Deterioration rates of wheat as measured by CO_2 production

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Al-Yahya, S.A. 1999. **Deterioration rates of wheat as measured by CO_2 production**. Can. Agric. Eng. **41**:161-166. Carbon dioxide production was used as an indicator to determine the allowable storage time (AST) for wheat under different conditions of temperature, moisture, and mechanical damage. The four grain moisture contents used were 15, 18, 21, and 24% wet basis (wb). Temperature levels used were 4, 15, 25, and 40°C. Three levels of percentage of mechanical damage used were 0, 15, and 30%. Each level of moisture was tested in three replicates with each temperature and each level of mechanical damage. Statistical comparisons were made, in regard of the AST among temperatures, moistures, and mechanical damage. The analyses showed significant differences among all of the levels. A general equation was developed to easily calculate the AST or deterioration rate under the above storage conditions.

On a utilisé la production de gaz carbonique comme indicateur pour déterminer la durée d'entreposage tolérable du blé sous des conditions variables de température, d'humidité et de dommages attribuables à la machinerie. Les quatre teneurs en humidité du grain choisies étaient de 15, 18, 21 et 24 % base humide. Les températures étaient de 4, 15, 25 et 40 °C. Des pourcentages de dommages attribuables à la machinerie de 0, 15 et 30 % furent utilisés. Chacun des taux d'humidité comportait 3 répétitions qui furent testées à chacune des températures et avec chacun des pourcentages de dommages attribuables à la machinerie. Des comparaisons statistiques, en ce qui concerne les durées d'entreposage, ont été faites entre les températures, les taux d'humidité et les pourcentages de dommages attribuables à la machinerie. Les analyses ont montré des différences significatives entre les traitements pour tous les niveaux de température, d'humidité et de dommages. Une équation générale a été développée pour permettre de calculer plus facilement la durée d'entreposage tolérable ou le taux de détérioration dans les conditions énoncées ci-dessus.

INTRODUCTION

Carbon dioxide production is a product of stored grain respiration and micro-organism respiration. Bailey and Gurjar (1918) used CO_2 production as a quantitative method for measuring the rate of respiration in wheat. They sealed wheat samples of known moisture content in jars and used barium hydroxide solution to absorb CO_2. The respiration rate was expressed in terms of mg CO_2 respired per 100 g dry matter per 24 h. The complete combustion of a typical carbohydrate is presented by:

$$C_2H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2835\,kJ \qquad (1)$$

According to Eq. 1, a 1% loss in grain dry matter carbohydrate is accompanied by the evolution of 14.7 g CO_2 / kg of grain dry matter. Because carbon dioxide production can be easily measured, many research workers have used CO_2 as an index of deterioration rate in grain (Saul and Lind 1958; Saul and Steele 1966; Steele 1967; Fawole 1969; Seitz et al. 1982; Fernandez et al. 1985; Friday et al. 1989; Al-Yahya et al. 1993; Aljinovic et al. 1995). In tests conducted by Saul and Lind (1958), grain was said to be in good condition if during drying the grain had lost less than 1% of its initial dry mass. Saul and Steele (1966) determined that a 0.5% loss of dry matter can be sustained without causing a reduction in grade due to mold damage. Steele et al. (1969) studied factors affecting CO_2 evolution in stored corn by both grain and micro-organism respiration. These factors included grain moisture content, grain-storage temperature, and mechanical damage.

Thompson's computer simulation model (Thompson 1972) used the Steele et al. (1969) equation to calculate the weight of CO_2 produced at the "standard" condition of 25 °C, 15.5% moisture content, and 30% mechanical damage. Until now, only a few papers in the literature have discussed CO_2 production as an index for the determination of the deterioration rate or the allowable storage time for stored wheat under various storage conditions. White et al (1982) determined CO_2 production for wheat, for only two weeks, under different temperature and moisture contents. They did not consider the effect of mechanical damage in their study.

