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Equilibrium Moisture Content of Triticale Seed

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Abstract. *Triticale is being studied as a substitute for corn in animal feed and as a forage crop for Florida. Storage of triticale seed is difficult in Florida's climate, and more information about equilibrium moisture content (EMC) relationships of triticale is needed to develop improved storage methods. Therefore, the research objective was to measure the EMC for triticale seed and to determine the best fit equation representing the EMC. This study measured the EMC of triticale at three different temperatures 5, 23, and 35°C using a static method using six desiccation jars with six different salt concentrations. These salts provided relative humidities (RH's), of 11, 23, 33, 58, 75, and 84% at 25°C. An average of ten weeks was required to reach equilibrium when the initial moisture content (MC) of the seed was 13% (wet basis). The results of this experiment were used to develop a prediction algorithm representing the relationship between RH and EMC with coefficient of determination (R^2) equal to 0.99. It was also found that the Modified Henderson equation represents this relationship accurately. Overall, this result will aid the development and improvement of drying and storage methods for triticale seed.*

Keywords.*EMC curve, Static method (desiccation jars), Water activity, Moisture content, Sorption Isotherm.*

Introduction

Triticale, *Triticosecale*, is a hybrid of wheat and rye. Global production of triticale in 2008 exceeded 14 million metric tons (Hansen, 2011). Meanwhile, USA production of triticale in 2007 was 52 thousand metric tons (USDA, 2009). Triticale grown in Florida is mainly for forage used as animal feed. The University of Florida's North Florida Research and Education Center (NFREC) in Quincy conducts research with triticale and has problems with drying and storing seed.

There has been little research on the Equilibrium moisture content (EMC) of triticale seed, so it is important to measure isotherms for triticale that can be used to develop algorithms to predict EMC relationships. The goal of this project was to create EMC curves for triticale seed at different temperatures and develop best fit algorithms to describe the EMC of triticale.

Material and methods

Sampling and testing

Triticale seed samples harvested in May 2012 were obtained from the NFREC. The seed was cleaned using standard US sieves. Manual inspection was also used to insure the purity of the seed from foreign materials. The static method was used in this experiment to measure the EMC, where the seed randomly sampled into six desiccating jars with three replications (Figura and Teixeira, 2007). The jars were sealed with glue to keep the seed in a controlled RH environment. The six salts listed in table 1 provided RH's from 11-84% at 23°C.

Table 1. List of the salt's types and corresponding relative humidity at each temperature

Jar Number	1	2	3	4	5	6
Salts Types	LiCl	$KC_2H_3O_2$	$MgCl_2$	NaBr	NaCl	KCl
RH % at 5°C	11.26	23.8	33.6	63.5	75.65	87.67
RH % at 23°C	11.3	22.8	32.93	58.4	75.39	84.7
RH % at 35°C	11.25	21.3	32.1	54.6	74.87	82.95

The seed samples and the saturated salt solutions were kept in the jars until each sample reached equilibrium. Sample initial weights were between 9-12g. Samples were weighed frequently until weight differences between measurements were less than 0.01 g. The time to reach equilibrium was approximately 10 weeks and it took nine months to do the three runs with different temperatures. All weight measurements were made with a Mettler AE 200 electronic balance (Mettler-Toledo Inc., Columbus, OH.) with capacity 205 g, readability 0.1 mg, and reproducibility ± 0.1 mg. After the samples reached equilibrium, the moisture contents (MC) were measured using the same procedure for wheat in given by ASAE S352.2 Standard (R2008) (ASABE, 2013) using a natural convection oven. The experiment was repeated three times with three different temperatures 5, 23 and 35 ° C in order to observe the effect of different temperatures on the EMC by conducting tests conducted in environments controlled to 5, 23 and 35℃ temperatures. Data loggers were used to monitor the temperatures and RH's outside and inside the jars.

Analysis Method

The observed data set was analyzed using the Psi-Plot program (Poly Software International.com, Pearl River, NY) and the SAS program version 9.2 (SAS Institute Inc. Cary, NC, USA). Modified Henderson and Chung-Pfost were used to develop EMC curves for triticale seed to be compatible with ASABE Standard D245.5 (R2001) (ASABE, 2013)

Modified Henderson equation $$RH = 1 - e^{-A*(T+C)*(MC_D)^B} \quad (1)$$

Modified Chung-Pfost equation $$RH = e^{\left[\left\{\frac{-A}{T+C}\right\}*e^{\left(-B*MC_D\right)}\right]} \quad (2)$$

Where RH = relative humidity, T = temperature, MC_D= dry-basis moisture content, and A, B, C are constants.

