Storage of wheat at high moisture

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Summary

Deterioration rates were determined for 15-19% moisture content wheat (Dropia cultivar) stored at constant temperatures. Deterioration rates were determined by measuring germination capacity of the grain and respiration rates of grain. Safe storage time was defined as the time for germination to decrease to 90%. Safe storage times of 19% m.c. wheat stored at constant temperatures ranged from 2.5 d at 30 and 35°C to 37 d at 10°C. Deterioration rates of 19% m.c. wheat stored with a step decrease in storage temperatures (35-25, 30-20, 25-20, and 20-15°C) were determined and safe storage times were satisfactorily predicted. Safe storage times of 17% m.c. wheat were 5, 7, and 15 d at 35, 30, and 25°C, respectively. Respiration rates and germination percentages of 15 and 16% m.c. wheat stored at 25°C remained constant for 70 d. The respiration rates of 17-19% m.c. wheat at 25°C increased while the germination percentages decreased with storage time. Germination dropped from 98 to 92-89% when the dry matter losses were about 0.05% and visible mould occurred when the dry matter losses were about 0.1% in 17-19% m.c. wheat.

Keywords*:* Storage life; Moisture content; Germination; Dry matter loss.

INTRODUCTION

Harvesting high moisture wheat has become a common practice to protect the grain from wet weather conditions which can cause weathering and mould infection of grain in the field. High moisture grain is susceptible to deterioration by microorganisms and hence should be dried before unacceptable quality loss occurs. A knowledge of deterioration rates of high moisture wheat under various storage conditions would help farmers and grain managers to know how quickly to dry the grain or adjust the storage conditions to prevent further quality loss. Existing grading systems for grain do not provide information about the storability of grain of the same grade. A measurement procedure which can determine the storability of grain of the same grade would help the storage manager to segregate grain according to the storability of each bulk. Such a measurement system should be simple enough to be adopted by a farmer and fast enough to determine the condition of incoming grain at grain handling facilities.

Wheat deterioration has been measured and models have been developed based on germination rates, visible mould growth, or the respiration rate of grain (Lacey et al., 1994; Schroth, 1996; Schroth et al., 1998). The wheat deterioration model was used in the development and validation of computer simulated studies on drying of wheat (Sinicio and Muir, 1996). These studies revealed that the model was not sufficiently precise because wheat deterioration occurred later than predicted by the model.

The objectives of this study were to determine the deterioration rates of 17 and 19% m.c. wheat stored at constant temperatures by determining germination capacity of the grain; to determine the deterioration rates of 19% m.c. wheat stored with a step decrease in storage temperatures; to determine the deterioration rates of 15-19% m.c. wheat stored at 25°C by measuring respiration rates of grain and to compare the deterioration rates of three cultivars of 17% m.c. spring wheat stored at 35-25°C.

Microfloral infection was determined by placing 25 seeds on no. 3 filter paper saturated with 5.5ml of 7.5% aqueous sodium chloride solution. The plates were incubated at 25°C for 7 d and the organisms were identified using a dissecting microscope. Free fatty acid values (FAV) were determined on 5 g of dried samples using a fat extractor.

MATERIALS AND METHODS

Deterioration rate was determined on wheat *(Triticum aestivum* L., cultivar 'Dropia'), a commonly grown cultivar in the Romanian planes. The grain was stored on a farm for 10 mo and was clean, dry (12.7% m.c.), had no apparent mechanical damage, and had 98% initial germination. Free fatty acid value of the dry wheat was 11 mg KOH/100g of dry grain. The grain was stored in plastic bags at 5°C before being used for the experiments.

Wheat was conditioned to the required moisture content by adding distilled water and allowing the wheat to come into equilibrium at room temperature for 6h (Schroth et al., 1998). Test grain in mesh bags containing 400 g samples was placed in the centre of galvanized-steel containers (127 mm diameter by 230 mm height). The containers had ventilation holes at the bottom to prevent accumulation of CO_2 but were covered by plastic lids at the top. The test grain had "guard" bags of grain above and below to prevent it from drying. Grain in the "guard" bags was replaced regularly with freshly moisturized grain. Moisture contents of the test grain measured during sampling were maintained within ±0.5 percentage points of the target moisture content. Storage temperatures of the grain varied ± 1°C from the set temperatures. Equilibrium relative humidity in all experiments was above 70%. Three replicates for 17 and 19% m.c. wheat and two replicates for 15-19% m.c. wheat were tested.