The objective of this study was to determine the production of CO_2 during storage of wheat until deterioration was achieved under different storage conditions such as grain moisture content, grain-storage temperature, and grain-mechanical damage.

EXPERIMENTAL PROCEDURES

Variety selection

'Yoka Ra Rogo' is the most common variety of wheat grown in Saudi Arabia, therefore, it was used in this experiment. It was grown at the Research Station which belongs to the Agriculture and Veterinary Medicine College in Gassim, Saudi Arabia. It was planted in November 1995 and hand harvested in March 1996.

Sample preparation

After harvesting, kernels were removed by hand-shelling. The samples were then passed through a Carter Dockage Tester (style No. XT3) to remove any fines, light material, or foreign grains. All damaged kernels such as large broken kernels and those damaged by insects or infected by field fungi were also

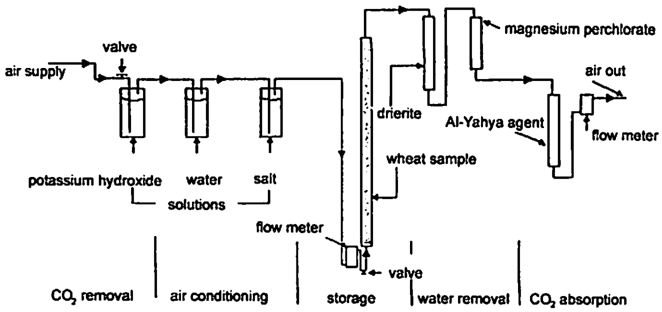

Fig. 1. Carbon dioxide production system.

removed using a binocular microscope. The remaining kernels were assumed to have 0% mechanical damage. The samples were kept at -10°C storage until testing. According to Fernandez et al. (1985), corn stored at -10°C responds to storage fungi almost the same as freshly harvested corn.

Storage rooms

Five storage rooms (3 x 2 x 2 m) were built for this experiment. The temperature in respective rooms was controlled at 4, 15, 25, 40, and -10°C (± 1°C), while the relative humidity was 80% ± 2%. The last temperature was used to keep the samples close to the freshly harvested condition.

Grain-moisture content

The moisture content of the grain at harvest was near 9% wb. At the beginning of each experiment, the samples were taken from a freezer and the desired moisture level was achieved by adding the required amount of water. The sample was thoroughly manually mixed for 12 h. An initial moisture content was measured before running each experiment using an oven temperature of 130 °C for 19 h (ASAE 1999).

Experimental design

Grain samples were stored at 4, 15, 25, and 40 °C. Grain moisture contents were 15, 18, 21, and 24%. Mechanical damage levels were 0, 15, and 30% (common mechanical damage in Saudi Arabia). Levels of damage were obtained by using a breakage tester based on mass basis. Three replications in each of the above levels were used. The total number of treatments was 144. The work was divided into four experiments. The first experiment had one level of moisture content of 24% at all temperatures (4, 15, 25, and 40°C) and with all mechanical damage levels (0, 15, 30%). For each temperature, nine grain bins were used with three levels of mechanical damage and each level was replicated three times. Grain temperature was measured using an electronic thermometer. Its probe was placed at the inlet where air passed into the grain bins. In the subsequent tests, the moisture contents were 21, 18, and 15% wb.

Carbon dioxide production

The carbon dioxide absorption technique was used to measure the carbon dioxide production of the wheat samples. The experimental setup used was similar to that of Al-Yahya et al. (1993). Each grain bin had a complete carbon dioxide absorption system.

Carbon dioxide removal

Carbon dioxide in the incoming air from outside the building was removed by bubbling the air stream through a 25% potassium hydroxide solution in a Drechel gas-washing bottle (Fig. 1). In accordance with Al-Yahya (1991), the potassium-hydroxide solution was changed every 3 to 4 days.

Humidification.