Data were examined, tested and evaluated using the graphic method, where the measured vs. predicted RH were drawn in one chart and based on the Coefficient of Determination (R^2) values to determine the best fit.

Figure 1. Triticale samples in the Desiccation jar and the electronic scale used to weigh the samples.

Results and discussion

Measured EMC

The EMC vs. ERH data are illustrated in figure 2, for the three different temperatures 5, 23, and 35ºC. This figure shows that EMCs for 5°C temperature were highest compared with the other temperatures, while EMCs for 35°C were lowest.

Method of prediction

Modified Henderson (MHE) and modified Chung-Pfost equations (MCE) were used to predict the RH for triticale seed representing three temperatures. Figure 3 shows the isotherm prediction curve using MHE for triticale seed at 35ºC, where the measured values match predictions smoothly and the R^2 between measured and predicted RH at each temperature was 0.9964.

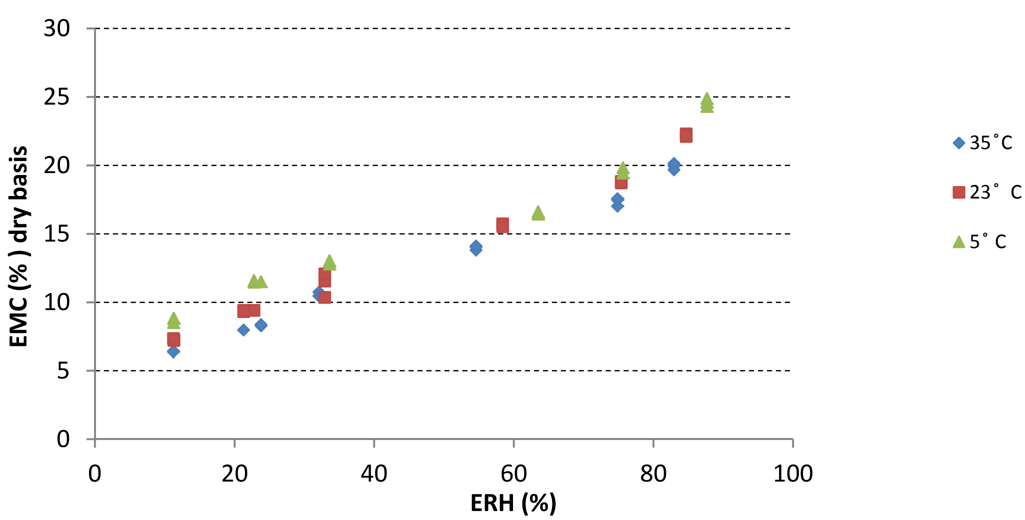

Figure 2. Raw EMC data (Sorption Isotherms) curves for Triticale Seed at three temperatures 5, 23, and 35ºC

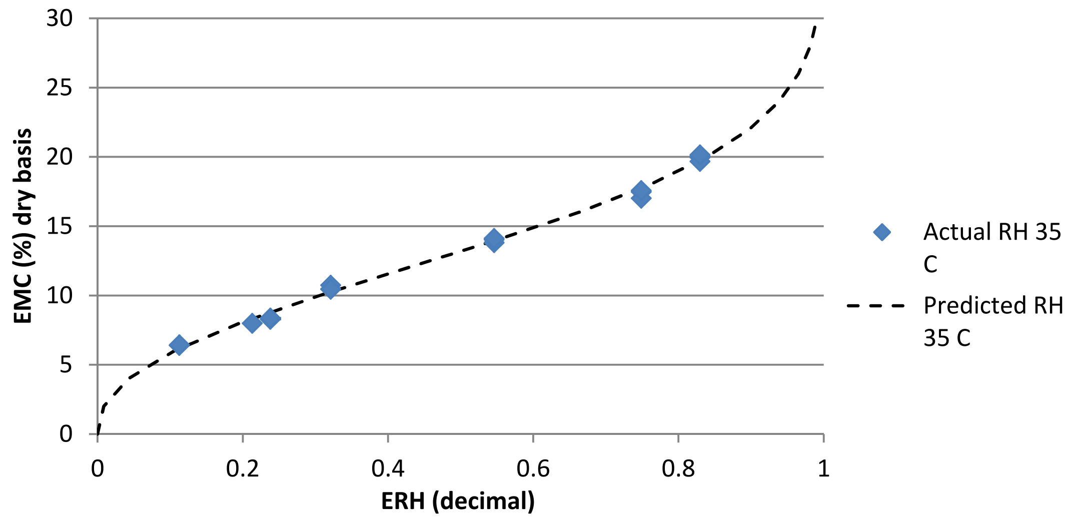

Figure 3. Comparison between predicted using modify Henderson and actual EMC for triticale at 35º C

The relationship between measured and predicted RH illustrated using coefficient of determination at three temperatures was shown in table 2. The highest R^2 value was MHE at 35ºC as shown in figure 4 and the lowest R^2 was MHE at 5ºC. MCE predictions for 5, and 23ºC were better than MHE and MHE was better than MCE at 35ºC. However both methods resulted in satisfactory predictions with all values of R^2 over 0.98.

