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QUALITY CHANGES IN GRAIN UNDER CONTROLLED ATMOSPHERE STORAGE

Noel D.G. WHITE[1] and Digvir S. JAYAS[2]

[1]Agriculture Canada, Research Station, 195 Dafoe Road, Winnipeg, MB, Canada, R3T 2M9

[2]Department of Agricultural Engineering, University of Manitoba, Winnipeg, MB, Canada, R3T 2N2

ABSTRACT

A review of recent literature largely confirms the conclusions drawn in an earlier review in 1981 concerning the effects of controlled atmospheres on stored grain. Seed longevity in storage is influenced mainly by temperature and moisture content and gases play a minor role. At constant temperature and relative humidity (r.h.), seed viability is decreased by the presence of oxygen (O_2) in the range of 0-21%. Seed germination, milling and baking characteristics of wheat, and the germination, milling, and cooking properties of rice are unaffected in 6 months when the grain is dry and atmospheres comprise 0.5% O_2, 9-9.5% carbon dioxide (CO_2), and 90% nitrogen (N_2). Malting barley is apparently unaffected by controlled atmospheres although some reports indicate a negative effect of high N_2 on seed germination because of pre-germination. Endosperm yellowing in paddy (rough rice) is caused by elevated temperature and relative humidity with controlled atmospheres (high CO_2) having little effect on yellowing. Controlled atmospheres do not affect the slow rise in free fatty acids in dry grain that occur in air storage, but the normal, rapid increase in moist grain is slowed. The storage of wet grain under controlled atmospheres has positive effects, slowing germination loss, maintaining grain quality longer than air storage, and inhibiting fungal growth. Atmospheres >20% CO_2 inhibit fungi in dry grain and 80% CO_2 is needed in wet grain; 20 to 60% CO_2 reduces mycotoxin production. Yeast and yeast-like fungi can survive at <0.5% O_2 and lactic bacteria can become active anaerobically at >90% RH causing fermented and tainted products. Controlled atmospheres of elevated CO_2 and depleted O_2 are beneficial to dry grain (including malting barley and seed grain) in long-term storage and wet grain in short-term storage.

INTRODUCTION

Impaired grain quality during storage is reflected by reduced seed germination, changes in milling and baking characteristics and biochemical (i.e. free fatty acids, electrolyte leakage, carbohydrate and nitrogenous compound changes) and nutritive (minerals, carbohydrates, proteins, and vitamins) changes in the seed. Grain quality is affected by moisture and temperature and the presence of insects, mites, molds, and mycotoxins (Pomeranz, 1992).

Controlled atmospheres with elevated CO_2 or N_2 and depleted O_2 can be used effectively to control insects and mites in stored grain (Annis, 1986; Jayas *et al.*, 1991). The effect of controlled atmospheres on grain quality is an important consideration, whether the atmosphere is used for a relatively rapid fumigation or for prolonged storage. A comprehensive review of the effects of controlled atmospheres on grain quality was presented by Banks (1981), who found generally negligible effects of the gases. The current review summarizes briefly recent contributions to the literature on grain quality under controlled atmosphere storage.

Seed longevity

Grain can be stored for relatively long periods without a loss in viability, with a decreasing scale of longevity for oats, rice, barley, wheat, triticale, rye, sorghum, and corn (Renard, 1988). The main factors that affect longevity are moisture and temperature (Harrington, 1972), with each 1% increase in seed moisture content (m.c.) halving the life of the seed. This rule applies when seed moisture content is between 5 and 14%. Below 5% m.c., the speed of aging may increase because of autoxidation of seed lipids and above 14% m.c. storage fungi kill the seed. Also, for each 5°C increase in seed temperature the life of seed is halved (from 0 to 50°C).

Grain stored dry (7.3 to 8.3% m.c.) in glass tubes within foundation stones in Nuremburg, Germany at 10.6°C for 123 years often retained some germination: 22% for oats, 12% for barley, and 0% for wheat (Roberts, 1972). The presence of O_2 reduces seed germination, even at low partial pressures (Roberts and Abdalla, 1968) in dry grain because of membrane damage caused by the production of free radicals (Villiers, 1973) and accumulating chromosome damage (Roberts *et al.*, 1967).