The relative humidity (RH) of the air stream was controlled by bubbling the air through two 250-mL Drechel gas-washing bottles in series. The first bottle was filled with water and the second with a saturated salt solution. The salt solution conditioned the air to the proper relative humidity. Based on Wexler and Hasegawa (1954) relationships, grain moisture content was controlled by using different salt solutions. Selection of each salt solution to control grain moisture content was based on the equilibrium relationships reported and by measuring relative humidities of air passing into the storage bins which were checked daily for RH by an electronic meter.

Sample storage and aeration

The sample storage and aeration component consisted of a 550 mm long and 60 mm internal diameter hard plastic tube. Fiberglass 50 mm deep was used at the bottom of the sample storage as an air-permeable floor. Air passing through the storage unit was controlled by both a manifold air-distribution unit and a needle valve. Air flow was monitored using a Matheson Model PM-1022 Acrylic Purge Flowmeter (Matheson Gas Co., Joliet, IL). Al-Yahya (1991) calibrated this flowmeter with a Gilmont No. 12 flowmeter (Matheson Gas Co., Joliet, IL). Airflow rates were set at 0.45 m^3/min throughout storage. The system was checked for air leaks at intervals of approximately 6 h.

Water absorption

Production of water and CO_2 results from grain and microorganism respiration. These two components are combined with air passing through the storage unit. In the experiment, two drying agents were used to absorb water vapor. The first agent was a 1:1 mixture of 8-mesh drierite anhydrous $CaSO_4$ and 8-mesh indicating drierite (97% $CaSO_4$ and 3% CoC_{12}). The first agent was placed in a plastic tube 400 mm long and 24.5 mm in diameter. The advantage of this agent is that it changes color from white-blue to pink when it absorbs water vapor. An air stream was then passed through the second agent, magnesium perchlorate ($Mg[ClO_4]_2$), which was placed in a plastic tube 400 mm long and 24.5 mm in diameter. The second drying agent was used only to determine whether any water vapor was passing through the first agent. Because the second drying agent did not change color when it absorbed water, 50.8 mm of the first drying agent was placed at the bottom of the second drying agent to ensure no water was escaping absorption.

Carbon dioxide absorption

In the experiment, Al-Yahya agent was used to absorb CO_2. This agent was developed by Al-Yahya (1991). The process for absorbing CO_2 was as follows. As mentioned earlier, CO_2 and water are the results of grain and micro-organism respiration. In the previous stage of the experiment, water was completely absorbed and CO_2 remained in the air stream. The accumulation of CO_2 was absorbed in a plastic tube 300 mm long and 15 mm in diameter. This tube contained the CO_2 absorbing agent, a mixture of vermiculite and potassium hydroxide solution. This agent was at the top of the tube with a depth of 150 mm. Also,

Table I. Storage time in hours for wheat at 24% moisture content stored at different levels of grain temperatures and mechanical damages.

Grain temp (°C)	Mechanical damage (%)	Dry matter loss (%)			
		0.25	0.5	0.75	1.0
	0	996	1380	1644	1896
4	15	684	1116	1332	1476
	30	540	876	1092	1224
	0	372	612	750	864
15	15	288	420	576	696
	30	180	348	480	600
	0	192	312	384	>384*
25	15	96	180	240	312
	30	84	144	192	252
	0	96	168	216	240
40	15	60	108	132	156
	30	48	96	120	144

* Experiment terminated at 384 h.

Table II. Storage time in hours for wheat at 21% moisture content stored at different levels of grain temperatures and mechanical damages.

