Simulation of Ambient-air Drying of Fungicide-treated, High-moisture Corn in Iowa

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Abstract
Twenty-six years of Des Moines, Iowa, weather data were used in a computer simulation of ambient air drying of fungi-resistant and fungi-susceptible corn hybrids treated with Rovral® fungicide. Drying of 20 and 24% moisture corn harvested 15 October was simulated. Compared with the susceptible corn hybrid (DF20YDF12) under the same conditions, the resistant corn hybrid (FR35YFR20) had lower airflow requirements and used less fan energy. Rovral fungicide-treated corn had a lower rate of grain deterioration, required lower airflow rates, and used less fan energy than untreated corn.

Keywords
Corn, Fungicides, Grain drying, Simulation

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
SIMULATION OF AMBIENT-AIR DRYING OF FUNGICIDE-TREATED, HIGH-MOISTURE CORN IN IOWA

S. A. Al-Yahya, C. J. Bern, M. K. Misra

ABSTRACT. Twenty-six years of Des Moines, Iowa, weather data were used in a computer simulation of ambient air drying of fungi-resistant and fungi-susceptible corn hybrids treated with Rovral® fungicide. Drying of 20 and 24% moisture corn harvested 15 October was simulated. Compared with the susceptible corn hybrid (DF20×DF12) under the same conditions, the resistant corn hybrid (FR35×FR20) had lower airflow requirements and used less fan energy. Rovral fungicide-treated corn had a lower rate of grain deterioration, required lower airflow rates, and used less fan energy than untreated corn. Keywords. Corn, Fungicides, Grain drying, Simulation.

Steene et al. (1969) studied deterioration of high-moisture corn under aeration and measured effects of grain moisture content, grain storage temperature, and mechanical damage. These researchers developed an equation for predicting CO2 evolution, their indicator of deterioration, at standard and constant conditions of 15.5°C (60°F), 25% moisture, and when 30% of the kernels had mechanical damage. They also developed multipliers for moisture, temperature, and mechanical damage for use under other than standard conditions. From their results, they concluded that when corn has evolved over 7.35 g of CO2/kg of dry matter (which corresponds to a loss of 0.5% of the original dry matter), its U.S. grade will drop one grade number due to mold damaged kernels. Wilcke et al. (1993) reported a drop from U.S. grade no. 1 to nos. 4 or 6 by the time combine-harvested corn with 25% mechanical damage reached 0.5% dry matter loss.

Thompson (1972) used results of Steele (1967) to predict the amount of CO2 produced under the aforementioned "standard" conditions:

\[ y = 1.3 \left[ \exp(0.006t) - 1 \right] + 0.015t \]  

where

\[ y = \text{g of CO}_2 \text{ produced kilogram of dry matter} \]
\[ t = \text{time (h)} \]

Under standard conditions, when \[ t = 230 \text{ h} \], then \[ y = 7.32 \text{ g/kg} \], which is the end of the corn's allowable storage time. If other than the standard conditions exist, the time required to produce 7.32 g/kg of CO2 is predicted from the expression:

\[ t = (230)M_mM_tM_d \]  

where

\[ M_m = \text{moisture multiplier} \]
\[ M_t = \text{temperature multiplier} \]
\[ M_d = \text{damage multiplier} \]

Thompson (1972) developed equations for each multiplier for specific ranges of moisture and temperature, based on data from Steele (1967).

Ambient-air corn drying is a slow (three to six weeks), in-storage drying process usually carried out within a cylindrical bin equipped with a full perforated floor and a positive-pressure, electric motor-driven fan. Because the process extends through most of the corn's allowable storage time, the corn can be at risk of spoilage during natural air drying. Fungicide treatment at harvest has the potential to reduce spoilage risk by extending the corn's allowable storage time (Al-Yahya et al., 1993; Wilcke et al., 1993; White et al., 1988).

Computer simulation models of ambient-air drying have been used to predict minimum airflow needed to dry corn without excessive dry matter loss (Thompson, 1972; Morey et al., 1976; Van Ee, 1980; Wilcke, 1985; Stroshine and Yang, 1990). Procedures to account for harvest date, location, moisture content, weather data, corn mechanical damage level, and variety have been developed, but none of the models account for effects of fungicide treatment.

