TECHNICAL NOTE:

EFFECT OF DRYING CONDITIONS ON TRITICALE SEED GERMINATION AND RICE WEEVIL INFESTATION

M. K. Khedher Agha, R. A. Bucklin, W. S. Lee, R. W. Mankin, A. R. Blount

ABSTRACT. *The combination of high protein content and a soft seed coat makes the wheat-rye hybrid Triticale (Triticosecale) vulnerable to attack by rice weevils. Drying triticale grain to moisture contents safe for storage can prevent infestation by rice weevils, but if grain is being stored for seed, high drying temperatures can affect seed germination. Grain can be effectively dried at low temperatures, but low-temperature drying is difficult in hot, humid regions such as the Gulf Coast. This study investigated the effects of drying temperatures from 35°C to 45°C on triticale seed germination and found no statistical differences between the germination rates of the seed at any of the drying temperatures and the germination rates of controls. Final moisture contents after drying ranged from 7.9% wet basis (w.b.) at 45°C for 48 h to 9.7% w.b. at 35°C for 24 h. New generations of rice weevils appeared in the control samples maintained at 23°C and 13.8% or 13.9% w.b. but were not observed in grain dried at any of the drying treatments. The results of this study showed that triticale seed can be dried to moisture contents that effectively control rice weevil infestation in hot, humid climates without significantly affecting germination rate.*

Keywords. *Drying, Rice weevil, Seed germination, Stored products pests, Triticale.*

Triticale (*Triticosecale*) is a disease-resistant wheat-rye hybrid that is well adapted to drought and difficult soils (Salmon et al., 2004). World production of triticale was 17.0 million metric tons in 2014 (FAOSTAT, 2014). U.S. production of triticale was 78,000 metric tons in 2012, up from 21,000 metric tons in 2002 (USDA, 2012). Triticale grain has a high content of the amino acid lysine and is used as a component of livestock feed rations; however, in Florida, triticale is grown mainly for forage. The University of Florida's North Florida Research and Education Center (NFREC) in Quincy, Florida, conducts long-term research to develop new varieties of triticale suitable as winter forage for beef cattle.

The combination of high humidity and warm temperatures during storage in Florida provides an optimum climate for rapid growth of both mold and insects. The combination of a soft seed coat and high protein content makes stored triticale seed highly vulnerable to insects, including the rice weevil, *Sitophilus oryzae* (L.) (Dobie and Kilminster, 1978). Drying seed in the warm, humid climate of northern Florida is problematic because seed viability is reduced at the high drying temperatures recommended to dry grain under conditions of high humidity (Brooker et al., 1992; Loewer et al., 1994). Rice weevil infestations of triticale seed at the NFREC are currently controlled by fumigating with pesticides. Determining optimum drying conditions can provide information needed to help reduce losses of seed and reduce the use of pesticides.

Most of the available literature dealing with optimum grain moisture contents for storage deals with weather conditions similar to those in the Midwestern U.S., and little information is available on optimum storage moisture contents for triticale seed in any climate. Triticale is a hybrid of wheat and rye, so drying recommendations for wheat are the best information currently available. Ross et al. (1973) gave a general recommendation that grain at 38°C be stored below 11.8% moisture content. Maier and Bakker-Arkema (2002) recommended wheat moisture contents of 10% for storage for more than one year in the southern U.S. All moisture contents are given as wet basis (w.b.). Khedher Agha et al. (2014) determined isotherms for triticale and developed a method to determine the degree of rice weevil infestation of triticale using NIR spectroscopy (Khedher Agha et al., 2013), but little other information is available in the literature relating to drying and storing triticale.

The objective of this study was to determine if low-temperature drying of triticale seed could successfully prevent rice weevil infestation while also maintaining seed viability.

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Table 1. Age of rice weevil adults for each replication.

Replication	Adult Age at Start of Test
1	54 to 59 days
2	59 to 64 days
3	62 to 67 days

Materials and Methods

The Trical 342 variety of triticale used in this study was harvested, threshed, and cleaned at the University of Florida's North Florida Research and Education Center at Quincy, Florida, in May 2012. The seed was kept sealed in a cold storage facility at 5°C until use. The seed was cleaned a second time using an air cleaner. The seed samples were mixed for uniformity before starting the experiment in 2014. The samples were kept sealed at room temperature of 23°C for one to four days before each drying experiment was started.

