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Storage of cereals and pulses — Part 1 : General considerations in keeping cereals

Stockage des céréales et des légumineuses — Partie 1 : Considérations générales sur la conservation des céréales

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

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It has been approved by the member bodies of the following countries :

Australia	Germany, F.R.	Poland
Austria	Hungary	Portugal
Brazil	India	Romania
Bulgaria	Israel	South Africa, Rep. of
Canada	Kenya	Spain
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No member body expressed disapproval of the document.

Storage of cereals and pulses —

Part 1 : General considerations in keeping cereals

0 Introduction

The seasonal nature of cereal production, in conjunction with year-round consumer requirements, has always made it necessary to store grain for more or less long periods.

However, the caryopsis of cereals, like all plant life with a reduced metabolic rate, undergoes an unavoidable physiological development which can have beneficial effects (breaking of dormancy, baking quality, quality for making pasta, cooking quality), but which leads to ageing and, after a time, to changes which are detrimental to it and of which the nature and intensity are dependent upon environment.

When considered on a world-wide scale, these various changes result in very substantial qualitative and quantitative losses.

Storage losses have been estimated as being an average of 5 %, and as much as 30 %, especially in countries with climates favourable to the rapid development of agents of deterioration and where storage techniques are poorly developed, such as developing countries in the damp tropics. The principal causes of loss of quantity and quality are metabolic changes in the grain and the attacks of micro-organisms (bacteria and moulds) and of vertebrate and invertebrate animals.

The magnitude of these figures highlights the need for promoting throughout the world a rapid improvement in techniques of conservation.

1 Scope and field of application

This Part of ISO 6322 describes general considerations related to the problems of keeping cereals. Other aspects of the storage of cereals and pulses are dealt with in ISO 6322/2 and ISO 6322/3.

2 References

ISO 712, *Cereals and cereal products — Determination of moisture content (Routine reference method)*.

ISO 6322/2, *Storage of cereals and pulses — Part 2 : Essential requirements*.

ISO 6322/3, *Storage of cereals and pulses — Part 3 : Control of attack by vertebrate and invertebrate animals*.

3 Aspects of the problem

3.1 Technical factors

The problem of keeping cereals arises at two different stages.

3.1.1 Immediately after harvesting, the cereals may sometimes remain moist for periods of time ranging from a few hours to several months. Although the product to be kept is particularly unstable, as a rule it is at this stage that storage conditions are least favourable. It is frequently a question of storage on the farm or in small, not always adequately equipped, silos, whilst awaiting the appropriate treatment.

3.1.2 At the international marketing stage, cereals are stored for anything from a few months to several years at or below a maximum moisture content, the level of which may be fixed in each country. Such storage can be handled by very large bulk storage organizations with modern, well equipped silos, or other types of bulk storage facilities. The type of problem arising varies with the type of store, its condition and its location.

3.2 Environmental and socio-economic factors

Problems peculiar to the keeping of grain vary greatly from one country to another. These variations depend upon the factors listed below.

3.2.1 Climatic conditions

Undoubtedly, climatic conditions are one of the most important factors where the keeping of grain is concerned, at every stage of its development, even before harvesting, from growth in the field to consumption, either by human beings or animals.

Geographical areas can be roughly divided into the following :

- hot and damp tropical climates, where deterioration of the grain can be very rapid;
- hot and dry climates, where cereals are harvested naturally dried and where, because of this, the problem is simpler (for example, the southern USA and the Middle East); however, in these regions the grain can remain hot for long periods after harvesting, which exacerbates insect infestation problems;

- temperate climates, where at least a part of the cereals is harvested moist (for example, Europe);
- very cold regions posing very special problems such as cereals which have spent some time under snow.

It is frequently the case that some of the developing countries have less favourable climates and are therefore at a disadvantage in the fight against grain deterioration.

3.2.2 Importing/exporting activities of the country

All countries which produce cereals have storage problems at the farm level. Those which export and import grain have further problems. Exporting countries, in particular, must use storage structures making it possible to deliver cereals which comply with often very stringent standards set by official organizations in those countries as well as by importing countries (especially where micro-organisms and insects are concerned). It should be remembered, however, that in many exporting countries it is important that any equipment used should be of low cost.

3.2.3 Technical management development

Some developing countries are not well informed about the many problems and are often ill-equipped to deal with them. On the other hand, the development of modern harvesting techniques (for example use of the combine harvester) considerably modifies the specific nature of the first storage (3.1.1) because of the enormous influx of moist grain.

The organization of the storage system is very important because of size differences in the storage structures used; the presence of huge quantities of grain in fact presents specific problems.