Stroshine and Yang (1990) modified the model developed by Thompson (1972) and used it to investigate the effects of kernel mechanical damage and hybrid traits on 22% moisture corn aerated at 2.23 m3/min-Mg (2.0 cfm/bu). To do this, hybrid multiplier, \[ M_h \], was added to equation 2. They developed hybrid multipliers, which account for a hybrid's resistance or susceptibility to storage fungi, using the data of Friday (1987) and Friday et al. (1989). Friday quantified the storage fungi resistance of several corn hybrids by use of CO2 evolution measurements on stored samples. Of hybrids tested, DF20×DF12 was susceptible and FR35×FR20 was most resistant to storage fungi.
Treat-

ment

Ysc

Yrc

Ysf

Yrf

\[ Y = gofCO_j \text{ produced per kg of dry matter.} \]
\[ t = \text{time (h).} \]
\[ Sc = \text{Susceptible control (untreated).} \]
\[ Re = \text{Resistant control (untreated).} \]
\[ Sf = \text{Susceptible, with fungicide (Rovral treated).} \]
\[ Rf = \text{Resistant, with fungicide (Rovral treated).} \]

Incorporating Des Moines, Iowa, weather data for the years 1963 through 1983, Wilcke (1985) developed the NADWIS (natural-air drying with stirring) simulation program. Wilcke’s model is based on Van Ee’s FALDRY model (Van Ee, 1980) and Morey’s model (Morey et al., 1976), which has developmental roots in Thompson’s storage model (Thompson, 1972). Wilcke’s model can be used to predict minimum airflow requirement, fan energy use, and dry matter loss for corn dried during the 20-year period using bins with or without heat or stirring equipment. It incorporates a variable airflow feature, which adjusts airflow upward by up to 20% in response to airflow resistance changes during drying.

OBJECTIVES

The objectives for this study were:

• Develop an ambient-air drying simulation model which accounts for effects of hybrid traits and fungicide treatments in corn. 

• Predict dry matter loss, minimum airflow requirements, and fan energy when drying both resistant and susceptible corn hybrids treated with various levels of Rovral® fungicide and based on historical ambient-air conditions for central Iowa.

LABORATORY STUDY

LABORATORY TEST PROCEDURE

Two corn hybrids, one susceptible (DF20xDF12) and one resistant (FR35xFR20), were planted in May 1990 at the Agronomy and Agricultural Engineering Research Center, 14 km west of Ames, Iowa. Both hybrids were hand harvested and hand shelled in October 1990 when they reached about 22% moisture (wet basis). Foreign material and broken corn kernels were removed. Total kernel mechanical damage was not measured, but was estimated to be 3%. There was no visible mold damage. Samples were placed in an apparatus allowing measurement of CO2 evolved during aerated storage at about 22% moisture. See Al-Yahya et al. (1993) and Al-Yahya (1991) for details of the CO2 test apparatus and fungicide treatments. Samples weighing 150 g were taken from every treatment when dry matter loss reached 0%, 0.5%, 1%, and 2% in the untreated susceptible corn hybrid for the analysis of moisture content, germination, visible fungi, and percent fungi infected by Aspergillus spp and Penicillium spp. See Al-Yahya (1991), for procedural details of the fungal growth analysis.

LABORATORY TEST RESULTS

Carbon dioxide-versus-time equations fitted to two replications of laboratory test results are listed in table 1. The equations represent four treatments studied which had the greatest effects on corn deterioration—a susceptible and a resistant hybrid with and without Rovral treatment.

COMPUTER SIMULATION PROCEDURES

Wilcke’s computer model (Wilcke, 1985) was modified to allow simulation of ambient-air drying of corn under all of the conditions defined by the equations of table 1. This new model, hereafter the Al-Yahya model, accounts for effects of kernel mechanical damage, hybrid trait, and fungicide treatment by applying appropriate multipliers to its calculated deterioration rates. Weather data for 1984 through 1989 were obtained from the National Climatic Data Center, Asheville, North Carolina, so that drying could be simulated for any year in the period 1963 through 1989. Otherwise, the model is the same as described by Wilcke and Bern (1986). See Al-Yahya (1991) for a listing of the Al-Yahya model.