Rice weevils were reared at the USDA-ARS Center for Medical, Agricultural, and Veterinary Entomology at Gainesville, Florida. The age of the adults at the time of the experiment was 54 to 70 days. Each replication consisted of a different rice weevil age group, as shown in table 1. The insects were kept in a controlled chamber at 23°C and 55% relative humidity (RH) from emergence until the day the experiment began.

Two gravity convection ovens were used as low-temperature dryers to produce a range of grain moisture contents. A proportional integral derivative (PID) controller was used to control the temperatures in the ovens using J-type thermocouples located in the center of the seedbed as temperature sensors. The average airflow rate of 1.5 $m^3 s^{-1}$ was calculated based on the average velocities for five-point grids across the air inlets and exhausts of the ovens. A 2 kg sample of triticale seed was placed in a basket, as shown in figure 1. The basket was made from perforated screen and had dimensions of 27.5 cm width, 28 cm length, and 8 cm depth, with 2 mm square openings. The depth of the seedbed was 2, 2.7, and 3.5 cm for drying durations of 24, 48, and 96 h, respectively. Additional details can be found in Khedher Agha (2014).

Figure 1. Drying chamber with screen basket.

Environmental Chambers

Two environmental chambers were used as storage areas for the samples after drying. The first chamber, the low-humidity chamber (LH) chamber, was kept at 23°C and 35% RH to observe the effects of a low-humidity environment on seed germination and insect mortality. Temperature in the LH chamber was controlled using a PID temperature controller. Glycerin (99.7% concentration) was used to control RH inside the LH chamber. The second chamber, the high-humidity (HH) chamber, was kept at 23°C and 55% RH to study the effects of high-humidity environments on seed germination and insect mortality. The temperature and RH of the HH chamber were controlled using PID controllers. The RH controller operated a small air pump that pumped air through deionized water kept in a glass flask.

A data logger was used to monitor the temperatures of the germinator, driers, inlet air, LH chamber, and HH chamber. Type-T, 24 AWG thermocouples were used to monitor air temperature. These thermocouples were placed under, inside, and above the seedbed, in the air inlet, in the germinator, and in LH and HH chambers.

Seed moisture contents were determined using a convection oven at 130°C for 19 h following the procedure for wheat given by ASABE Standard S352 (ASABE, 2012). Grain was stored in a sealed container to keep the samples at the desired moisture content.

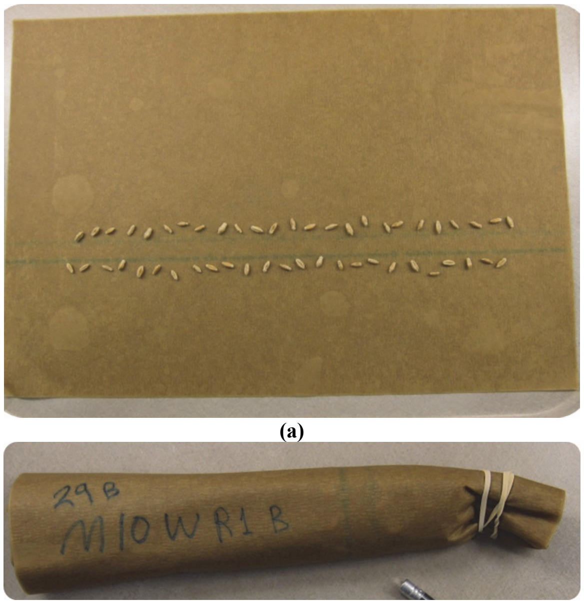
Seed Germination

Seed germination tests were conducted using the procedure of the Association of Official Seed Analysts (AOSA, 2013). Seed germination paper (25.4 cm wide × 38.1 cm long) was used as a substrate to provide the optimum amount of moisture and air to the seed for germination. The germination paper was submerged in water and then pressed with a wood roller on a tilt board to keep the minimum amount of water in the paper required to provide seed with the optimum amounts of air and moisture. Seeds were counted using a vacuum apparatus with 50 small holes in a plastic board. Two rows of 25 holes each were arranged evenly in a zigzag pattern.