Table 2. Coefficient of determination (R^2) between measured and predicted RH at each temperature

Temperatures (º C)	5	23	35
Modified Henderson	0.9835	0.9936	0.9964
Modified Chung-Pfost	0.9934	0.994	0.9945

Figure 4 represents the goodness of fit. The points follow the diagonal meaning that the measured vs. predicted RHs are similar values.

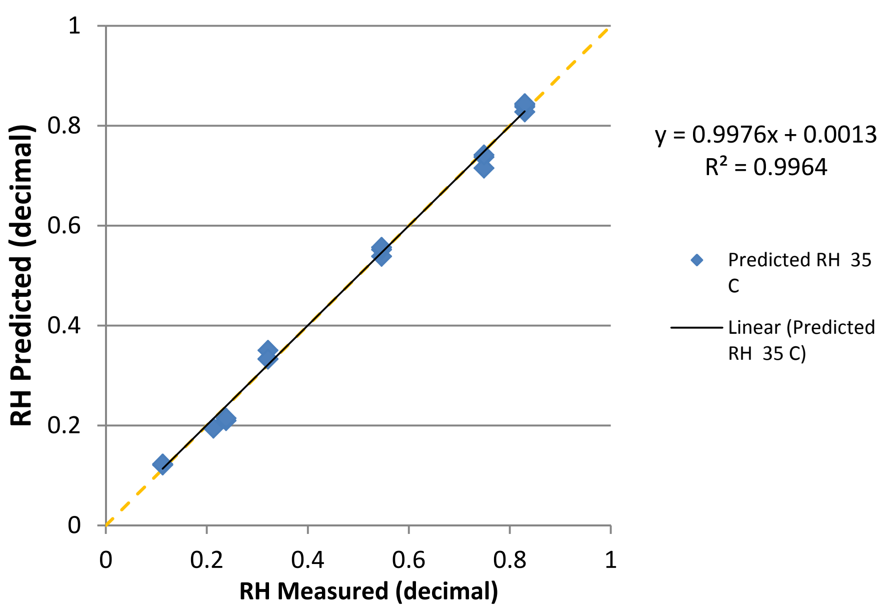

Figure 4. Comparison between measured vs. predicted RH using Modified Henderson for triticale at 35ºC

The constants for MHE and MCE are listed in table 4, where the constant A was similar for different temperatures. But the other constants varied between -33.5584 and 24.78.

Table 3. Constants for EMC equations at each temperature

Temperatures(ºC)	5			23			35		
Constants	A	B	C	A	B	C	A	B	C
Modified Henderson	2.9E-5	2.838	5.2604	2.9E-5	2.3744	20.0497	2.9E-5	2.3235	24.7811
Modified Chung-Pfost	10	0.197	-4.2498	10	0.1687	-21.6452	10	0.1784	-33.5584

The effect of the temperature on the sorption isotherm curve is shown in figure 5, where the effect of lower temperature was greatest. The predicted curves for MHE gave a smooth fit with R^2 between 0.9835, 0.9936, and 0.9964 for the three temperatures 5, 23, and 35ºC respectively.

Figure 6 shows the prediction curves using MCE. The predicted curves fit measured points smoothly with R^2 values of 0.9934, 0.994, and 0.9945 for the three temperatures 5, 23, and 35ºC respectively. MCE curves have R^2 values higher than MHE for 5 and 23ºC.

