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DRYING RATE CONSTANTS FOR YELLOW DENT CORN AS AFFECTED BY FATTY ACID ESTER TREATMENTS

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ABSTRACT. *Ethyl oleate and ethyl stearate solutions at various concentrations were used to treat corn samples prior to drying. Observed moisture contents and drying times were fitted to a thin-layer drying equation. Drying rate constant (k) values for untreated corn samples were not significantly different from those of corn samples that were treated with either distilled water or aqueous solutions containing various levels (0 to 40%) of fatty acid esters. Drying environment, characterized by various levels of temperature (21, 38, and 49° C) and relative humidity (18, 32, and 84%), significantly affected the drying rate constant in the thin-layer drying equation used to model corn drying. Values of k increased as drying temperature increased and relative humidity of drying air decreased. Rewetting rate constants for all corn samples were not significantly affected by chemical treatments applied to the corn prior to drying.* ***Keywords.** Corn, Drying, Rewetting, Fatty acid esters, Storage.*

Ethyl oleate and other similar fatty acid esters have been used to reduce the time for dehydration of fruits. Radler (1964) was one of the first to apply ethyl oleate, ethyl stearate, and ethyl caprylate on grapes. Other fruits that have been dried with the aid of various fatty acid ester treatments are cherries, blueberries, and prunes (Ponting and McBean, 1970). Suarez et al. 1984) studied the applicability of using ethyl oleate during the drying of sweet corn and immature field corn. They found that use of the chemical generally resulted in a significant increase in the drying rate of either type of corn. Williams (1989) found that use of fatty acid esters during drying of mature field corn in the midwestern United States initially increased the drying rate of treated corn over untreated corn.

Successful use of such fatty acid esters in the southeastern United States would depend on their ability to increase drying rates under higher absolute humidity conditions than typically exist in the Midwest. Furthermore, the effect of fatty acid ester use on rewetting rates would be of importance to storage in high humidity climates. Corn that rewets faster than conventionally dried corn would not be desirable in the Southeast, particularly, since Bunn et al. (1981) have noted existing rewetting problems in South Carolina due to unfavorable aeration and storage conditions caused by the humid climate. Therefore, the objective of this study was to investigate the effect of use of selected fatty acid esters, applied prior to drying, on drying and rewetting rate constants of yellow dent corn.

MATERIALS AND METHODS

In order to meet the objective of this study, three drying experiments and a subsequent rewetting experiment were conducted. Drying curves were obtained in the initial drying experiment for corn samples treated prior to drying with solutions of various levels of three fatty acid esters. The second drying experiment provided drying curves for corn samples treated prior to drying with solutions of various levels of one fatty acid ester. Dried corn samples were then used in the rewetting experiment. The third drying experiment completed the series of experiments by accounting for a variable that was not adequately controlled in the first two experiments. This variable, shaking of samples prior to the drying experiment, was only used on treated samples. Untreated samples received no shaking in the first two drying experiments.

SAMPLE PREPARATION

First Experiment. Yellow dent corn used in the initial drying experiment was shipped on the ear from Florida. The corn was grown in Florida by Funk's Seeds International, Inc. (Belle Glade, FL) during the early summer of 1988 and harvested just directly prior to shipment. The ears arrived at Clemson within 24 h after harvest packed in mesh bags inside of corrugated cardboard boxes. At Clemson the bags of ear corn were stored at 1° C for five days until shelling. The ears were hand-shelled with the kernels being well mixed before storage at 1° C in a sealed container until drying 20 days later. The corn, a mixture of hybrids and readily available

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at the time, had a moisture content of 27% (w.b.) when drying was started.

Individual 200-g samples of corn were prepared and placed in resealable plastic sandwich bags. The bagged samples were allowed to come to room temperature before being treated with 0.22 mL of an aqueous fatty acid ester solution except for the untreated samples which had no solution or shaking applied. The solutions were dropped onto the corn samples contained in sandwich bags with a pipette. After solution addition, each bag of corn was sealed and shaken by hand for 30 s in a circular motion. Corn samples were then poured directly into individual tared drying trays. The trays were constructed of hardware cloth and along with corn samples were positioned in the drying bins as shown in figure 1.

