in the daily human diet as one of the world's major staple food sources (Shewry & Hey, 2015). About half of the calories consumed globally come from wheat, which is also high in minerals (Cu, Mg, Zn, P, and Fe), vitamins (B-group and E), dietary fiber, riboflavin, niacin, and thiamine, as well as proteins (gluten) (Khalid, Hameed & Tahir, 2023). Wheat grains, also known as caryopsis, are normally oval in shape, though they can range from practically spherical to long, narrow, and flattened shapes depending on the wheat. The grain is usually between 5 and 9 mm in length, weighs between 35 and 50 mg and has a crease down one side where it was originally connected to the wheat flower. It was reported that wheat grain contains 2 - 3 % germ, 13 - 17 % bran and 80-85 % mealy endosperm (Kim, Savin & Slafer, 2021; Šramkováa, Gregovváb & Šturdíka, 2009). The most nutritious part of the wheat grain is represented by the germ. However, its application is very limited in staple food. First, because of its high amount of unsaturated fatty acids and high activity of lipase and lipoxygenase, which produce rancidity more rapidly in storage (Boukid, Folloni, Ranieri & Vittadini, 2018; Li et al., 2016). Second, it contains anti-nutritional elements such as phytic acid, raffinose, and wheat germ agglutinin (Zhao et al., 2020).

Since prehistoric times, many storage systems and procedures have been devised with the aim of extending the use of seasonal food resources beyond the period when they are available (Peña-Chocarro, Jordà, Mateos & Zapata, 2015). In Africa, there are three storage techniques with differing architectures: traditional/local storage which includes local cribs and rhombus, platforms, open fields, roofs and fireplaces; improved/semi modern grain storage techniques which include ventilated cribs, improved rhombus and brick bins; and modern centralized storage at the commercial level involving silos and warehouses. The first two storage techniques predominate, since farming is mostly done by subsistence farmers. In Algeria, traditional storage techniques of wheat still exist by farmers in underground pits. These pits are locally named 'Matmours' (Benhamada & Idoui, 2020).

Because to poor structures, rodent activity, inadequate drainage, and a lack of availability, losses during storage operations were at their highest. Microbial contamination of wheat including fungi, yeasts and bacteria can occur at any point in the grain production chain, including preharvest, harvest, transportation, storage, and processing (Los, Ziuzina & Bourke, 2018). Additionally, many meteorological factors, such the degree of precipitation and relative humidity, together with particular field microflora, might affect the kind and quantity of microbial load on the kernels. The presence of some pathogenic microorganisms raises questions about the safety of food, particularly when consuming raw wheat-based food (Sabillón, Stratton, Rose, Regassa, & Bianchini, 2016; Singh, & Channaiah, 2022; Verrill, Lando, Wu, Tatavarthy, & Obenhuber, 2022). When safety actions are designed based on customers' eating habits, foodborne illness and outbreaks connected with contaminated wheat flour can be avoided (Magallanes & Simsek, 2020).

The aim of this study is to give information about storage management strategies of cereals in general and wheat in particular, including traditional storage in Algeria, as well as the level of storage losses owing to various causes and the impact of spontaneous fermentation and storage conditions on the wheat's quality.

Wheat storage

Whether traditional or modern, there are five main storage methods for the wheat. For the duration of grain storage, each offers a number of advantages and disadvantages (Pekmez, 2016).

Bulk storage

Both horizontal and vertical warehouses are suitable for the preservation and storage of grain. During this process, the bulk stack cereals' (wheat, barley, rye, oat, corn, chickpea, and lentil) surface needs to be properly balanced. It is possible to store more grain per area unit. It also makes grain sample control simple, reduces personnel costs, and saves time (Pekmez, 2016). The bulk storage system is being improved further by installing pest-monitoring system (acoustic detection) and automation for aeration, grain cooling, and pest-control measures (Rajendran, 2003).

Storage in bag

This is the most commonly used method of grain storage in several countries in any of a variety of buildings, *e.g.* with or without plastered walls, a floor made of earth, stone, or cement, a roof made of thatched or corrugated iron, stone, locally made brick, mud, and wattle. Bag storage increases operating expenses, increases pest losses, and increases spillage. Furthermore, if the flooring is not properly constructed, water infiltration occurs. This raises the humidity in the warehouse, allowing *Cryptolestes* spp. to multiply; it also destroys the bags' bottom layer (Rajendran, 2003).