Two germination papers were placed under the seed, and then the seed was placed on the lower third of the paper, and covered with another sheet. The papers were then rolled together, as shown in figure 2. The roll was placed in a plastic container covered with a plastic bag to prevent evaporation and was then placed in a germinator, which kept the seed between 15°C and 20°C. After seven days, the seeds were counted manually to determine the germination percentage. Following the AOSA-recommended procedure, the germinated seeds were inspected to identify normal versus irregular germination. The procedure was repeated twice to provide a total of 100 seeds. A photo was taken as a record for each germination result.

Rice Weevil Mortality

One hundred adult rice weevils were placed along with



(a)

(b)

Figure 2. Germination paper (a) before rolling with 50 triticale seeds and (b) after rolling.

200 g of dried seed for each moisture content in a transparent plastic container to measure the effect of dried seed on rice weevil mortality. A screen was mounted in the middle of the container cover. After placement of the seed and adult weevils, the container was kept in a controlled environmental chamber at 23°C. Treatment samples were kept at 35% and 55% RH as control samples. Each week, mortality tests were conducted using two sets of U.S. standard sieves with 1 and 2 mm openings for separating insects from seed. Live insects were collected and counted using a vacuum insect counter apparatus. Dead insects were counted manually using tweezers. They were placed on white paper and monitored for 5 to 10 min to determine if any insects were feigning death. The percentage of mortality was then calculated, and a photo was taken of each sample as a record.

This procedure was repeated each week for each sample. After six weeks, the mortality percentage was calculated. During the same period, live insects were also counted and monitored to determine if any new generations had emerged.

Treatment Design and Statistical Analysis

The effects of drying temperature, drying duration, and moisture content on the seed germination index and insect mortality were observed. The seed was dried at three different temperatures (35°C, 40°C, and 45°C) to produce the grain moisture contents shown in table 2 in order to test the effects of drying triticale seed on seed germination and insect mortality. The experiment used a completely randomized design with a split-split plot design with three factors (drying temperature, drying duration, and moisture content). Three replications were conducted. The experimental unit was 100 adult insects of the same age placed with each 200 g sample of seed.

Table 2. Drying temperatures, drying durations, and moisture contents for tests of drying effects on seed viability.

Drying Temperature (˚C)	Drying Duration (h)	Moisture Content (% w.b.)
35°C	24	9.7
	48	9.2
	96	9
40°C	24	9.1
	36	8.8
	48	8.6
45°C	12	9.7
	24	8.6
	48	7.9
23°C at 35% RH	24 to 96	13.9
23°C at 55% RH	24 to 96	13.8

The data obtained from the drying experiments were analyzed using PROC GLM in SAS (ver. 9.4, SAS Institute, Inc., Cary, N.C.) to test pairwise comparisons between the means of significant treatments using the Tukey-Kramer method for multiple comparison procedures.

Results and Discussion

Seed Germination

Germination tests showed that there were no significant differences between drying treatments ($p = 0.59$). Drying at temperatures of 35°C, 40°C, and 45°C did not affect the germination rate of the triticale seed, as shown in table 3. Germination rates for six of the eight replications were close to 89%, with high and low values of 90% and 84%.

Rice Weevil Mortality

All treatments of dried grain moisture contents caused high mortality percentages (≥99.7%) after seven weeks. It was also observed that during the two weeks of exposure to dried grain at 7.9% moisture content, mortality was 92%, as compared with 15% for the control treatment. Storage in the LH chamber as a control also produced a high mortality rate of 93%. Even the HH control treatment without drying showed a high mortality rate of 73.7%, as shown in table 4.

The high mortality percentages resulted not only from drying but also from the natural mortality of adult insects, which reached an average age of 110 days including the 49-day period spent measuring mortality after completion of the drying tests. At the end of the 49-day period of observing mortality, a new generation of adults began to emerge from the seed of some treatments.

Results for the new generation were recorded and analyzed. There were highly significant differences between dried grain moisture treatments, as shown in table 5. The sig-

Table 3. Effects of drying temperature and drying duration on triticale seed germination (%, with standard deviations shown in parentheses).

	Drying Duration					
Drying Temperature	12 h	24 h	36 h	48 h	96 h	No Drying
35°C	-	90.3 (2.5)	-	87.6 (3.0)	89.7 (1.9)	-
40°C	-	89.9 (3.6)	90.0 (2.2)	88.5 (1.8)	-	-
45°C	89.1 (2.0)	89.5 (3.4)	-	88.7 (3.5)	-	-
Low-humidity control	-	-	-	-	-	89.5 (2.8)
High-humidity control	-	-	-	-	-	90.7 (3.0)

Table 4. Effects of drying temperature and triticale seed moisture content on insect mortality (%, with standard deviations shown in parentheses). Values followed by the same letter are similar.