The three compounds used in the first experiment were Vicchem 659 Victana, Vicchem 653 Victol, and Vicchem 651 EE-Muls-Oyle. They were supplied by Victorian Chemical Co. Pty. Ltd. of Richmond, Victoria, Australia. Victana is a mixture of ethyl oleate and ethyl stearate with 90% active ingredients, Victol contains ethyl oleate with 60% active ingredients, and EEMuls-Oyle is another ethyl oleate and ethyl stearate mixture with 60% active ingredients. The concentrations of the aqueous solutions for each chemical were 40, 20,10, 5, 2.5, and 0% fatty acid ester. An untreated sample was also prepared where no solution was applied on the corn sample.

Second Experiment. Ear corn for the second drying experiment and subsequent rewetting was hand-harvested in the fall of 1988 from plots in the Clemson University Calhoun Experimental Fields. The corn was an equal mixture of Coker 77B and Dixie 18 yellow dent hybrids at 25.2% (w.b.) moisture content. Ears were hand-shelled immediately after harvest and the kernels stored in a sealed container at 1° C until drying 120 days later. No mold was visible on the corn kernels as the low temperature minimized kernel and microbial respiration. Furthermore, since samples are to be only compared within a drying experiment, any deterioration would be equivalent for all the second experiment samples.

A second sample preparation and drying experiment was conducted due to the inability of the first experiment to find an optimum compound or solution concentration. Preparation of samples followed methods used for the first samples except only one compound, Victol in lower concentrations, was used. The solution concentrations were 2.5, 1.25, 0.625, 0.3125, and 0% Victol along with an untreated sample. Rewetting effects were also evaluated using these samples.

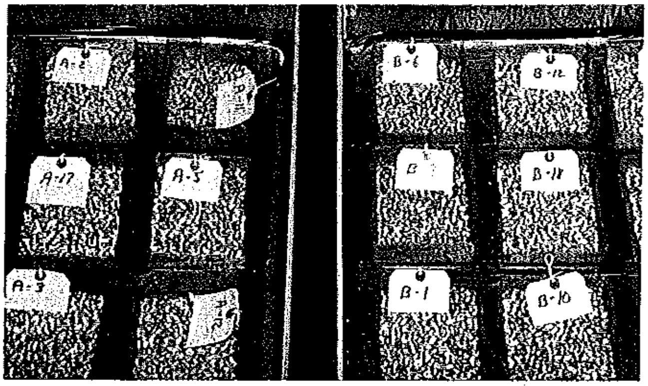

Figure 1–Drying trays with corn samples in drying bins.

Third Experiment. Corn for the third drying experiment was harvested by hand in the fall of 1989 from plots in the Clemson University Calhoun Experimental Fields. The corn was an equal mixture of Coker 77B and Dixie 18 yellow dent hybrids at 35.4% (w.b.) moisture content. Ears were hand-shelled immediately after harvest and the kernels stored in a sealed container at 1° C until drying 14 days later.

The third drying experiment was conducted to take into account the variable of shaking. In the first two drying experiments, shaking was not a part of the process for the untreated samples whereas it was for all the chemically treated samples. The three types of samples prepared using the previously described method were shaken and untreated, shaken and 0% Victol, and unshaken and untreated.

DRYING

Drying was conducted in a laboratory drying system previously used by Bunn and Krueger Wishert (1991). The system contained a fan, a humidifier, connecting duct work and three wooden drying bins. Each wooden bin had dimensions of 58.4 × 121.9 × 61.0 cm with a 38.1 × 40.6 cm bottom inlet for attachment to the air handling plenum and a perforated, corrugated metal floor 25.4 cm above the bin bottom and inlet. At the openings to the air handling plenums were slotted dampers to control airflow at 0.057 to 0.085 m^3/min into each bin. Dry bulb temperatures for the heated air were obtained with use of resistance strip heaters within each bin plenum entrance. Duct tape was used on the floor of each bin to force air up through 18 15.2 × 17.8 cm areas over which the hardware-cloth drying trays were placed.

First Experiment. Air passing from the fan and humidifier was at 21±1° C and 84±2% relative humidity (RH) for the first experiment. Heating of air in two of the bins to 38±1°C and 49±1° C reduced the air relative humidities to approximately 32% and 18%, respectively. The third bin was supplied with air from the fan and humidifier without any added heat. The drying condition of 21±1° C and 84±2% RH was designated environment 21-84. In a similar manner, drying conditions of 38±1° C and 32% RH, and 49±1°C and 18% RH were designated environments 38-32 and 49-18, respectively. Corn samples were poured into individual tared drying trays after treatment and before placement in each drying bin. The trays of corn were weighed at the beginning of and periodically during drying to determine moisture loss. Two replicates of the seventeen treatments were dried in the three bins.