PROGRAM INPUT

The model simulated corn drying in a 5.5-m (18-ft) diameter bin at a depth of 4.6 m (15 ft). The model used 10

| Table 1. Carbon-dioxide production equations for treated and untreated susceptible and resistant corn hybrids (Al-Yahya et al., 1993) |
|---|---|---|
| Treatment | Equation | R^2 | t,h |
| Ysc | 0.004376(t) + 0.0001185(t^2) - 0.00000004(t^3) | 0.95 | 2.6 |
| Yrc | 0.02035(t) - 0.00002262(t^2) + 0.00000001(t^3) | 0.96 | 1.5 |
| Ysf | 0.01570(t) - 0.00001007(t^2) + 0.00000009(t^3) | 0.95 | 1.6 |
| Yrf | 0.01603(t) - 0.00002076(t^2) + 0.00000007(t^3) | 0.96 | 1.1 |

| Table 2. Hybrid multipliers |
|---|---|---|
| Hybrid | Susceptible (DF20xDF12) | Resistant (FR35xFR20) |
| Damage level (%) | 3 | 3 |
| Storage time for 0.5% DML (h) | 328 | 262 |
| Hybrid multiplier, M_h | 1.25 | 0.91 |
| Predicted storage time (h) from Steele (1987) | 381 | 278 |
| Friday (1987) | 420 | 292 |

| Table 3. Fungicide multipliers |
|---|---|
| Hybrid |Susceptible (DF20xDF12) | Resistant (FR35xFR20) |
| Damage level (%) | 3 | 3 |
| Storage time for 0.5% DML (h) | 420 | 360 |
| Fungicide multiplier, M_f | 1.33 | 1.46 |
| Predicted storage time (h) from Steele (1987) | 506 | 405 |
| Friday (1987) | 558 | 426 |

| Table 4. Predicted minimum airflow rates and relative fan power requirements for not over 0.5% DML 23 of 26 years in Central Iowa |
|---|---|---|---|
| Corn Hybrid | Moisture | Susceptible | Resistant | Generic |
| | | 20% | 24% | 20% | 24% | 20% | 24% |
| Airflow (m^3/min-Mg) | 1.0 | 0.70 | 3.2 | 1.9 | 0.78 | 2.8 | 1.4 | 0.89 | 2.8 |
| (cfm/bu) | 0.90 | 0.65 | 2.9 | 1.7 | 0.70 | 2.5 | 1.3 | 0.80 | 2.5 |
| Fan power index‡ | 1.2 | 0.76 | 1.0 | 4.4 | 0.87 | 2.1 | 4.8 | 2.6 | 1.0 | 8.3 |

* With no fungicide treatment (NT).
† With fungicide treatment (T).
‡ Relative to generic hybrid at 20% moisture. All values computed assuming a corn depth of 4.6 m (15 ft) and a Shedd’s curve multiplier of 1.5.
layers and a harvest date of 15 October for all runs. Simulations were completed for moisture contents of 20 and 24%. Many Iowa farmers harvest corn at about 20% moisture for natural air drying. Wilcke (1985) stated that 24% is the practical moisture limit for ambient-air dried corn in single-fill bins. An initial grain temperature of 10°C (50°F) was assumed to approximate the outdoor air temperature on the 15 October harvest date.

Fan input power was assumed constant through each run. Airflow was changed in 0.056-m³/min-Mg (0.05-cfm/bu) increments between runs. Only ambient-air drying was considered, so supplemental heat inputs were zero in all runs. Desired final average and maximum moisture contents were 15.5% for all runs.

**PREDICTION OF CO₂ PRODUCTION**

The damage multiplier equation developed by Stroshine and Yang (1990) using data from Steele (1967) was used to predict Mₜ for equation 2:

\[
Mₜ = 1.97e^{-0.0199d}
\]  

where \(d\) represents damage level (%).

Hybrid multipliers were computed using data from Al-Yahya et al. (1993) for resistant and susceptible hybrids. These multipliers were computed using the equation:

\[
Mᵢ = \frac{t}{(230) \ Mₜ Mₘ M_d}
\]  

where \(Mᵢ\) is the hybrid multiplier. Values of \(Mᵢ\) are listed in Table 2 along with storage times for this study and those predicted using equations from Steele (1967) and Friday (1987). The \(Mᵢ\) values are averages of \(Mᵢ\) calculated at 12-h intervals from \(t = 100\) h to the 0.5% DML time. Times for the other studies were adjusted to conditions of the current study, i.e., 26°C (78.8°F) storage temperature, 21.6% corn moisture, 3% mechanical damage. The Steele data were also adjusted to account for hybrid susceptibility and resistance using the \(Mᵢ\) values listed. For conditions when neither a resistant nor a susceptible hybrid was being considered, a generic hybrid condition (\(Mᵢ = 1\)) was assumed.