Germination was measured by placing 25 seeds on no. 3 filter paper (90 mm diameter) saturated with 5.5 mL of distilled water. The plates were stacked, covered with a plastic bag and incubated at 10°C for the first 3 d to begin germination. On the fourth day the cover was removed and the plates were incubated at 25°C. Germination was assessed on the seventh day.

Respiration rates were measured on 75 g grain samples at 25 ± 1°C using a respirometer. Gas

concentrations were measured every 20 minutes during a test period of 2 hour for each sample.

RESULTS AND DISCUSSION

Deterioration of 19% m.c. wheat

We use the following equation 1 (Sigmaplot, 1997) to the measured germination data :

$$G = g/[1 + (t/c)^b]^e$$

where *G* is the germination (%), *g* the initial germination (98%), *t* the storage time (d), and *b*, *c*, and *e* are the constants for each moisture content (Table 1).

Table 1

Coefficients of the germination equation for 19% m.c. wheat

Temperature (°C)	*Coefficients*			R^2
	b	*c*	*e*	
35	*2.39*	*14.40*	*5.88*	*0.91*
30	*1.72*	*27.89*	*6.98*	*0.96*
25	*3.82*	*22.22*	*20.98*	*0.99*
20	*3.86*	*37.59*	*12.88*	*0.97*
15	*3.99*	*57.82*	*2.14*	*0.92*
10	*4.42*	*94.46*	*5.89*	*0.97*

Mould growth was visible on wheat stored at 35-208C after germination dropped below 90%. Mould growth was not visible on grains stored at 15 and 108C even after germination had dropped to 70%.

During the early days of storage, infection levels were high for *Aspergillus glaucus* group species and *A. flavus* Link at 35°C, for *A. candidus* Link at 30 and 25°C, and for *A. candidus* and *Penicillium* species at 20°C (Table 2). At later storage times, the infection levels were high for *A. glaucus* Link at 35°C, *A. candidus* at 30 and 208C, and *A. glaucus* and *A. candidus* at 25°C. Bacteria were present on the incubated seeds of wheat stored at 30 and 25°C on days 9 and 11, respectively. Free fatty acid values were high in wheat stored at high temperatures, e.g., FAV in wheat stored at 30, 25, and 20°C on days 4, 5, and 12 were 23, 15, and 11 mg KOH/100g of dry grain. Free fatty acid values were low when the percentage of seeds infected by microflora was low and increased with storage time when the percentages of seed infections were high.

Germination of wheat exposed to a step decrease in storage temperatures was determined for four temperature conditions. Initial storage temperatures of 35 and 308C, were reduced to 25 and 20°C after 36 h and initial temperatures of 25 and 208C were reduced to 20 and 15°C after 3 and 7 d, respectively. Visible mould growth was not observed until after germination had dropped below 90% in all these temperature conditions. *Aspergillus glaucus* group were the predominant fungi except for the initial temperature condition of 20°C where *A.flavus* had a higher infection rate and FAV were high when infection levels were high for *A. glaucus.*

Safe storage time of 19% m.c. wheat

A germination drop to 85% usually results in grain downgrading. The safe storage time of wheat, therefore, was defined as the storage time for the germination to decrease to 90%. The following correlation equation 2 for 19% m.c. wheat at 10-35°C was developed:

$$\log T = 2{,}057 - 0{,}049\,\acute{O},\quad R^2 = 0{,}97$$

where *T* is the safe storage time (d), and *Ó* the storage temperature (°C).

The safe storage times of wheat stored with a step decrease in storage temperatures were predicted by the method described by Schroth et al. (1998). The method predicted safe storage times well, except when the temperature was dropped from 30 to 20°C.

Safe storage times of 17% m.c. wheat

The germination results with 17% m.c. wheat were fitted to Eq. (1) (Table 3). The safe storage times of 17% m.c. wheat were 5, 7, and 15 d at 35, 30, and 25°C, respectively.

Table 3

Coefficients of the germination equation (Eq. (1)) for 17% m.c. wheat

Temperature (°C)	*Coefficients*			R^2
	b	*c*	*e*	
35	*3.18*	*5.63*	*0.20*	*0.99*
30	*1.67*	*165.68*	*31.88*	*0.99*
25	*3.26*	*112.10*	*76.07*	*0.99*

Deterioration of 15-19% m.c. wheat based on respiration rate

The rate of carbon dioxide production by the grain and microorganisms increased from 23 to 463 (mg/d)/kg d.m. within 6h after increasing the moisture content from 12.7 to 19%. The measured rates of O_2 consumption at 15, 18, and 19% m.c. were higher than those predicted by Lacey et al. (1994) but were equal at 16 and 17% m.c. grain.