Second Experiment. Air passing from the fan and humidifier was at 21±1° C, however, due to equipment failure, RH for the second experiment dropped to 65±2%. Heating of air in two of the bins to 38±1° C and 49±1° C reduced the air relative humidities to approximately 26% and 14%, respectively. As in the first experiment, the third bin was supplied with air from the fan and humidifier without any added heat. Drying conditions of 21±1° C and 65±2% RH, 38±1° C and 26% RH, and 49±1° C and 14% RH were designated environments 21-65, 38-26, and 49-14, respectively. Corn samples were handled and weighed as described in the first experiment. Three replicates of the six treatments were dried in the bins in the second experiment.

Third Experiment. Air conditions, handling methods, and weighing methods for the third experiment were the same as those for the first experiment. Six replicates of the three treatments in the experiment were dried in the bins.

REWETTING

Rewetting was conducted using the drying bins and the drying trays. All samples dried in the second experiment were rewetted by passing unheated air at 21±1° C and 84±2% RH through the samples. The individual drying trays with corn were weighed initially and periodically to determine the moisture gain over a 24-h period.

DATA ANALYSIS

Weight change over time for each sample was used to calculate its moisture content over time in both drying and rewetting. A drying rate constant (k) was derived for each sample by fitting moisture content and time to a thin-layer drying equation of the form:

$$e^{-kt} = (M - M_f) / (M_o - M_f) \qquad (1)$$

where M was bulk sample mean moisture content (d.b.) at time t, M_f was sample final moisture content (d.b.), M_o was sample original moisture content (d.b.), and t was time in minutes from placement of sample into the drying bin. Final moisture content was used in the equation as opposed to an equilibrium moisture content such as suggested by Brooker et al. (1974) since a final moisture content is more realistic from a practical standpoint. Fatty acid esters, if of any use, would be used in drying corn to approximately 15% (w.b.) moisture content rather than to an equilibrium moisture content. The k-value was considered a rewetting rate constant in the rewetting experiment. Correlation coefficients for observed data points compared to predicted points using the thin-layer equation for drying ranged from 0.975 to 0.999. Use of the equation in rewetting resulted in an R^2 of 0.613.

A split-plot experimental design was used to evaluate the effect of environment, treatment, and their interaction on the k-values at a 5% probability level (Steel and Torrie, 1960). Environment was a main effect while treatment level and treatment-environment interaction were subplot effects. Significant effects were then further analyzed with Tukey's multiple comparison test for significance at the 5% level of probability (SAS, 1985).

RESULTS AND DISCUSSION

FIRST EXPERIMENT

Split-plot analysis of variance showed that drying environment had a significant effect (see table 1) on the drying rate constant (k). Use of Tukey's multiple comparison test showed a k mean of 0.00174 for environment 21-84 significantly less than those of 0.01092 and 0.02331 for environments 38-32 and 49-18, respectively. Furthermore, the means for environments 38-32 and 49-18 were significantly different from each other.

Table 1. Drying rate constant (k)* means for three drying experiments and one rewetting experiment as affected by the processing environment†

Environment	Experiment 1	2	3	4
21° C and 84% RH‡	0.00174a	0.00099a	0.00282a	0.00516b
38° C and 32% RH	0.01092b	0.03308b	0.01104b	0.00518c
49° C and 18% RH	0.02331c	0.05289c	0.01906c	0.00514a

* Means in experiment 4 are rewetting rate constant.

† Means within columns with different letters differ significantly ($P < 0.05$) using Tukey's standardized range test after the effect of environment was found to be significant ($P < 0.05$) in the split-plot analysis.

‡ Due to equipment failure, initial humidities in experiment 2 were lower than those of experiments 1 and 3, however, ambient humidity rose in environment 21-84 (actually 21-65) of experiment 2 during the later stages of drying.

For all treatments in this experiment, no significant difference was attributed to treatment or to treatment and environment interaction. Figure 2 shows a drying curve for an untreated corn sample in environment 21-84 compared to curves for corn samples with a 2.5% Victol treatment in environments 21-84 and 49-18, respectively. This figure illustrates that different treatments within the same environment had similar drying curves, whereas similar treatments among different environments had different drying curves.

