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Cereal Quality Characteristics as Affected by Controlled Atmospheric Storage Conditions

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Abstract: The quality of cereal grains during storage is affected by entomological, microbiological and environmental factors, resulting in physicochemical and organoleptic changes that lead to significant product qualitative and quantitative losses. The objectives of this study were to evaluate the quality of certain cereal grains under controlled and/or modified storage conditions. Cereal grains of corn and wheat were stored under controlled atmospheric conditions of 2 and 8% O_2 for 12 and 6 months time periods, respectively. The results indicated that storage under high nitrogen atmospheric conditions kept the flour acidity stable for all the storage period and enhanced the germination ability of grains. Finally inhibition of the existing entomological and microbial counts occurred.

Key words: Cereal, quality characteristics, storage, modified atmosphere

Introduction

Food and feed grain commodities such as corn, wheat, rice, oats etc., can be stored for considerable periods of time. They serve not only as a nutrient source but also as strategic and economic elements in the society. The quality preservation during long-term storage of grains is a severe problem in many parts of the world (Gras *et al*., 2000). High temperatures and excessive moisture in the stored products or high humidity under ambient storage conditions permit the proliferation of insects and molds, which cause large losses of qualitative, nutritional and hygienic nature.

According to Food and Agricultural Organization of the United Nations (FAO) data (FAO, 1981), it is estimated that a percentage of about 8-10% of the total grains storage in warehouses or in silos is being lost as a consequence of inappropriate storage conditions yearly. Therefore, the main reasons that cause grain quality degradation in the world are the following: over drying (cracking of seed), grain respiration (weight loss-quality degradation), damages due to insects and rodents infection (weight loss), mold and other bacterial contamination (mycotoxin quality degradation) (Kazazis, 1980; Wilcke *et al*., 2000).

Modern trends in stored-product pest management show increasing emphasis on preventive control measures, which will avoid the use of traditional pesticides. International objection to the use of toxic chemicals in food is growing as a result of increasing evidence of the hazards that these chemicals pose to human health, the environment, wild life and even to agriculture. Resistance of pests to several long-standing pesticides has become widespread world-wide. Therefore, there is a pressing

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need to introduce pest control measures that will not require the use of toxic chemicals. The Controlled Atmosphere (CA) technique is one that has been studied very closely over the past few decades and promises to play an increasingly important role for pest control in crop storage in the forthcoming years. Due to the few adverse effects on the commodity, the environment, or the consumer, the use of CA in crop storage is accepted internationally (Muir *et al*., 2000; McGaughey *et al*., 1989).

Controlled or modified atmosphere (CA) storage is the storage of grains with the composition of the intergranular air controlled in some manner. Changing the relative concentrations of oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2), the quality of the grain may be preserved for a longer time than storage under ambient air concentrations. Ambient or normal atmospheric air has an approximate composition of 78% nitrogen, 21% oxygen, 0.035% carbon dioxide and other gases. Intergranular air composition affects rain deterioration because insects, mites and aerobic moulds require oxygen to respire (Muir *et al*., 2000).

Controlled atmospheric storage of dry grains is used to control insects and maintain the viability of seeds for extended periods of time. Storage under nitrogen atmospheric conditions has the advantage of inhibition of the living insect population while slightly affecting the larva's population, which is successfully controlled in a CO_2 atmosphere (Muir *et al*., 2000). Grain preservation under controlled N_2 atmosphere and moisture level (14-16%) in comparison to the regular one (11%), could save significant energy spent for the excess drying process (Gunasekaran, 1986). Grain quality deterioration could be avoided with such techniques since excess drying results in seed-cracking and/or flour formation (Gunasekaran, 1986; Fan *et al*., 2000).

Storability is a characteristic criterion of quality, which expresses the ability of grains to maintain their sensory characteristics, nutritional value and other physicochemical conditions without alterations (Pomaranz, 1974; Iconomou *et al*., 1998; Hruskova and Machova, 2002).