At the present time, varying types of more or less advanced storage systems (bulk or sack) exist side by side throughout the world and often in the same country.

It is desirable to segregate lots of grain on arrival at the bulk storage depot according to moisture content so as to avoid mixing damp and dry grain.

3.3 Qualitative factors

Whether or not a cereal is in good condition must be judged in relation to the ultimate use of the cereal, i.e. for human or animal consumption, in the natural state or after processing, or for non-edible industrial products.

The quality factor is usually laid down in regulations which, for each country, determine quality criteria, for example the quality of the grain itself and the permissible quantities of foreign substances (other varieties of grain, insect or rodent residues, residues of pesticides, toxins).

Mandatory quality standards set by importing countries obviously have an effect on the keeping problems facing exporting countries. Countries with less advanced storage methods at their disposal may find difficulty in meeting these standards.

Thus, although each individual country may have its own problem, because of international trade there are very great overlaps and many problems which, at the technical and scientific level, are similar; present knowledge makes it possible to formulate definite rules for ensuring the safe storage of cereals.

4 Specific characteristics of cereals as products to be stored

4.1 Cereal seed as a living organism

The resting grain is a living caryopsis in which the germ and the aleurone layer have a reduced rate of metabolic activity which may accelerate very rapidly when the environment is favourable. The endosperm cells are composed essentially of reserve substances (carbohydrates, proteins and, in smaller quantities, lipids), which supply energy for the metabolic processes.

The fundamental metabolic activities of grain are of two kinds as follows.

4.1.1 Respiration, which mainly affects carbohydrates and lipids, occurs in aerobic conditions if the moisture content and temperature of the grain are sufficiently high; the respiration produces carbon dioxide, water vapour and a considerable amount of heat (2 830 kJ per mole of glucose oxidized).

Under anaerobic conditions, a fermentative metabolic process occurs, producing less heat (92 kJ per mole of glucose). The fermented grain has a typical sour-sweet alcoholic smell and has undergone other changes that make it unsuitable for human consumption, although it is suitable for animal feeding.

Oxidation phenomena are normal in stored grain, but take place only at a low rate if grain is dry; care must be taken that no appreciable acceleration occurs, since this indicates that grain is unsuitable for further storage.

4.1.2 Germination of the seed, which is the normal outcome of its metabolic activity in the presence of oxygen and optimum conditions of moisture and temperature, occurs in several successive stages: imbibition, activation of the enzymes, active cellular multiplication, soon accompanied by cell growth and followed by the development of the young plant; only this last stage is visible externally.

Germination (sprouting), even in its initial stages, is a serious change in grain already stored or to be stored. It occurs most frequently in wet years, while the crop is still standing in the fields. There are two important practical consequences:

- chemical change of the reserve substances;
- increase of enzymic activities: wheat with high alpha-amylase content, harvested in northern Europe in wet years, is a well-known example.

Such cereals are often unfit for human consumption.

The germination potential, which determines the viability of the grain in general, must be preserved.

4.2 Microflora

The seed is permanent host to a considerable microflora; most of these micro-organisms are cosmopolitan, the majority are innocuous, but some produce harmful by-products. Microflora communities present on freshly harvested grain include many types of bacteria, moulds and yeasts.

While the grain is ripening and its moisture content falling, the number of field micro-organisms, mainly bacteria, diminishes. When the grain is harvested, it is invaded by storage micro-organisms and the field microflora gradually dies out. If the moisture content is below 18 % (*m/m*), the microflora does not multiply whereas above 18 % (*m/m*) it does so rapidly.

Thus, at harvest, the qualitative and the quantitative composition of the microflora depends more upon ecological factors than upon the variety of cereal.

During transport and storage, additions to the microfloral population occur. Micro-organisms on the grain at harvest tend to die out during storage and are replaced by micro-organisms adapted to storage conditions.

4.3 Weed seeds and other foreign matter

Most commercial bulks of grain, which have not been screened or aspirated, contain a proportion of other grains, weed seeds, chaff, straw, stones, sand, etc. The vegetable materials may have physical and biological properties which differ from those of the main constituent and may therefore affect the storage behaviour.

4.4 Important physical properties affecting storage

The most relevant physical properties affecting storage are moisture and temperature.

4.4.1 A bulk of cereal contains, besides the grains, a considerable interstitial volume of air, for example, in wheat, approximately 40 % of the total bulk volume is air.

The fluid-flow property of bulk grain is such that the grain can be fed into either hoppers or pipelines and makes it suitable for drying by blowing (or sucking) dry air through it.