Storage in warehouse

A warehouse is built for the storage and physical protection of grains or bagged grain. It could also comprise products and equipment for packaging and processing bagged grain, as well as pest control agents. When deciding where to build the warehouse, consider topography, soil conditions, accessibility, orientation, and closeness to human habitations. Cereals and cereal products could be stored in bulk stacks as well as sacks using this method (Pekmez, 2016).

Storage in silo

Silos are a practical way to store grain. Bulk grain saves space and can be mechanically processed, lowering packaging and processing costs. Grain recycling in silos helps to decrease potential grain temperature increases through aeration. For bulk grain storage, there are many types of silos in varied sizes. Silos are made of concrete, bricks, or sheet metal that is fastened together (Nwaigwe, 2019).

Advanced storage methods

In many industrialized countries, grain storage methods have evolved with advances on the primary systems, such as aeration, refrigerated storage, modified atmospheric storage, and hermetic storage systems (Said & Pradhan, 2014).

Aeration is an appropriate method of lowering grain temperature, and it is accomplished by the use of fans and mechanical aeration. Commercially, forced aeration plays important and effective role in preserving grain. In the other hand, the decrease of the temperature below 18 °C in subtropical climates when ambient temperatures are too high to reduce insect activity is a principal objective of refrigerated aeration. This storage technique, combined with the air-drying method, can provide information on the feasibility of aeration for safe commercial storage in tropical climates. Modified atmospheric storage is a new gaseous application technology; it has successfully replaced fumigants. Modified atmospheres (MA) and controlled atmosphere (CA) prevent fungal growth and maintain product quality. Also, in hermetic storage method, the generation of oxygen-depleted and carbon dioxide-enriched interstitial atmosphere is a result of the respiration of the aerobic organisms living in the commodity. Low O_2 and high CO_2 environment kills insect and mite pests, and prevents aerobic fungi from growing, which reduces losses due to the activity of these lasts (Marcos Valle, Castellari, Yommi, Pereyra & Bartosik, 2021; Said & Pradhan, 2014).

Underground storage in Algeria using ‘Matmour’

In recent years, underground storage for long-term conservation has become a critical component of farming communities’ cereal surplus handling. Grain is said to be preserved for years in underground pits. The pits keep the grain cool and are airtight in some cases. The grain on top and around the edges, on the other hand, is frequently mouldy. The underground pit had various capacities and could contain more than 1000 kg. The pits could be placed in outside or inside the houses. In general, the mouth was round, large enough to allow one person to go through, and bell shaped in cross section (Figure 1). The wall could be covered with a layer of earth, straw, chaff and water or with dung and mud (Peña-Chocarro et al., 2015).

This storage method in undergrowth pits (Figure 2) still exists in North Africa, especially in Algeria, they are named locally ‘Matmour’. In the past, it was applied just to store wheat and ensure consumption throughout the year, but currently the purpose of this storage is to obtain a traditional product called 'Mzayet' to use to prepare black couscous in the North-Eastern regions of Algeria. The ‘Mzayet’ obtained is dark brown in color and has an accentuated acid odor, due to spontaneous fermentation through the native microflora of wheat, which is provided especially by lactic acid bacteria (Benhamada & Idoui, 2020; Benhamada & Idoui, 2021).

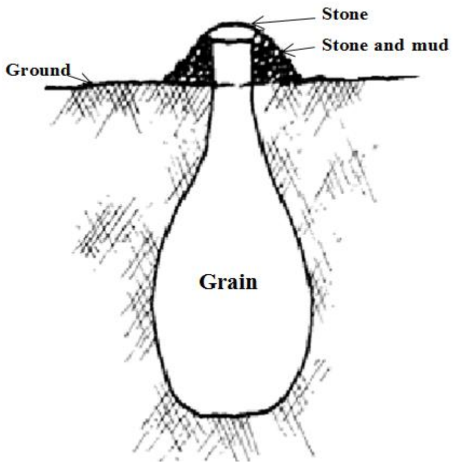

Figure 1. Sectional view of an underground silo (Lindblab & Druben, 1980)

Figure 2. Appearance of a ‘Matmour’ situated in Boudria BeniYadjis, Jijel, Algeria (original photos)

Losses during storage

Insects

Insects are the first invaders and one of the main threats to the maintenance of grain quality during storage. They consume, contaminate, and disseminate microflora (Rajendran, 2003). For prompt and efficient pest control procedures to safeguard stored grains, it is essential to identify and monitor stored-grain insect infestations as soon as possible (Cai et al., 2022). Losses of stored commodities caused by insect infestation are often only quantified in terms of weight loss. In fact, insect infestation has an impact on nutritional value, with some nutritional components being more severely altered than others (Stathers, Arnold, Rumney & Hopson, 2020). Over 100 insect species contaminate stored grain, the majority of them are beetles, some of them are moths, and the rest are primitive insects known as psocids (Rajendran, 2003).