Fungicide multipliers were also computed using data from Al-Yahya et al. (1993) and equation 5:

\[
Mᵢ = \frac{t}{(230) \ Mₜ Mₘ M_d}
\]
Al-Yahya et al. (1992) found no significant differences among four Rovral treatments tested (Rovral + water, Rovral + water + oil, Rovral + water + 1/2 oil, Rovral + water + activator 90 surfactant), so the pooled data of the four treatments were used to compute values of $M_F$. Values of $M_F$ for the susceptible and resistant hybrids are listed in table 3, along with storage times for this study and those predicted using equations from Steele (1967) and Friday (1987). For untreated corn, $M_F$ was assumed to be equal to unity. The calculation procedure described in the previous paragraph was used here also. Wilcke et al. (1993) reported $M_F$ values of 1.1 to 1.2 for 22% moisture Pioneer 3475 treated with 15 or 20 ppm Iprodione.

Values for multipliers in tables 2 and 3 will be within 0.01 of table values assuming times to 0.5% dry matter loss are within two standard deviations of values observed in this study.

**COMPUTER SIMULATION RESULTS**

For successive runs with 26 years of weather data, airflow was increased in 0.056 m$^3$/min-Mg (0.05 cfm/bu) increments until drying was completed in at least 23 of the 26 years simulated with ≤ 0.5% dry-matter loss in the worst layer (88% probability of drying success), or drying was not completed by 20 May. Simulated ambient air drying results for generic and for both treated and untreated susceptible and resistant corn hybrids harvested mid-October in central Iowa at both 20 and 24% moisture contents are shown in tables 4 through 8.

**AIRFLOW AND FAN POWER**

Table 4 shows predicted minimum airflow and relative fan power for each condition. For the untreated generic hybrid ($M_F = 1, M_h = 1$), the minimum airflow requirement was 0.89 m$^3$/min-Mg (0.8 cfm/bu) for 21% and 2.8 m$^3$/min-Mg (2.5 cfm/bu) for 24% moisture. This corresponds closely with the recommendation from MWPS (1980) for Central Iowa which is 1.1 m$^3$/min-Mg (1.0 cfm/bu) for 21% moisture and 2.8 m$^3$/min-Mg (2.5 cfm/bu) for 24% moisture corn.

In every case, resistant hybrid airflow requirement is less than and susceptible hybrid airflow requirement is greater than that required for the generic hybrid. Likewise, in every category, the 20% moisture airflow requirement is less than that for 24% moisture and the airflow requirement for treated is less than that for not treated. The effect of fungicide treatment on airflow was slightly larger than the effect of susceptible versus resistant hybrid. Fan power requirements were computed relative to generic corn, assuming a 4.6 m (15 ft) depth with a multiplier of...
This multiplier was applied to account for any packing and fine material effects. 1.5 applied to Shedd’s resistance to airflow data for shelled corn (Shedd, 1953). This multiplier was applied to account for any packing and fine material effects.

**ENERGY, DRY MATTER LOSS, AND FINISH DATE**

Tables 5 through 8 show fan energy, maximum dry matter loss, and finish date for each of the 26 years simulated, for each of the 10 scenarios at their airflows as listed in table 4. From these tables, note that:

- Average maximum dry matter loss does not vary much among the six scenarios.
- At each moisture level, resistant corn used the least fan power, on average, followed by generic and susceptible.
- Fan energy for 24% moisture was two to 14 times that for 20% moisture, in comparable scenarios.
- Drying was never completed in the fall on the 20% moisture corn and in some years was not completed by the 20 May cutoff. The susceptible hybrid, which required higher airflow, was most likely to be finished by 20 May, followed by the generic and then resistant hybrid.

Extending allowable storage time by use of resistant hybrids and/or application of fungicide offers the possibility of safely storing 20 to 24% moisture corn with aeration from harvest to mid-May in central Iowa.

**USE OF SIMULATION RESULTS**

It is important to note that hybrid and fungicide effects predicted in this simulation study are based on laboratory tests at about 22% moisture. These effects are assumed to be the same as the corn dries down to 15% moisture. At these lower moisture levels, different fungi may be active, and effects may be different. Additional research is needed to determine the magnitude of differences.

**CONCLUSIONS**

These conclusions can be drawn, based on computer simulation incorporating 26 years of Des Moines, Iowa, weather data:
Compared to a generic hybrid, the resistant hybrid required 20% lower airflow, 28% lower fan power, and 20% less fan energy, and the susceptible hybrid required 14% higher airflow, 22% higher fan power, and 12% more fan energy.

Compared with untreated corn, corn treated with Rovral required on average 40% lower airflow, 54% less fan power, and 47% less fan energy.

REFERENCES