Peanut seeds with 6.2% m.c. stored at 38 to 40°C had unaffected germination after 26 weeks under N_2 or CO_2 atmospheres, while viability decreased sharply in air (Luo *et al.*, 1983). Packaging of shelled peanuts under vacuum or N_2 atmospheres for distribution in Senegal after 7 months at room temperature resulted in similar or better germination than in other systems (Rouziere, 1986). Slay *et al.* (1985) indicated that storage of shelled peanuts at room temperature and low O_2 had no significant effect on germination.

Corn stored for 360 days in Mexico in hermetic storage lost germination at the same rate as in air at 14% m.c., but at 15.5 and 17.6% m.c. viability was higher under hermetic storage than in air at the same moisture level (Moreno *et al.*, 1988); fungi were not present on seeds in hermetic storage, but *Aspergillus glaucus, A. tamarii*, and *Penicillium* spp. were present on all seeds under air storage.

Green gram seeds stored for 6 months at 12, 14, and 16% m.c. in hermetic storage had lower sugar values and free fatty acid values than seed stored in air (Singh and Yadav, 1987). Bass and Stanwood (1978) stored sorghum seed for 16 years at 4, 7, and 10% m.c. under vacuum, air (hermetically sealed), CO_2, N_2, He, or argon atmospheres, at temperatures from -12 to 32°C. Under these conditions, controlled atmosphere storage had no effect on seed germination which was not significantly different from that of seeds stored in hermetic containers. Seeds in air had less germination than all sealed treatments at temperatures above 0°C. Petruzelli (1986) stored wheat at 15-33% m.c. under hermetic storage and reported that seed viability decreased more rapidly at higher moisture content, while in aerobic storage longevity was enhanced as moisture content increased from 24-31% (under hermetic storage, germination fell to 0% in 8 days at 32.7% m.c. and to 60% in 150 days at 15% m.c.). When moisture content increased above 31%, longevity was greater under hermetic rather than aerobic storage. Above 24% m.c. at 25°C, seed metabolism was activated and could be sustained only in the presence of O_2. At <24% m.c., oxygen had a negative effect on longevity.

Wheat stored at 10.5% m.c. and various combinations of N_2, CO_2, and O_2 for 13.5 months at 27°C showed no decline in germination under N_2, CO_2, or N_2 + CO_2. Atmospheres of N_2 were considered superior to CO_2 because of slower diffusivity (Yadav and Mookherjee, 1975); the permeation of CO_2 through polyethylene is over 30× that of N_2 (Bell and Armitage, 1992). Atmospheres of <1% O_2, 9-9.5% CO_2, and a balance of N_2, generated by the combustion of petroleum fuels, do not affect germination of dry wheat, rice, or malting barley during 6 months storage (Storey, 1980).

Moor (1984) conducting tests in commercial silos (950 t) of malting barley treated with N_2 (0.5% O_2) for 5 or 9 months in Australia, found neither a detrimental nor beneficial effect on germination. However, the N_2 caused some loss in germinability because of pregermination. Unpolished rice stored in containers pressurized with N_2, CO_2, or air showed negative effects in terms of chemical composition. At ordinary temperatures and pressures, there was no difference in effects of N_2 or CO_2 on rice quality in storage. Inert gas filling was effective in preserving rice quality (palatability) at low temperatures (Yanai and Ishitani, 1980).

Carbon dioxide (35%) atmospheres were reported to have a negative effect on the germination of wheat, soybean, and rapeseed but little effect on corn or green pea germination in 12 months, although moisture content of the grain was not given (Hamel, 1990). Generally, low O_2 or high CO_2 atmospheres have no detrimental effects on viability of dry grain and both low O_2 (<0.5%) and high CO_2 (>50%) help preserve germination in wet grain (Banks, 1981).

Yellowing of rice

The quality of paddy and milled rice can be measured by an increase in kernel yellowness as deterioration progresses. Bason *et al.* (1990) and Gras and Bason (1990) have reported that temperature has the greatest effect on quality, moisture content is very important, and CO_2 has little effect on grain quality, with O_2 having a small deleterious effect. Bason *et al.* (1990) calculated that O_2 levels of 2% or 0.2% would reduce yellowing rate by 20% and 35%, respectively. Elevated CO_2 is effective generally in preserving the palatability of stored rice (Muda and Elah, 1990; Sukprakarn *et al.*, 1990).