In addition the storability of corn and wheat under controlled atmospheres at different initial seed moistures is of high interest to the grain industry business due to (i) reduction of seed respiration (ii) development of unfavourable conditions to insects/rodents and (iii) inhibition of mold growth. To evaluate the storability of cereal grains the following analyses have been carried out in our experimentation: (i) physicochemical (ii) sensory evaluation and (iii) microbiological and entomological determination.

If the level of oxygen (O_2) is much lower than ambient air (20%), particularly at approximately 2-3% O_2, insects and mites will not survive. Some insect species (e.g., grain borers, the angoumois grain moth, weevils and bruchids) constitute a hidden insect infestation because most of their life cycle takes place while insects are locked inside the grain kernel or bean seed (Dunkel, 1995). Under ideal conditions, four weeks is the shortest time for a complete life cycle of stored grain insects and mite. Therefore, if the grain has a visible insect problem or if a hidden insect infestation is suspected, it is advisable to place the grain immediately into modified atmospheric storage, with decreased O_2 (Dunkel, 1995). Sealed (airtight) storage generally achieves low O_2 levels (1%). At 1% O_2, filamentous fungi will cease to grow.

The mortality of *Tribolium castaneum* and *Plodia interpunctella* increases with decreasing O_2 concentration. Adults of *T. castaneum* and *T. confusum* are killed when exposed to $<2\%$ O_2 in combination with N_2 or He for about 96 h (Ali Niazee, 1972). Adults of *Sitophilus granarius* and *S. oryzae* when exposed to CO_2, N_2, or He have increased mortality. Adults of *S. granarius and S. oryzae* were the most susceptible followed by larvae, pupae and eggs. In a comparative study on the effectiveness of 99.9% nitrogen, 60% CO_2 and 99.9% argon atmospheres against different insects, it was noted that argon treatment was the most effective in a short exposure period whilst the majority of the pests were more tolerant of a CO_2 atmosphere. However, N_2 is cheaper than argon gas and hence is preferred by most conservators (Selwitz and Maekawa, 1998; Rajendran and Parveen, 2005). Insect mortality increases with increasing temperature and decreasing moisture content of the grain (i.e., decreasing water activity) (Banks and Fields, 1995; Jayas *et al*., 1995).

The aim of this study was to evaluate the quality of corn and wheat grains under controlled storage conditions.

Materials and Methods

A specific mechanical installation was established for the experimentation of this study where a nitrogen generator and a gas analyzer were used for measuring O_2 and CO_2 concentrations in the silos (Fig. 1) and the project is described below:

- Two silos of 1.5×1.5 m dimensions or 3.0 tn each.
- Screw conveyor.
- Six sensors for temperature and six for relative humidity measurements
- Twelve-position recorder type SHIMADEN SR 186
- N_2 supplier-device type Prism Alpha Nitrogen Generator-SWAN 15
- A gas control device for N_2, CO_2 and O_2 measurements type 740 CO_2 analyzer, Fruit Control SRL

Five tones of corn were stored for 360 days, at low oxygen atmospheric conditions (2 and 8% O_2). In addition, one tn corn was stored under environmental conditions (21% O_2:) and was used as a control. The initial moisture of the seed was 16.3%. Five tones of wheat were also stored for 180 days under the same atmospheric conditions (2 and 8% O_2). Additionally 1 tn corn was stored under environmental conditions (21% O_2:) and was used as a control. The initial moisture of the seed was 8.6%.

The quality control applied during the storage period of the products was based on the following tests (AACC, 1976).

Fig. 1: Installation of the experimental two silos (3.5 tn each), with the following parts: (i) Screw conveyor (ii) Sensors for temperature and for relative humidity measurements (iii) inlet and outlet of gases (N_2. O_2)

- Sensory and physical evaluation (appearance/color, odor, infective seeds, foreign matter) was determined according to European Union Regulation No. 1569/1997.
- Physicochemical analyses (Total N_2, proteins, fat, ash, moisture, flour acidity (% H_2SO_4), aflatoxins, weight-volume of 100 seed and water activity a_w) were carried out according to AOAC (1990) methodology.
- Entomological and microbiological tests (No. of insects and total microbial count) according to standard methods and AOAC (1990) methodology, respectively.
- Botanical tests (seed germination ability) according to Zucconi *et al*. (1981).