Grain temp (°C)	Mechanical damage (%)	Dry matter loss (%)			
		0.25	0.5	0.75	1.0
	0	1176	1776	2136	2400
4	15	936	1416	1752	2016
	30	768	1248	1584	1848
	0	600	960	1200	1368
15	15	456	768	984	1152
	30	336	600	792	936
	0	432	672	840	960
25	15	264	456	624	720
	30	216	408	552	672
	0	288	528	>600*	>600*
40	15	168	360	504	>600*
	30	120	240	360	480

* Experiment terminated at 600 h.

in the middle of the tube, magnesium perchlorate was placed to a depth of 50 mm and at the bottom of the tube a depth of 50 mm of drierite was added. These two agents (in the middle and in the bottom) were used to absorb any water liberated from the Al-Yahya agent; according to the chemical equation:

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O \quad (2)$$

The water liberated due to the chemical reaction in Eq. 2 had to be included in the net mass-gain of carbon dioxide accumulation. Readings of CO_2 mass were taken every 12-48 hours depending on the grain moisture content. Readings were taken every 12 hours during the experiments for 21 and 24% MC while 24 hours was used with 18% MC wheat and 48 hour was used with 15% MC wheat. Columns containing the Al-Yahya agent were changed after being saturated with CO_2 (their color changed from dark to light gray upon absorption of CO_2). Any change in color of drierite material at the bottom would indicate that this column was saturated and it should be changed very soon. After each experiment, the whole system was disassembled and cleaned. Cleaning steps were taken in the following order: warm water, soap, warm water, and cooled distilled water.

Statistical analysis

A statistical analysis was done using the SAS statistical package (SAS 1991) on results of all experiments, a randomized complete block design which included 48 treatment combinations consisting of four levels of grain-moisture content, four levels for temperature, and three levels of mechanical damage. The allowable storage time can be expressed as a function of three variables:

$$AST = f(MC, D, T) \quad (3)$$

where:
AST = allowable storage time (d),
MC = moisture content (% wet basis),
D = mechanical damage (%), and
T = temperature (°C).

A multiple regression analysis was applied to predict the above function by using the general linear model (GLM). An analysis of variance (ANOVA) was used for the data collected in the carbon dioxide tests. Orthogonal contrasts were used to make comparisons among treatment means (Snedecor and Cochran 1989). Comparisons were made for moisture levels, temperature levels, and mechanical damage levels for the time dry-matter loss reached 0.5%.

RESULTS and DISCUSSION

The experimental work has been divided into four experiments, therefore the results for each experiment are discussed separately.

Experiment No. 1

Table I shows the safe storage time in hours of wheat at 24% moisture content stored at 4, 15, 25, and 40°C, and three levels

Table III. Storage time in hours for wheat at 24% moisture content stored at different levels of grain temperatures and mechanical damages.

Grain temp (°C)	Mechanical damage (%)	Dry matter loss (%)			
		0.25	0.5	0.75	1.0
	0	1872	2976	3744	4368
4	15	1248	2112	2832	3408
	30	1104	2016	2592	3120
	0	960	1872	2544	3024
15	15	816	1536	2160	2688
	30	624	1296	1824	2304
	0	696	1368	1872	2256
25	15	528	1056	1488	1848
	30	480	984	1368	1728
	0	408	792	1104	1344
40	15	336	648	936	1176
	30	288	576	816	1056

of mechanical damage (0, 15, and 30%) at each temperature. The storage time increased with decreasing levels of temperature, grain-moisture content, and mechanical damage. When samples were stored at 15°C the storage time, when the wheat fell from grade No.1 to grade No. 2, was increased. At 4°C and 1.0% DML(dry matter loss), the storage time was 1896 h when the sample had 0% mechanical damage. But, when the same sample had 30% mechanical damage the storage time decreased by 35%. The effect of storage temperature was also visible. At 0.5% DML and with 0% mechanical damage, storage time was 1380 h when the sample was stored at 4°C. But when the same sample was stored at 40°C, the storage time decreased by 87%.