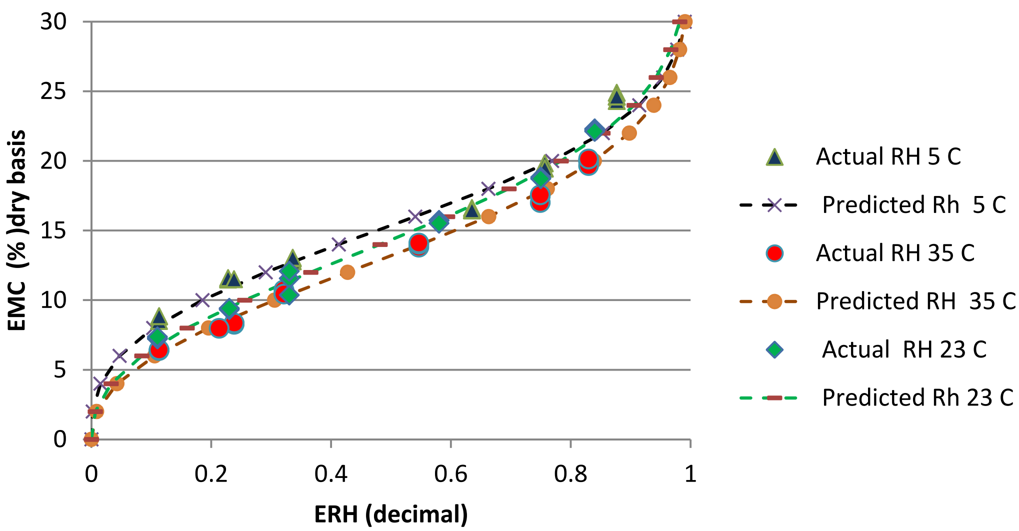

Figure 5. Comparison between predicted using modify Henderson and actual EMC for triticale at 5, 23, and 35˚C

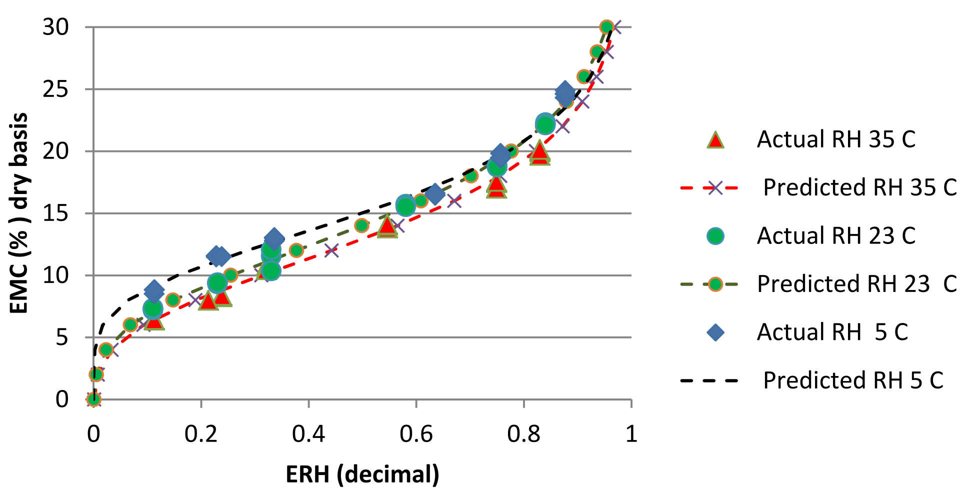

Figure 6. Comparison between predicted using Modified Chung-Pfost and actual EMC for triticale at 5, 23, and 35ºC

Conclusion

EMC curves based on the Modified Henderson and the Modified Chung-Pfost equations for triticale seed at different temperatures both represented the relationshipbetween the RH and MC in an acceptable way. The algorithms described the EMC of triticale seed with R^2 values over 0.98. The future work for this project is to develop a best fit algorithm thatpredicts the relationships for all the temperatures in a single equation.

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USDA, 2011, Small Grains 2011 Summary.

Appendix

Table 4. The obtained EMC and ERH data for triticale seed at three temperatures

Temperature 5 C		Temperature 23 C		Temperature 35 C	
EMC % (db)	ERH	EMC % (db)	ERH	EMC % (db)	ERH
8.822605	0.1126	7.221433	0.113	6.41033	0.1125
8.510827	0.1126	7.262443	0.113	6.3945	0.1125
8.845723	0.113	7.364435	0.1125	6.434679	0.1126
11.47767	0.228	9.323924	0.213	8.28036	0.238
11.58625	0.228	9.412546	0.213	8.371109	0.238
11.50538	0.238	9.410737	0.228	7.984766	0.213
12.7881	0.336	11.55861	0.3293	10.46571	0.321
13.0001	0.336	10.36368	0.3293	10.74424	0.321
13.04478	0.336	12.07916	0.3293	10.45308	0.321
16.44375	0.635	15.73842	0.584	13.81599	0.546
16.61496	0.635	15.72662	0.584	14.03767	0.546
16.47434	0.635	15.52639	0.584	14.11673	0.546
19.44051	0.7565	18.7597	0.7539	17.48284	0.7487
19.82796	0.7565	18.83327	0.7539	17.01887	0.7487
19.46986	0.7565	18.7271	0.7539	17.57114	0.7487
24.61045	0.8767	22.30858	0.847	20.06723	0.8295
24.89312	0.8767	22.21357	0.847	19.96232	0.8295
24.30484	0.8767	22.11768	0.847	19.67279	0.8295
24.63338	0.8767			20.14694	0.8295