The respiration rates of 15 and 16% m.c. wheat stored at 25°C remained constant for about 45 d and then showed a slight decreasing trend, whereas the respiration rates of 17, 18, and 19% m.c. wheat increased linearly with time (Table 4). Our measured respiration rates of 16% m.c. wheat were 21 and 18 (mg/d)/kg d.m. on days 10 and 30, respectively, and were considerably higher than the 10 (mg/d)/kg d.m. of CO_2 measured after 15 d at 35°C.

The measured rates of CO_2 production during storage at 17, 18, and 19% m.c. were combined and fitted to the following equation 3:

$$\ln X = -15.6 + 0.21t - 0.004t^2 + 1.08\,M, \quad (R^2=0.95)$$

where X is the rate of CO_2 production ((mg/d)/kg d.m.), t the storage time (d), and M the moisture content (%).

Table 4

Carbon dioxide production, estimated dry matter loss, respiratory quotient, and germination capacity of wheat stored at 25°C

Moisture content (%)	*Storage time (d)*	*CO^2 production[a] ((mg/d)/kg d.m.)*	*Dry matter loss[a, b] (%)*	*RQ[a] (%)*	*Germinatio[a] (%)*
15	*15*	*23*	*0.02*	*0.93*	*95*
	30	*32*	*0.05*	*2.35*	*91*
	47	*15*	*0.08*	*1.46*	*93*
	77	*10*	*0.10*	*0.53*	*92*
16	*10*	*21*	*0.02*	*0.99*	*96*
	30	*18*	*0.04*	*0.63*	*98*
	41	*19*	*0.06*	*2.16*	*96*
	73	*8*	*0.07*	*1.09*	*92*
	94	*11*	*0.11*	*1.49*	*90*
17	*6*	*72*	*0.02*	*1.13*	*96*
	12	*37*	*0.04*	*1.48*	*91*
	24	*278*	*0.17*	*1.21*	*61c*
	30	*372*	*0.30*	*1.08*	*34c*
18	*5*	*111*	*0.02*	*1.36*	*92*
	11	*326*	*0.11*	*1.32*	*73c*
	14	*479*	*0.19*	*1.29*	*39c*
	20	*598*	*0.42*	*1.08*	*27c*
19	*2*	*197*	*0.02*	*1.39*	*92*
	4	*267*	*0.05*	*1.41*	*89*
	6	*460*	*0.10*	*1.30*	*78c*
	8	*829*	*0.18*	*1.19*	*73c*
	10	*822*	*0.30*	*1.09*	*32c*

[a] Means of two replicates. RQ - respiratory quotient.

[b] 1% loss of dry matter per kilogram of dry grain produces 14.7g of CO_2.

[c] Visible mould on these samples.

To determine the grain condition using respiration rate, the relationship between the respiration rate and germination capacity of the grain was determined. The germination capacity of grain at 17-19% m.c. stored at 25°C can be predicted from the measured respiration rate and moisture content by the equation 4:

$$Y = 100 - 0.1\,X + 0.093\,M,$$

where Y is the germination capacity of grain (%),and X the rate of CO_2 production ((mg/d)/kgd.m.).

The coefficient of determination of Eq. (4) was 0.77. This type of relationship is useful to determine the condition of the grains coming to grain-handling facilities, for which the storage conditions (time and temperature) are not known but the moisture content and respiration rate of the grain can be determined in 2 h rather than the 7 d required for germination. For grain stored for a known length of time at 25°C and moisture levels of 17-19%, the germination capacity can be predicted with Eq. 5 from the storage time, moisture content of the stored grain, and

CO_2 production:

$$Y = 54.56 - 1.213t + 2.832M - 0.076X \quad (R^2 = 0.94)$$

Germination decreased below 90% for 17-19% m.c., wheat when dry matter losses were about 0.05% (Table 4). At 15 and 16% m.c., germination stayed above 90% when the dry matter loss had increased to 0.1%, approximately double that for the higher moisture contents. In this study visible mould was observed on days 24, 11, and 6 on 17, 18, and 19% m.c. grain, respectively. No mould growth was observed on 15 and 16% m.c. grain during the storage time. Visible moulds were observed on day 7 in 18% and higher moisture content grains stored at and above 25°C reported visible mould on day 7 in 19% m.c. grain stored at 25°C. Visible mould on 17% m.c. grain in this study occurred between 12 and 24 d. Mould growth became visible when the respiration rates were about 300 (mg/d)/kg d.m. and cumulative dry matter losses were about 0.1%. These dry matter losses for 17-19% m.c. can be compared with 0.045% d.m. loss for germination to decrease to 95-90% and 0.13% d.m. loss for visible mould, reported a dry matter loss of 0.087% is acceptable for initial germination to decrease to 90%. This higher value may be due to their assumed respiratory quotient (RQ) value of 1 for predicting the cumulative CO_2 production from the measured O_2 consumption rates. The reported RQ values were less than 1 except for grains stored at 15°C. Hence, wheat can be stored up to a dry matter loss of about 0.1%, if it is not meant for seed because visible mould occurred after this value in all cases in this study.