4.4.2 Because of the very low thermal conductivity of the grain [0,125 to 0,167 W/(m·K)], the heat given off resulting from metabolic phenomena, in the absence of ventilation, builds up locally, bringing about spectacular temperature rises, more especially as the specific heat capacity of grain is relatively low [approximately 1,88 kJ/(kg·K) for wheat with 15 % moisture content]; however, it increases as the moisture content of the grain increases. In addition to inherent metabolic activity, heat may be produced by the activity of micro-organisms, insects and mites.

4.4.3 Grain is hygroscopic and gives up or absorbs moisture so as to maintain an equilibrium with the concentration of moisture in the air surrounding it. The relationship may be expressed as a sigmoid curve, which is practically straight over most of the significant storage range, say from 40 to 80 %

relative humidity. There is some variation in the relationship between moisture content of the grain (usually expressed as a percentage of wet mass) and that of the air (usually expressed as a percentage as relative humidity) with temperature, such that the equilibrium relative humidity is higher for a given moisture content as temperature increases. There is also some difference between grain which is gaining and that which is losing moisture, i.e. there is a hysteresis phenomenon in the relationship between the moisture content of the grain and the relative humidity of the intergranular atmosphere.

Periodic changes in the relative humidity of the atmosphere only affect the surface layers of bulks of grain, the relative humidity of the interstitial air between grains below the surface being principally controlled by the original moisture content and temperature. Gradients of equilibrium relative humidity and moisture content may be set up by persistent differences in temperature between the surface and the interior of the grain bulk caused by changes in external temperature or heating within the grain mass. The moisture flows down the temperature and vapour pressure gradients to the coolest part of the grain and raises the moisture content there.

4.4.4 The terms "dry", "moist" and "safe" are applied to grain storage. "Dry" or "safe" indicates that the grain has a moisture content at which, taking into account the likely range of temperature to be experienced during storage and transport, there is no risk of appreciable metabolic activity of the grain itself nor of attack by moulds and other micro-organisms. "Moist" grain is that whose moisture content is above that level. The range of "safe" moisture content varies with the crop dependent on temperature (including artificial means of reducing temperature) and period of storage. As a general rule, a "safe" moisture content is one not exceeding that in equilibrium with 65 % relative humidity.

4.5 Preservation of grain quality

It is essential to retain certain indispensable properties in grain which is to be used for human or animal food, for malting or for seed :

- a certain level of enzymic activity, especially alpha-amylase, in the case of cereals to be used for bread making;
- the original nature of the various protein constituents, as these determine the rheological properties of dough;
- the percentage germination and germinative energy, which must be kept very high for seed and malting barley.

These requirements preclude any intense heat treatment, such as heat sterilization, which denatures the proteins.

From the point of view of utilization in food — human and animal — it is obviously essential to maintain the food value of the product (flavour, nutritive elements, nutritious effectiveness) at the highest possible level; moreover, it is necessary to safeguard product hygiene as much from the point of view of any possible toxic substances (toxins) as from the point of view of added substances (residues of pesticides).

5 Deteriorative changes which occur in grain

Causes of changes which occur during storage can be divided into two quite distinct categories :

- the immediate causes of the deteriorative changes;
- the environmental factors affecting these causes.

5.1 Causes of change

5.1.1 Enzymic changes

Enzymic changes due to enzymes proper to the grain manifest themselves in a variety of ways. Such changes to proteins, carbohydrates and lipids may occur during storage, but these are insignificant unless the grain is moist.

However, some enzymic action, for example that of lipases, will cause changes in dry grain.

5.1.2 Other changes of biochemical and chemical origin

By their very nature, reactions of biochemical and chemical origin are varied. These reactions generally require fairly high temperatures such as are encountered during drying or as the result of "heating" caused by the activity of insects, moulds and other micro-organisms :

- Maillard reactions which produce many intermediate compounds, the physiological activity of which has been recognized, eventually lead to non-enzymic browning;
- deterioration of starch granule structure, which involves very substantial changes : for example damage to the granule and formation of dextrins at the time of drying;
- denaturation of proteins, which leads to the loss of specific properties : solubility, rheological properties in the hydrated state, enzymic activities;
- diminution of the quantity of available lysine;
- destruction of vitamins (B₁, E and carotenoids).

Some reactions, especially non-enzymic oxidation of lipids, may take place within the normal range of storage temperatures.

5.1.3 External causes : living organisms

Deterioration may be caused by living organisms i.e. vertebrate and invertebrate animals and micro-organisms. Although the direct effects of attack by living organisms are important, certain indirect effects may be much more serious, especially heating due to the activity of insects and micro-organisms and the production of toxic by-products by some of the latter.