Results and Discussion

Table 1 and 2 show the bibliography and experimental data of corn and wheat seed, respectively.

At the end of the storage period, no aflatoxins B_1, B_2, G_1 and G_2, were detected in all corn and wheat grain samples tested with Thin Layer Chromatography (TLC). Sensory (color, odor), physicochemical (total N_2, proteins, fat, ash, weight-volume 100 seed and a_w) and microbial (total plate count and mold numbers) analysis showed no significant differences among the various samples.

The performed tests showed limited seed quality differences for the various storage grain conditions. According to Rehman (2006) no significant changes in the nutritional quality (moisture, total sugar, protein, starch, titratable acidity) were observed during storage of cereal grains at temperatures less than 20°C and moisture of stored product up to 14% (Pomeranz,1974).

Corn Experiment

Figure 2 shows the changes of percent seed germination during the storage of corn under controlled (O_2: 2 and 8%) and atmospheric conditions. The storage of corn under controlled conditions

Table 1: Chemical constitution of corn% of dry weight

	Bibliography data* (%) DW	Experimental data (%) DW
Seed moisture	12.0-16.50	14.13±0.50
Ash	1.20-2.10	1.36±0.30
Proteins (N_{tot} × 5.70)	9.0-12.10	8.9±0.17
Flour acidity (% H_2SO_4)	0.026-0.032	0.03±0.01
Fat	4.60-9.10	5.57±0.73
Water activity (α_w)	0.75-0.78	0.77±0.01
Fiber compound	2.10-2.50	-
Total insoluble sugars	74.50-81.0	-
Germination index	70.0-90.0	78.80±0.10
Weight of hectoliter (kg)	68.0-84.0	72.96±0.20
(Total microbial count: TMC)	-	238×10^5

* N.L. Kent, Technology of Cereal, 2nd Edn. (1978)

Table 2: Chemical constitution of wheat% of dry weight

	Bibliography data* (%) DW	Experimental data (%) DW
Seed moisture	8-18	8.60±0.30
Total Nitrogen		2.32±0.01
Proteins (N_{tot} × 5.70)	8-15	13.23±0.08
Fat	1.5-2.0	1.90±0.09
Ash	1.5-2.0	1.94±0.09
Fiber compound	2.0-2.5	-
Total insoluble sugars	2.0-3.0	-
Water activity (α_w)	-	0.015±0.01
Starch	60-68	-
Germination index	-	83.20±0.10
Water activity (α_w)	-	0.385
Weight of hectoliter (kg)	68.0-84.0	77.20±0.24

* Kent-Jones and Amog: Modern Cereal Chemistry 6th Edn. (1967)

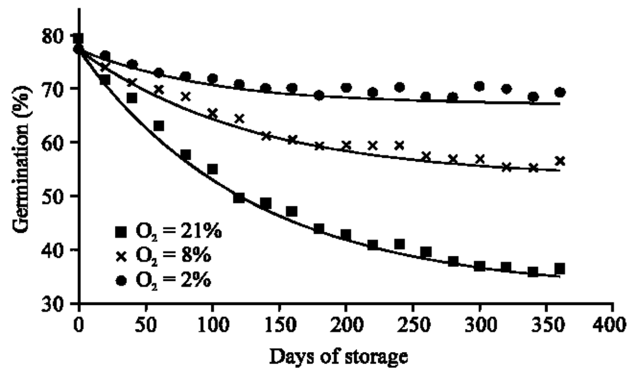

Fig. 2: Corn seed germination (%) changes during storage of 360 days period under controlled (O_2: 2 and 8%) and atmospheric conditions