Drying Temperature	Seed Moisture Content 7.9%	8.6%	9.1%	9.7%	No Drying
35°C	-	-	99.7 (0.6) ab	100.0 (0.0) a	-
40°C	-	100.0 (0.0) a	99.3 (1.2) ab	-	-
45°C	99.7 (0.6) ab	100.0 (0.0) a	-	99.7 (0.6) ab	-
Low-humidity control	-	-	-	-	93.0 (7.2) b
High-humidity control	-	-	-	-	73.7(2.5) c

Table 5. Tukey comparison of treatments for new-generation adults.

Difference Level[a]	Mean No. of New-Generation Adults	Treatment	LSMEAN
A	323	23°C, 55% RH, 13.9% MC	10
A	205	23°C, 35% RH, 13.8% MC	12
B	4	35°C, 24 h, 9.7% MC	1
B	1	35°C, 48 h, 9.2% MC	2
B	0.3	35°C, 96 h, 9.0% MC	3
B	0	40°C, 24 h, 9.1% MC	4
B	0	40°C, 36 h, 8.8% MC	5
B	0	40°C, 48 h, 8.6% MC	6
B	0	45°C, 12 h, 9.7% MC	7
B	0	45°C, 24 h, 8.6% MC	4
B	0	45°C, 48 h, 7.9% MC	9

[a] Difference levels with the same letter are not significantly different.

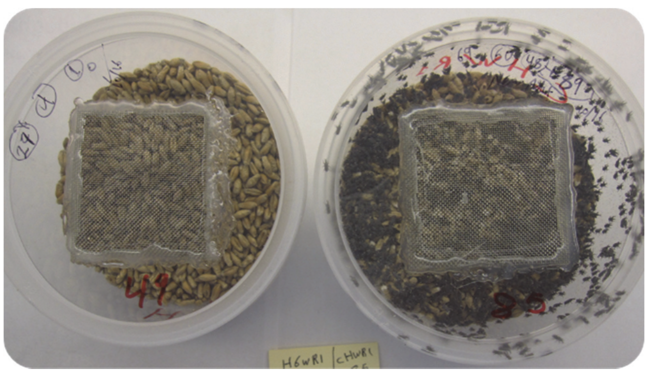


Figure 3. Seed samples (left) with drying treatment and (right) without drying treatment showing a new generation of rice weevils emerging.

nificant differences between mean weevil mortalities were between the control (LH and HH at the same level) and the rest of the treatments. All the dried grain moisture content treatments had no more than four new-generation adult weevils, while 200 to 400 new-generation adult weevils emerged from the control treatments. This result explains the effect of dried grain moisture content treatment in the long run; within only two months, the control treatments showed three times the quantity of new-generation weevils, while the dried treatments resisted infestation by a new generation of weevils.

Figure 3 displays the typical difference between samples with and without drying treatment. There were initially 100 rice weevil adults in both containers. The left container was dried to 8.6% MC, and the right container was not dried. After two months, all insects were dead in the dried sample. In the sample that was not dried, a new generation of insects emerged, with three times the original number of insects.

Conclusions

This study investigated the effects of drying temperatures of 35°C to 45°C on triticale seed germination and found that there were no statistical differences between the germination rates of the seed at any of the drying temperatures and the germination rates of controls. Final moisture contents after drying ranged from 7.9% at 45°C for 48 h to 9.7% at 35°C for 24 h. New generations of rice weevils appeared in the control samples maintained at 23°C and 13.8% or 13.9% but were not observed in grain dried with any of the drying treatments. The results of this study showed that it is possible to dry triticale seed to moisture contents lower than those recommended by Ross et al. (1973) and Maier and Bakker Arkema (2002) for warm climates (11.8% and 10%, respectively) while also maintaining seed viability. As expected from the drying recommendations for other grains (Ross et al., 1973; Brooker et al., 1992; Loewer et al., 1994), drying triticale seed to moisture contents of 7.9% to 9.7% effectively controlled infestation by rice weevils.

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