The infesting organisms produce carbon dioxide and moisture but can also release enzymes and, thereby, give rise to considerable deterioration; moulds, however, are only active under aerobic conditions.

5.1.3.1 Animal pests : rodents, birds, insects and mites (see ISO 6322/3)

As a result of feeding on the grain, animal pests cause tainting and contamination and leave behind damaged grain. Heating caused by the activity of insects within bulks of grain sets up temperature gradients resulting in moisture migration and consequential damage due to development of micro-organisms and even sprouting in zones of high moisture content.

5.1.3.2 Micro-organisms : moulds, yeasts, bacteria

The nature of damage caused by micro-organisms depends on the action of the dominant elements of the microflora; there is often difficulty, however, in separating the effects of attack by micro-organisms from inherent changes in the grain itself, both causes being encouraged by similar external factors.

The principal effects of attack by micro-organisms are decomposition of the grain, heating and its consequential secondary effect, and the production of toxins; there are also allergies produced in humans and animals which come into contact with grain infested with certain species of micro-organisms.

5.1.4 External causes arising before storage

Grain can be broken or abraded during harvesting, transport and storage.

Grain harvested by combine harvester has a higher proportion of broken grains than that harvested by reaper binder. The proportion of broken grains is also a varietal characteristic.

Broken kernels of all grains, including those which are internally fissured, are more subject to attack by moulds and other micro-organisms and by more species of insects and mites than are entirely sound kernels.

Broken grains are undesirable because enzymic and chemical changes are more likely to occur.

Grains such as rice barley and oats, from which the husk has been removed, are deprived of protection and, in the case of oats, are more liable to become rancid and to suffer heat damage during kilning.

Grains of other cereals, weed seeds and other material of vegetable origin may also be more liable to attack than the sound kernels of the main constituent grain.

5.2 Environmental factors affecting the causes of change

The environmental factors of temperature, relative humidity and composition of the atmosphere regulate the chemical and biological changes taking place during storage; their effects are influenced by the duration and nature of storage. Problems of storage and transport are dealt with in ISO 6322/2.

5.2.1 Operative factors in change

5.2.1.1 Time

The rates of reaction and development of the different factors of deterioration need to be known in order to determine the probable period of safe storage, taking into account the various operative causes.

In assessing the factors in relation to temperature and humidity, it must be emphasized that because of the physical properties of grain bulks, changes in temperature and moisture content normally take place slowly. It is important to measure the actual conditions in the bulk.

5.2.1.2 Temperature

Temperature influences practically all chemical and biochemical reactions according to a substantially exponential law : this explains the extreme importance of this factor. However, biological activity, especially of insects, mites and micro-organisms, tends to be markedly limited within specific ranges of temperature. Thus, heating due to insect activity seldom causes temperatures to rise above 40 °C or that due to micro-organisms to temperatures above 65 °C. Oxidative reactions can cause temperatures to rise to ignition point in some commodities but there is no evidence that whole cereals are subject to spontaneous combustion.

5.2.1.3 Relative humidity

Relative humidity is perhaps the most important factor to be considered. Both low and high relative humidities can cause deterioration of the grain at a given temperature. The exact relative humidity at which deterioration occurs is temperature dependent.

5.2.1.4 Atmospheric composition

The relative proportions of oxygen and carbon dioxide in the intergranular air affect the nature of the metabolism of any micro-organisms and animal pests and of the living cells of the grain. They also influence the level of non-enzymatic oxidation and certain enzymic reactions.

5.2.2 Combined action of environmental factors on the various causes of change

Although it is easy to distinguish between them in theory, in practice these various factors have an inter-dependent, closely conjugated action which makes their study a complex task. An examination is made below of some examples relating to the combined action of such factors as causes of change.

5.2.2.1 Vertebrates

Birds and rodents can subsist and multiply on cereals stored under conventional aerobic conditions. The moisture content of the grain is not critical.

5.2.2.2 Invertebrates

Most animal pests of stored grain cannot complete their life cycle at temperatures below 10 °C or much above 35 °C; for most of the serious pests the minimum is about 15 °C, and development is slow below 20 °C. Grain of less than 9 % moisture content is generally secure from attack except by the *Trogoderma granarium* Everts (khapra beetle), which breeds down to 3 % moisture content. For each species of insect and mite there is a particular range of temperature and relative humidity (moisture content of grain) which is most suitable : *Acarus siro* Linnaeus (the flour mite), for example, breeds at temperatures down to 3 °C.

The subject of attack by vertebrate and invertebrate pests is dealt with in ISO 6322/3.