SECOND EXPERIMENT

Drying results from the second experiment were very similar to those from the first (table 1). Split-plot analysis of variance showed that drying environment had a significant effect on the drying rate constant (k). Figure 3 shows such an effect with sample drying curves for corn treated with 0.625% Victol in the three environments. Use of Tukey's multiple comparison test revealed a k mean of 0.05289 for environment 49-14 was significantly greater than means of 0.00099 and 0.03308 for environments 21-65 and 38-26, respectively. Means for environments 21-65 and 38-26 were also significantly different from each other.

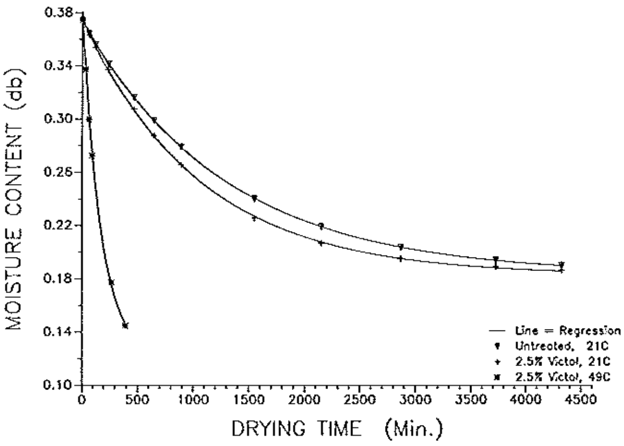

Figure 2–Drying curves for untreated corn and corn treated with 2.5% Victol, and dried at various temperatures and relative humidities.

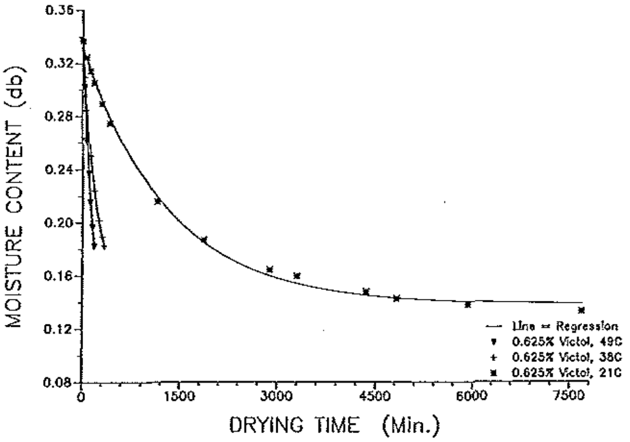

Figure 3–Drying curves for corn treated with 0.625% Victol, and dried at various temperatures and relative humidities.

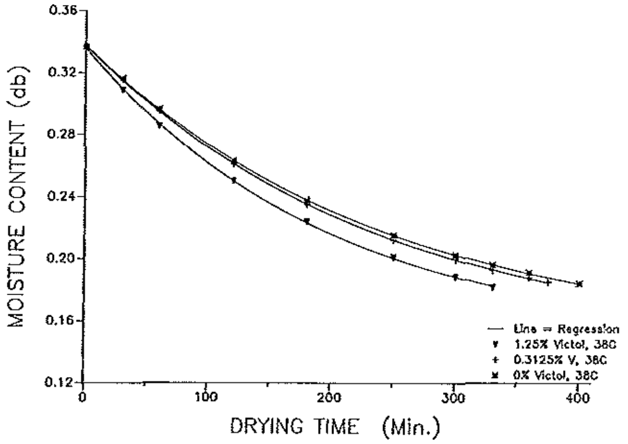

Figure 4–Drying curves for corn treated with various levels of Victol, and dried at 38° C and 26% relative humidity.

Drying rate constant (k) was significantly affected by the treatment. Tukey's multiple comparison test of significance and a more conservative test, Scheffe's test, revealed the k means as affected by treatment had some grouping of means (table 2). However, no pattern, trend, or relationship is apparent between the level of chemical and the drying rate constant. Furthermore, all k means were within 2% of each other, so no definitive inferences can be made for this portion of the study.

The interaction of environment with treatment had a significant effect on the drying rate constant (k). As with the treatment (table 2), no pattern, trend, or relationship was observed between the drying rate constant means for the 18 drying environment-treatment levels. Means for k for all treatments within the 21-65 environment varied by 2% whereas k for the other two interaction levels varied by only 1%. Figure 4 is representative of this observation as it shows sample drying curves for corn with treatments of 0, 0.3125% and 1.25% Victol in environment 38-26.