Mites

Mites are very important pests of wheat and cereals in general at all stages of processing and during its storage. They are very difficult to observe in naked eye and can lead to serious economic losses if proper management has not been taken into account. The mites are the cause of both the qualitative and quantitative losses. They preferably feed on germ and demolish its contents; they also consume the other parts of the grain but to a smaller extent (Mahmood, Bashir, Abrar, Sabri & Khan, 2013).

Rodents

Rats and mice may cause considerable damage to crops in the field and products in storage. This can happen in a variety of ways: they may consume a portion of the goods; they may contaminate a portion of the product with their excrement; they may cause damage to buildings, storage containers, and packaging material; they may also be carriers of diseases that are harmful to humans (Htwe et al., 2021; Sarwar, 2015).

Micro-organisms

Field microflora

The bacteria referred to as field microflora infect the grains based on the crop's cultivation conditions and harvesting time (Figure 3). The kernels contamination is predominated by bacteria, with yeast being the second most abundant component. However, the number of filamentous fungi increases during the later stage of ripening (Araujo, Dunlap, Barnett, & Franco, 2019; Palma-Guerrero et al., 2021).

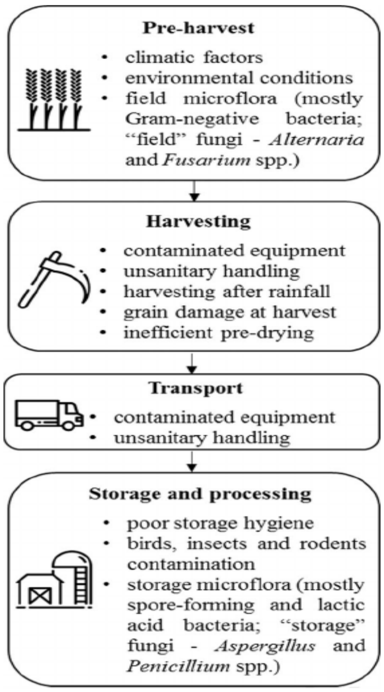

Figure 3. Sources and factors of microbial contamination during cereal grain processing (Los, Ziuzina & Bourke, 2018).

In comparison to bacterial pathogens such as *Salomonella*, *Escherichia coli*, and *Bacillus cereus*, bacterial species infecting grain are arguably non-pathogenic. *Salmonella* and *E. coli* are enteric bacteria, and their presence on grain is usually an indication of fecal contamination from birds or rodents. Recently, wheat grains were discovered to have a large number of bacteria from the *Streptomyces* genus (Forghani et al., 2019; Rasimus-sahari, Mikkola, Andersson, Jestoi & Salkinoja-salonen, 2016).

Fungi that grow on crops have traditionally been split into two categories: field and storage fungi (Pitt & Hocking, 2009). Field fungi are fungi that invade seeds developing on the plants in the field or after the seeds have matured and the plants are either still standing or are cut and swathed, awaiting threshing. Field fungi consist primarily of species of *Alternaria*, *Cladosporium*, *Fusarium*, and *Helminthosporium*, which infest grain in the field at high water activity and high relative humidities reaching 90 % to 100 % (Bullerman & Bianchini, 2009).

Storage microflora

Though modern methods are used during harvesting and proper storage practices are maintained to minimize contamination and infestation by microorganisms and pests; however, these conditions are not always met (Los, Ziuzina, & Bourke, 2018).

Generally, wheat grain stored under ideal conditions have water activity below the minimum needed for microbial growth, these storage conditions are unfavorable for the growth of bacteria that is why bacteria are not significantly involved in the spoilage of dry grain; however, pathogenic and spoilage microorganisms may survive in a dormant state and be transferred to processed products where they become a problem (Bullerman & Bianchini, 2009). Enteric pathogens, such as *Salmonella* spp., may be among these microflorae if fecal contamination has occurred anywhere from preharvest through milling. Other spore-forming bacterial pathogens, such as *Bacillus cereus* and *Clostridium botulinum*, may be present as well due to soil contamination. In milled products and foods made from milled products, nonpathogenic bacteria can cause spoiling (Manthey, Wolf-Hall, Yalla, Viajayakumar & Carlson, 2004).