Nutrient changes in grain

A controlled atmosphere of 97-98% N_2, 1-2% CO_2, and 1% O_2 slows hydrolytic processes in the lipids of rice grain, as compared with grain stored in air (Terebulina *et al.*, 1983). Pure N_2 atmospheres at 20°C also stabilize protein and amino acids and the cooking properties of rice at 18.4 and 23.2% m.c., as compared with air storage (Nadykta *et al.*, 1983). Elevated N_2, with negligible O_2, retains higher gluten quality in stored wheat than in air storage (Quaglia *et al.*, 1980) and the milling and baking properties of wheat are maintained longer, even at high moisture, than in air (Lombardi *et al.*, 1980). An anoxic environment (N_2) slows the oxidative activity and better preserves the organoleptic properties of grains and even hazelnuts (Keme *et al.*, 1980).

Carbon dioxide is sorbed by cereals and their products in elevated CO_2 atmospheres and its sorption by grain proteins may help preserve the quality of the grain (Yamamoto and Mitsuda, 1980). Grain stored dry under airtight conditions (usually 15-25% CO_2 after several months) retains its quality (Penteado *et al.*, 1990) but wet grain (>16% m.c.) can be tainted with fermentation odours, be discoloured, and be unsuitable for bread making (after 2 months at 21% m.c.). At high moisture, there is an increase in reducing and a decrease in non-reducing sugars (Bell and Armitage, 1992). After storing wheat for 3 - 4 years under vacuum, CO_2, or N_2, Stopczyk (1987) concluded that changes to sugars depended mainly on moisture and temperature rather than atmosphere. Starch viscosity decreases more in air storage than in CO_2 storage. Munzing (1988) indicated that flour from wheat stored at 20% m.c. under CO_2 led to reduced loaf volume in 6 months and that an N_2 atmosphere (negligible O_2) was preferable for long-term storage of wet wheat. Dry wheat stored for 18 years at low O_2 showed no reduction in loaf volume (Pixton, 1980).

Wet rapeseed or sunflower seed (13-15% m.c.) stored under airtight conditions produce off-odours due to microbial fermentation, but the production of free fatty acids is slower than in air storage (Poisson *et al.*, 1980).

Microflora

Elevated CO_2 (20-60%) inhibits fungi and the production of mycotoxins by fungi in stored grain (Paster, 1987) including T-2 toxin (Paster *et al.*, 1986), patulin (Paster and Lisker, 1985), ochratoxins (Paster *et al.*, 1983), penicillic acid (Lillehoj *et al.*, 1972), and aflatoxin (Diener and Davis, 1972). The prevention of aflatoxin production in wet corn is of considerable importance in animal feed grain (Wilson and Jay, 1975). Reduction of O_2 is less effective in preventing mycotoxins than elevated CO_2 atmospheres (Hocking, 1990).

In dry grain, 20% CO_2 inhibits microflora; in wet grain 80% CO_2 is needed. Some species of *Fusarium, Aspergillus*, and *Mucor* are tolerant of high CO_2 levels (Hocking, 1990). In wet grain, at 1-2% O_2 and 15-40% CO_2, typical microflora are the yeasts *Hansenula* and *Candida* (60-80% RH) followed by anaerobic fermentation caused by lactic acid bacteria and yeasts (>90% RH). Filamentous fungi disappear gradually during storage (Bell and Armitage, 1992). Fungi do not grow at <1% O_2 (Richard-Molard *et al.*, 1986). Yeasts can survive at <0.5% O_2. Richard-Molard *et al.* (1984) found that corn stored at 21% m.c. in hermetic storage produced a CO_2 atmosphere with 0.5% O_2 in 4-5 days and that there was slight alcoholic fermentation. After 12 months, grain quality was still acceptable, although lactic bacteria showed noticeable metabolic activity after 6 months. An absence of O_2 will inhibit but not quickly kill fungi (Jay, 1984). Storage of dry wheat at cool or warm temperatures for up to 3 months in elevated CO_2 atmospheres (15 to 50%) has negligible effects on seed germination or microfloral incidence (White *et al.*, 1990; White and Jayas, 1991).

CONCLUSIONS

Controlled atmospheres have no detrimental effects on the quality of dry grain (germination, milling, and breadmaking). Atmospheres with high CO_2 are especially beneficial for storing wet grain because deterioration is slowed and mycotoxin production is prevented.

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