Experiment No. 2

Table II shows the storage time of 21% moisture content of wheat stored at 4, 15, 25, and 40°C and three levels of mechanical damage. Storing the wheat at higher temperature and higher mechanical damage decreased the storage time or increased the deterioration rate. At 5% DML, increasing the level of mechanical damage from 0% to 30% when the sample was stored at 15°C decreased the storage time 360 h. Also, decreasing the temperature from 40 to 4°C when the mechanical damage was 15% for both samples caused an increase of the storage time by 1056 h.

Experiment No. 3

Table III shows the storage time in hours, of wheat at 18% moisture content stored at 4, 15, 25, and 40°C and three levels of mechanical damage (0, 15, and 30%) at each temperature. In

Table IV. Storage time in hours for wheat at 24% moisture content stored at different levels of grain temperatures and mechanical damages.

Grain temp (°C)	Mechanical damage (%)	Dry matter loss (%)			
		0.25	0.5	0.75	1.0
	0	2448	3936	4944	>5424*
4	15	1584	2880	3840	4656
	30	1344	2496	3360	4128
	0	1536	2688	3504	4224
15	15	1152	2112	2832	3504
	30	1104	1968	2688	3264
	0	1104	2113	2928	3611
25	15	912	1824	2544	3264
	30	768	1536	2208	2832
	0	864	1728	2400	>2688**
40	15	720	1440	2016	2640
	30	672	1296	1872	2400

* Experiment terminated at 5424 h.
** Experiment terminated at 2688 h.

this experiment, the trends were similar to those in experiment No.1 and experiment No. 2. Storing the wheat at lower temperature and lower mechanical damage caused reduction of deterioration rate. Comparing storing wheat at a temperature of 4°C to grain-storage temperature of 40°C when the mechanical damage was 30% increased the deterioration rate more than three times. When comparing storing the wheat at mechanical damage levels of 0% to 30% when the sample was stored at 25°C, the deterioration rate increased by a factor of 1.5. The effect of temperature was greater than the effect of mechanical damage in regard to storage time.

Experiment No. 4

Table IV shows the storage time in hours of wheat at 15% grain- moisture content stored at 4, 15, 25, and 40°C and three levels of mechanical damage (0, 15, and 30%) at each temperature. Decreasing the grain-storage temperature played a major role in increasing the safe storage time of wheat. At 30% mechanical damage level and 40°C, the wheat grade changed from No. 1 to No. 2 after 1296 h. The same sample would remain at grade No. 1 up to 2496 h if stored at 4°C.

Combination of experiments

Table V shows the effect of all of the studied factors (moisture content, storage temperature, and mechanical damage). It shows the storage time in days until a 0.5% DML when the wheat samples were stored at four levels of moisture content, four

Table V. The allowable storage time in hours for wheat (0.5% DML).

Grain temp (°C)	Mechanical damage (%)	Moisture content (%)			
		15	18	21	24
4	0	3936	2976	1776	1380
	15	2880	2112	1416	1116
	30	2496	2016	1248	876
15	0	2688	1872	960	612
	15	2112	1536	768	420
	30	1968	1296	600	348
25	0	2112	1368	672	312
	15	1824	1056	456	180
	30	1536	984	408	144
40	0	1728	792	528	168
	15	1440	648	360	108
	30	1296	576	240	96

levels of storage temperature, and contained three levels of mechanically damaged kernels. When the moisture level, grain-storage temperature, and mechanical damage were increased, the storage times were decreased. At 4°C grain-storage temperature and 15% mechanical damage, the storage time of 24% wheat moisture content was 1116 h while the storage time of 15% wheat moisture content at the same conditions increased by a factor of 2.6. With the increasing of storage temperature, the difference in storage time increased. When the wheat was stored at 40°C and 15% mechanical damage, the storage time was 108 h at 24% MC while it was 1440 h at 15% MC. The difference in this case was a factor of 13.

Statistical analysis in the form of estimate contrasts among treatment means was performed at 0.50% DML. The statistical results between levels of temperature, moisture, and mechanical damage were found to have significant differences.