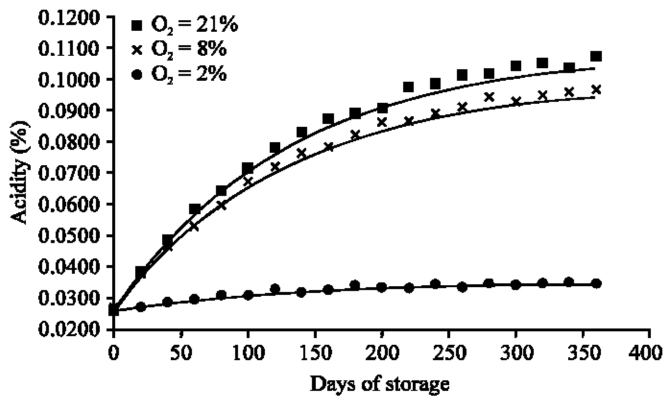

Fig. 3: Corn flour acidity changes during storage of 360 days period under controlled conditions (O_2: 2 and 8%) and atmospheric conditions

results in approximately 35% higher seed germination in comparison with the control at the end of the storage period. This observation is very significant if the stored corn is going to be used as seed for cultivation.

The control presented a drop of germination during storage, which varied from 77 to 35%. On the contrary, in the controlled atmosphere of 2% oxygen a small fall (67%) was observed. Significant reduction in seed germination was also evident during storage in controlled atmosphere of 8% oxygen (55%). Hence, storage under 2% O_2: showed better germination compared to storage under 8% O_2 and even better compared to atmospheric conditions. Thus, corn seeds stored under low oxygen concentrations seemed to offer better advantages for seeding, probably due to lower oxygen storage conditions.

Figure 3 shows the changes of corn flour acidity during storage under controlled (2 and 8% O_2) and atmospheric conditions. The control presented a four-fold increase of corn flour acidity during storage, varying from 0.026 to 0.102% H_2SO_4. On the contrary under controlled atmosphere of 2% oxygen a small increase (0.036% H_2SO_4) was observed. Significant increase of corn flour acidity (0.094% H_2SO_4), was also shown during storage under controlled atmosphere of 8% oxygen. Storage under 2% O_2 showed better resistance to oxidation (%) compared to storage under 8% O_2 and even better compared to atmospheric conditions.

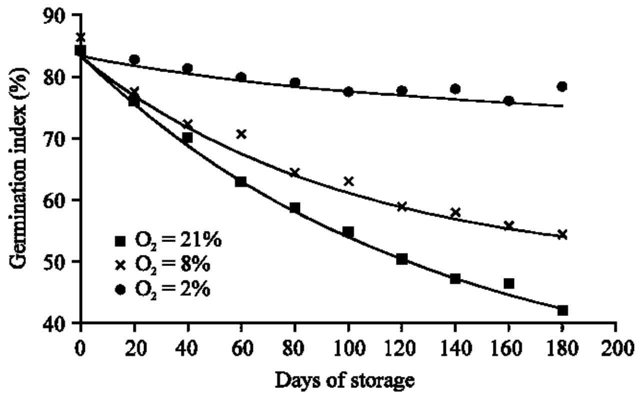

Fig. 4: Wheat seed germination during storage of 180 days period under two controlled conditions (O_2: 2 and 8%) and an atmospheric condition

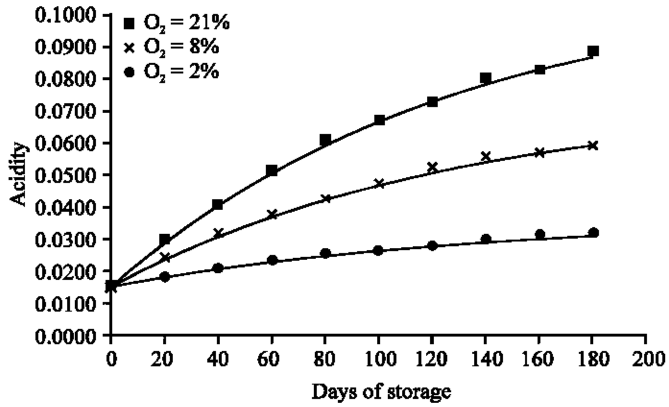

Fig. 5: Wheat flour acidity changes during storage of 180 days period under two controlled (O_2: 2 and 8%) and an atmospheric condition