Common spoilage microorganisms found on wheat grain include yeast and mold. In this case, the spoilage occurs usually due to inefficient drying, what favors microbial growth and may result in increased mycotoxins levels. At low relative humidity's (65 % to 90 %) and lower moisture contents (14 % to 16 %), stored-grains can be invaded by *Eurotium*, *Aspergillus*, *Penicillium*, *Rhizopus*, *Mucor*, and *Wallemia* At colder temperatures, *Penicillium* species predominate, but *Aspergillus* and *Eurotium* species are more prevalent at ambient temperature (20 to 25 °C) (Bullerman & Bianchini, 2009). Stored wheat grains are a rich source of antagonists that can effectively suppress mycotoxigenic fungi and the mycotoxins they create, as well as biodegrade, yeast, and bacteria. By using these antagonistic microorganisms, contamination from fungi and mycotoxin may be decreased, and they may eventually take the place of conventionally employed synthetic chemicals (Solanki et al., 2021).

Effects of storage conditions on wheat quality

Moisture

In stored grains of uniform moisture content, the moisture will move if a temperature gradient exists in the bulk as a result of temperature variations surrounding the grain bin. The equilibrium relative humidity of the air surrounding the grain increases with temperature if the moisture content of the grain stays constant. As a result, with stored grains with homogeneous moisture content, a relative humidity gradient exists parallel to the temperature gradient (Bala, 2016).

Temperature

Temperature is a crucial factor limiting the distribution and abundance of insects, mites and fungi contaminating and destroying stored grain (Bala, 2016). The temperature of wheat increases during storage. Insect infestation is the reason behind the increase in temperature in wheat grains. Insects not only consume grains as a source of growth (energy), but also respirate and emit heat into the environment (Sawant, Patil, Kalse & Thakor, 2012).

Biochemical changes

During storage, protein and lipid content change, which is related to respiration. The protein content of the wheat during storage decreases. This decrease is attributed to the proteolytic activity of the stored wheat which increased by higher temperature and humidity conditions. Otherwise, molds can use the nutrients in the wheat including proteins for their growth and survival which might have caused the decrease in protein content of the wheat during storage (Rosentrater, 2022). A recent works on fermented wheat in underground silos (matmour) reported that the natural spontaneous fermentation of the grains during storage enhanced nutritional quality of wheat. In fact, the bioactive compounds and the antioxidant activity of wheat samples were significantly increased (Benhamada & Idoui, 2020; Benhamada & Idoui, 2021).

Spontaneous fermentation in underground pits

Fermentation is an exothermic metabolic process which involves the consumption of food nutrients through the activities of microorganisms (either native or deliberately introduced) that serve as fermenters. Spontaneous fermentation of cereals in underground pits involves LAB, yeasts and fungi. The fermentation with filamentous fungi, LAB, and yeast may be considered as a potential process to increase the release of phenolic compounds contributing to the production of food products with an added value. In actuality, the profile of phenolic compounds changes as microorganisms multiply as a result of the activity of cellulolytic, pectinolytic, and ligninolytic enzymes. These enzymes, produced by microorganisms, are involved in release of phenolic components by softening the kernel structure and breaking down of cell wall matrix (Sandhu, Punia & Kaur, 2016).

Numerous authors have noted an increase in protein and amino acids (AAs) during the fermentation process of cereals. They have attributed this increase to the activities of hydrolytic enzymes, the proteolysis that breaks down complex proteins into AAs, and the fermentation process's creation of new AAs. It was suggested that the degradation of storage protein and synthesis of new protein could have caused this increase (Adebiyi, Obadina, Adebo & Kayitesi, 2017) (Figure 4).