Regression and correlation

The means of all of the experimental data for temperature, moisture, and mechanical damage levels were used to obtain a general equation to determine AST under any storage conditions of moisture, temperature, and mechanical damage. Many models were tried to simulate Eq. 3 and, subsequently, Eq. 4 was obtained:

$$AST = a_0 + a_1(MC) + a_2D + a_3T + a_4(MC)^8 + a_5DT + a_6(MC)^2D + a_7(MC)T^2 \quad (4)$$

The values of the constants a_0, a_1, ..., a_7 are listed in Table VI. The values of R^2 and C.V. are 0.98 and 10.3 day, respectively.

Table VI. Values of constants in Eq. 4.

Constant	Value
a_0	8838.24
a_1	-326.71
a_2	-47.02
a_3	-90.62
a_4	1×10^{-8}
a_5	0.54
a_6	0.05
a_7	0.05

Figure 2 shows the relationship between the observed and the estimated values of AST based upon Eq. 4. It can be seen that there is good agreement between both results. For instance, at MC = 18%, D = 15%, T = 15°C, the measured AST is 1536 h (Table III). Using Eq. 4, the predicted value of AST is 1542 h. Equation 4 can be used to predict the AST at any storage conditions.

Gurjar (1917) measured CO_2 only for 24 h using 100 g samples of dry matter at different storage temperatures and moistures. He put the samples in a glass container. The carbon dioxide level was measured by a barium hydroxide [Ba $(OH)_2$] solution. The study by Gurjar was done for a very short time (24 hours) while in the current study the samples were left until the actual storage time was achieved. In the case of Gurjar's study, the storage time was predicted based on 24 h data. Gurjar (1917) also used a volumetric method for measuring CO_2 while in this study, a quantitative method was used. Although, there are differences between these studies, some comparisons can be made. Table VII shows the comparison of the results at some selected storage conditions.

CONCLUSION

The production of CO_2 during storage of wheat until deterioration was achieved under different storage conditions such as grain moisture content, grain-storage temperature, and grain-mechanical damage was experimentally determined. Data of CO_2 were used as an index of allowable storage time (AST). Based on these results, a general equation was developed to calculate the AST at any storage conditions. The maximum AST for wheat was 3936 h at 4°C, 15% moisture content and 0% mechanical damage. The minimum AST was 96 h at 40°C, 24% moisture content and 30% mechanical damage. As was expected, AST for low temperature, low moisture content, and low mechanical damage was longer than for higher temperature, moisture content, and mechanical damage.

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Table VII. Comparison between Gurjar (1917) study and the current study.

Gurjar (1917) study			Current study		
Temperature (°C)	Moisture content (%)	Mg CO_2/24 h per 100 gm	Temperature (°C)	Moisture content (%)	Mg CO_2/24 h per 100 gm
37.8	15	1.2	40	15	1.02
37.8	16	2.72	40	18	2.23
4	15	0.24	4	15	0.45
25	15	0.45	25	15	0.83
35	15	1.3	40	15	1.02

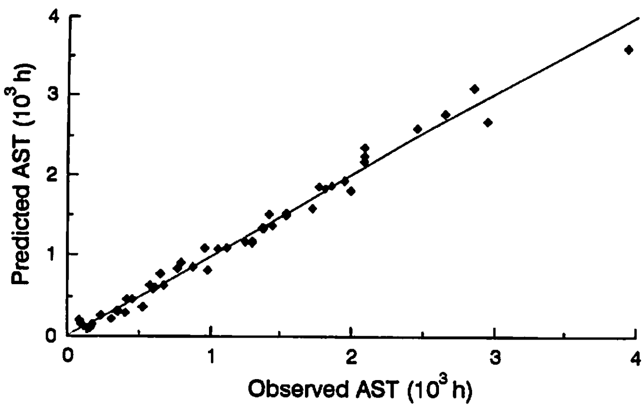

Fig. 2. The relationship between the observed and predicted values of AST.

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