5.2.2.3 Micro-organisms : aerobic conditions

Micro-organisms, particularly moulds, in general do not develop below 65 % relative humidity¹⁾, the equivalent for wheat of about 14 % (m/m) moisture content at 25 °C. However, the moisture content — relative humidity relationship alters with temperature in such a way that the higher the temperature, the higher the relative humidity corresponding to a particular grain moisture content. At relative humidities higher than 65 %, moulds continue to develop even at low temperatures : this is a problem especially with damp maize.

As with insects, moulds develop more rapidly as the temperature rises and the moisture content of the grain and the relative humidity of the immediate atmosphere increase. They can also cause grain to heat, being capable of raising its temperature to about 65 °C. A succession of different species of micro-organisms is involved in this process.

Since all grain is exposed to mould spores, safe storage depends on preventing or delaying their germination and development.

For storage for an indefinite period and for safe transport, the moisture content in any part of a consignment should not be greater than the equivalent of 65 % relative humidity, at the temperature of the grain at the time of being taken into store or of commencing transportation.

However, the grain may be at a higher moisture content if the temperature is lowered, by aeration with atmospheric air or by refrigeration, to a level at which moulds will not develop to significant levels within the normal period of storage or transport.

1) However, certain important moulds, for example *Aspergillus restrictus*, are able to develop at lower relative humidities.

5.2.2.4 Micro-organisms : airtight storage

As a general rule, the total bacterial population diminishes during storage, except in the case of very moist grain, where such reduction is preceded by an increase in the number of bacteria, mainly lactic bacilli.

Airtight storage prevents the growth of moulds in grain of high moisture content, but certain yeasts are able to develop. Changes in quality at moisture contents above 18 % (m/m) make the grain unsuitable for uses other than animal feeding and industrial purposes.

Normally, the activity of the micro-organisms produces low-oxygen conditions. These conditions may also be created artificially, for example by vacuum or addition of carbon dioxide or nitrogen.

5.2.2.5 Enzymic reaction

Most enzymic reactions in grain which require water in the liquid phase occur at the moisture contents at which grain normally commences to germinate.

Certain enzymic reactions may take place during grain drying, their nature depending on the maximum temperatures reached during the process and its duration.

5.2.2.6 Denaturation of proteins

The critical temperature at which this occurs during drying by heat is dependent on the grain moisture content and the duration of conditions of high temperatures.

5.2.2.7 Maillard reactions (see 5.1.2)

In general, Maillard reactions require a fairly high temperature, but can also occur at temperatures slightly above 20 °C during periods of prolonged storage. The reactions are inhibited by both high and low moisture contents in the grain but they proceed more rapidly in conditions of low humidity : rates of reaction will have an optimum at an equilibrium relative humidity of 60 to 70 %.

5.2.2.8 Non-enzymic oxidations

Oxidative reactions limited by the presence of moisture occur mainly at equilibrium relative humidities of less than 20 %.

6 Tests designed to assess the condition of grain

In so far as numerous changes can occur, it is important to arrange tests making it possible to reveal and assess the sanitary condition of a consignment of grain. It will then be possible to forecast storage periods compatible with preservation of the technological and nutritional value of the grain.

6.1 Definition of fitness for storage

The general condition of a consignment of grain has two main aspects.

6.1.1 The current state results from changes which have already taken place. It represents the immediate utilization potential value of the grain for a given purpose.

6.1.2 The forecast state represents the potential risk of change to the consignment, for a given storage period and in view of its future use. It depends on the current condition of the grain, the causes of change present in the grain and the environmental factors.

6.2 Criteria of acceptance

The criteria of acceptance, together with the corresponding analytical procedures, can be classified as follows.

6.2.1 Tests directly linked to industrial or nutritional use or use for malting or as seed

These tests are designed to establish whether the grain is suitable for its intended use. They may give information about the maximum time for which the grain can be kept.

6.2.2 Tests indirectly linked with ultimate use

These tests interpret the general condition of the grain by integrating the effects of multiple causes of change; in this category can be classified the following methods.

6.2.2.1 Methods for evaluating the viability of grain

Such methods involve measurement of the percentage germination and the germinative energy.

6.2.2.2 Methods for estimation of total fungal or bacterial microflora

At present, efforts are being made to finalize rapid methods for the evaluation of total microbial contamination.

6.2.3 Tests showing one particular aspect of change

Among such tests the following can be mentioned.

6.2.3.1 Determination of moisture content¹⁾

The most important single immediate factor indicating potentiality for storage or immediate use is moisture content. Rapid and accurate determination in each lot is essential.

1) Method specified in ISO 712.