Changes of corn moisture during the 360 days storage period indicated a gradual moisture reduction under all storage conditions (from 16.3 to 12.6%) despite the atmospheric conditions. This is in accord with previous investigations (Moreno *et al*., 2000; Muir, 2000). Corn stored for 1 year in Mexico in hermetic storage lost germination at the same rate as in the air at 14% moisture content; however, at 15.5 and 17.6% moisture content viability germination was higher under hermetic storage than in the air at the same moisture level (Rehman, 2006).

Presence of insects population (adult *Lepidoptera*), was found during the storage period of corn grain but only under atmospheric conditions (control). Quezada *et al*. (2006) reported that after six days in a modified atmosphere, 100% of all insects were found dead, irrespective of the humidity of the stored product. Under non-modified conditions in all moisture contents, no insect mortality was observed. It has been stated that stored grain insects will perish if the oxygen level of a hermetic storage atmosphere should fall to approximately 2% (Oxley and Wickenden, 1963).

Fungi were not present on seeds under hermetic storage, however, *Aspergillus glaucus* group, *A. tamarii*. and *Penicillium* sp. were present in all seeds stored in the air. This is in accordance to a recent research, according to which a severe infection was observed from *Aspergillus rubber* in maize stored under normal oxygen conditions and with humidity of 16%. On the contrary no infection from mould was observed under modified atmosphere conditions (Quezada *et al*., 2006). Moreover, the level of 1% oxygen resulted in inhibition of mould growth (Moreno *et al*., 2000).

Wheat Experiment

Wheat grain moisture changes were stable at about the same level 8.6±0.3% under two controlled (2 and 8% O_2) conditions as well as atmospheric conditions during the total storage period of 180 days.

The wheat seed germination (%), as shown in Fig. 4, appeared to reduce at the end of the storage period, varying from 42 to 54% for control and 8% atmospheric oxygen, respectively. whereas it was stable (75%) at 2% oxygen atmospheric conditions.

The wheat flour acidity, as shown in Fig. 5, seems to present a high increase (six-fold) under environmental conditions, varying from 0.015 to 0.086% H_2SO_4. On the other hand, a small increase (0.031% H_2SO_4) was observed during storage under modified atmosphere (2% O_2). A significant increase in wheat flour acidity (0.059% H_2SO_4) was also shown during storage under atmospheric oxygen of 8%.

Presence of live insects of *Sitophilus oryzea* in wheat grain was observed as it was received for the experiment. The above insect population was live in the control samples, whereas it was killed after the first 6 days under modified atmospheric storage.

Conclusions

The results of storage of corn and wheat grains, under controlled or modified atmospheric conditions, led to the following conclusions:

- Storage under high nitrogen and/or low oxygen condition led to a significant reduction or elimination of the insect population of cereal grains.
- Preservation at the above conditions had a significant effect on the germination ability of the seeds as well as on the acidity of the flour derived from these cereals.
- These data indicated that the corn and wheat grains stored at 2% O_2 atmospheric conditions, maintained better their germination ability and flour acidity of seeds compared to storage under controlled (8% O_2) and atmospheric conditions.
- Storage of cereals with high humidity is very important, since excess energy is not required for product, drying, which also downgrades the product.

The above mentioned differences among the various grain storage conditions which have significant impact on the quality characteristics (germination ability and flour acidity of seeds) could be advantageous to prolong time storage periods of cereal grains. However, cereal grain industries are always interested in developing effective grain storage systems that will extend the initial quality of grains to the maximum storage capability.

The main advantage of storage under modified atmosphere is the lowest economic cost for cereals storage compared to the use of freezing air under low temperature. Finally, the use of nitrogen can aid the storage of wheat having increased humidity, compared to the existing method requiring product drying to avoid cross contamination by mould due to an increased humidity of the grain.

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