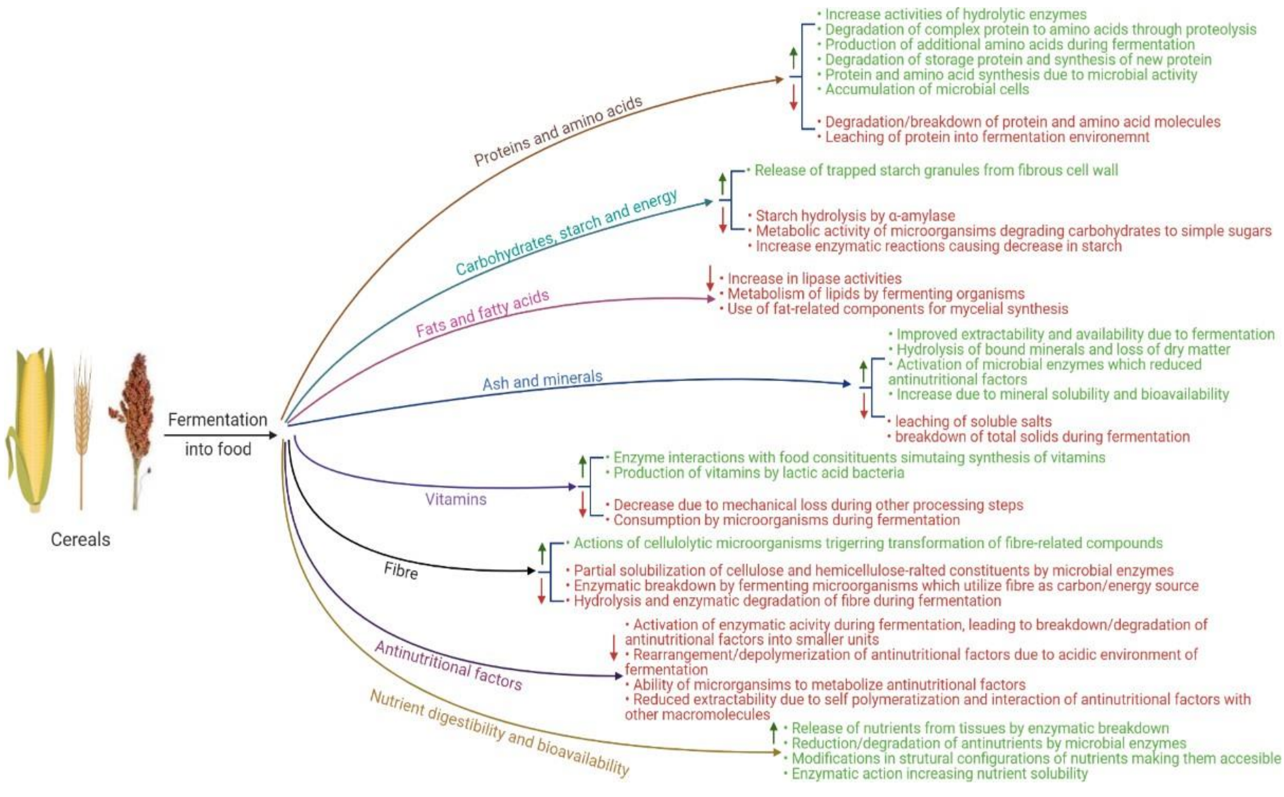

Figure 4. A summarized mechanisms of nutrient modifications in fermented cereals (Adebo et al., 2022).

During wheat storage in underground silos, lactic acid bacteria is responsible for fermentation and induces acidification due to the production of organic acids (lactic acid particularly) and fatty acids by lactic acid bacteria (LAB) (Benhamada & Idoui, 2020; Gourchala, Hobamahoro, Mihoub & Henchiri, 2014). In the process of natural fermentation, enzymes produced by bacteria and yeasts can liberate bound phenolics (by esterase activity), change the structure of flavonoids (via glucosidase activity), and metabolize phenolic acids (via decarboxylase activity) (Ripari, Bai, & Gänzle, 2019). Also, TPC content and titratable acidity increase, also, pH decrease (Garrido-Galand, Asensio-Grau, Calvo-Lerma, Heredia & Andrés, 2021). TPC and TFC appear to have a favorable correlation with antioxidant activity, which is theoretically associated with antioxidant properties. This was verified by (Benhamada & Idoui, 2021). Additionally, this finding aligns with the research conducted of Sanchez ´ Magana et al. (2019), who reported finding favorable associations between TPC and AoxA in corn. Accordingly, phenolic compounds have a crucial role in the antioxidant activity of cereal grains and, consequently, in the health advantages connected with them, including their antibacterial and anti-inflammatory qualities.

Conclusion

Cereal grains are stored in order to keep the product fresh from storage to consumption. It is said that a grain preserved is as beneficial as a grain produced in addition, so that post-harvest and storage losses are kept to a bare minimum, concerted measures should be done. Wheat contamination by pests and pathogens poses a serious human health problem, therefore control and prevention procedures must be developed to combat the contamination. The microbial fermentation of cereals in general and wheat in particular present benefits for food nutrition and health. Fermentation adds nutritious value to the product, improving its qualities and elevating it above the original cereal as a better food ingredient.

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