The microflora causing wheat deterioration during storage were identified on day 12 on 17% and on day 6 on 19% m.c. samples. At 17 and 19% m.c. the predominant microflora were species of the *Aspergillus glaucus* group, *A.flavus*, *A. candidus*, and *Penicillium* species.

Free fatty acid values increased in the 17% m.c. wheat from 18 on day 12 to 44 mg KOH/100g dry grain on day 30; and in the 18% m.c. wheat, it increased from 17 on day 11 to 48 mg KOH/100g dry grain on day 20. Similarly, FAV in the 19% m.c. grain increased from 21 on day 6 to 51 mg KOH/100g dry grain on day 10. Free fatty acid values did not increase as rapidly as respiration rate with increasing moisture content.

Respiratory quotients may indicate the type of substrate being oxidised. The RQ of dry grain (12.7% m.c.) was 0.49. The RQ values 6h after the moisture content of wheat was increased to 15-19% ranged from 0.60 to 1.78. The increasing RQ values with moisture content may be due to increased breakdown of carbohydrates. The decreasing RQ values of 17-19% m.c. (except 1.48 and 1.41 for 17 and 19% m.c. grain on day 12 and 4, respectively), with storage time indicate the breakdown of lipids and proteins by the microorganisms (Table 4).

CONCLUSIONS

The increasing of values of the moisture content increased breakdown of carbohydrates, lipids and proteins because of accelerated metabolism and finally decreasing the wheat quality.

The microorganisms also grows with increasing of the values of the moisture content and increase the quality losses.

Germinations drops during storage and the losses of dry matter are significant, reducing the efficiency of storage.

REFERENCES

1. Corte Madera, Ca. Sinicio, R., Muir, W.E., 1996. Comparison and sensitivity analyses of models for simulating aeration of stored wheat. Canadian Agricultural Engineering 38, 183-193.

2. Lacey, J., Hamer, A., Magan, N., 1994. Respiration and losses in stored wheat under different environmental conditions. In: HIGHLEY, E., WRIGHT, E.J., BANKS, H.J., CHAMP, B.R. (Eds.), Proceedings of the Sixth International Working Conference on Stored-product Protection, CAB International, Canberra, Australia, Vol. II, pp. 1007-1013.

3. Mills, J.T., Sinha, R.N., Wallace, H.A.H., 1978. Multivariate evaluation and isolation techniques for fungi associated with stored rapeseed. Phytopathology 68, 1520-1525.

4. Sanderson, D.B., Muir, W.E., Sinha, R.N., Tuma, D., Kitson, C.I., 1989. Evaluation of a model of drying and deterioration of stored wheat at near-ambient conditions. Journal of Agricultural Engineering Research 42, 219-233.

5. Schroth, E., 1996. Modelling allowable storage time of 17% moisture content wheat. M.Sc. Thesis. Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, 122 p.

6. Schroth, E., Muir, W.E., Jayas, D.S., White, N.D.G., Abramson, D., 1998. Storage limit of wheat at 17% moisture content. Canadian Agricultural Engineering 40, 201-205.

7. SIGMAPLOT, 1997. Sigmaplot scientific graph system. User's Manual. Jandel Scientific,

8. Tabak, H.H., Cooke, W.B., 1968. The effect of gaseous environment on the growth and metabolism of fungi. The Botanical Review 34, 126-252.

9. Tipples, K.H., 1995. Quality and nutritional changes in stored grain. In: JAYAS, D.S., WHITE, N.D.G., MUIR, W.E. (Eds.), Stored Grain Ecosystems. Marcel Dekker, New York, pp. 325-352.

10. Wallace, H.A.H., Sholberg, P.L., Sinha, R.N., Muir, W.E., 1983. Biological, physical and chemical changes in stored wheat. Mycopathologia 82, 65-76. Science 42, 130-141.

11. White, N.D.G., Sinha, R.N., Muir, W.E., 1982. Intergranular carbon dioxide as an early indicator of biological activity associated with the spoilage of stored wheat. Canadian Agricultural Engineering 24, 35-42.