THIRD EXPERIMENT

Split-plot analysis of variance showed that drying environment had a significant effect on the drying rate constant (k). Use of Tukey's multiple comparison test showed a k mean of 0.00282 (table 1) for environment 21-84 significantly less than those of 0.01104 and 0.01906 for environments 38-32 and 49-18, respectively. Furthermore, the means for environments 38-32 and 49-18 were significantly different from each other.

Table 2. Drying rate constant (k) means for second drying experiment as affected by interaction of drying environment with treatment and by treatment

	k			
Treatment	21-65*	38-76*	49-14*	All Env.†
2.5% Victol	0.00100dc	0.03311b	0.05286a	0.00285ab
1.25% Victol	0.00100c	0.03320b	0.05297a	0.00287a
0.625% Victol	0.00099fed	0.03322b	0.05286a	0.00283bc
0.3125% Victol	0.00099fe	0.03308b	0.05304a	0.00283cd
0.0% Victol	0.00099ed	0.03302b	0.05305a	0.00284bc
Untreated	0.00098f	0.03286b	0.05256a	0.00281d

* Means of three samples. Means within numbered columns for k with different letters differ significantly ($P < 0.05$) using Scheffe's standardized range test after the effect of treatment was found to be significant ($P < 0.05$) in the split-plot analysis.

† Means of nine samples. Means within right-hand column for k with different letters differ significantly ($P < 0.05$) using Tukey's standardized range test after the effect of treatment was found to be significant ($P < 0.05$) in the split-plot analysis.

For all treatments in this experiment, no significant difference was attributed to treatment, or treatment and environment interaction. This observation rules out shaking as having any effect on k means.

REWETTING

Rewetting of corn samples first dried after adding fatty acid ester solutions was conducted to determine the effect of fatty acid esters on moisture adsorption. Figure 5 shows rewetting curves for corn samples treated with various levels of Victol and dried in environment 38-26 to be essentially parallel but with different initial moisture contents ranging from 12.1 to 13.6% (d.b.).

Split-plot analysis of variance showed that drying environment had a significant effect on the k means. No significant difference was attributed to treatment, or treatment and environment interaction. Means of the k-values are shown in table 1. Use of Tukey's multiple comparison test revealed a k mean of 0.00518 for

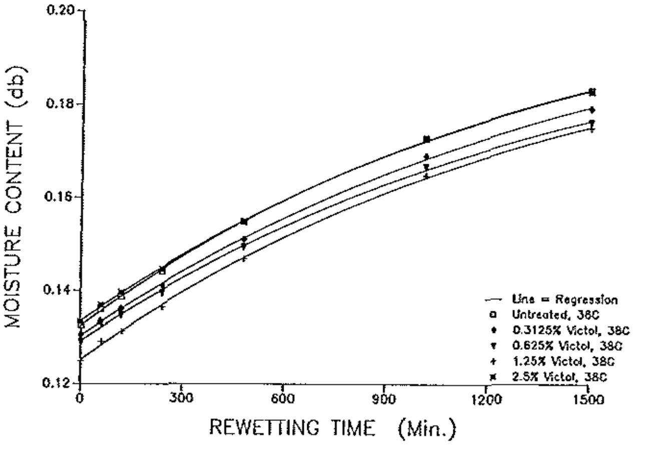

Figure 5–Rewetting curves for corn treated with Victol, and dried at 38° C and 26% relative humidity.

environment 38-26 was significantly greater than means of 0.00516 and 0.00514 for environments 21-65 and 49-14, respectively. Means for environments 21-65 and 38-26 were also significantly different from each other.

SUMMARY

In general, results of the drying experiments indicate that for corn with initial moisture contents of 25.2 to 35.4%, ethyl oleate and ethyl stearate have little or no effect on k values and subsequently on drying rate, and that no level of treatment was found to significantly change the drying rate of the corn of this study. The only changing factors that significantly contributed to faster drying, as measured by increasing k values, were an increase in drying temperature and a decrease in relative humidity of drying air.

Level of treatment and its interaction with environment were found to significantly change the drying rate of corn in the second drying experiment of this study. However since the degree of variation between drying rate constant means was small and no pattern of relationship was established, the use of fatty acid esters to increase drying rate may not be practical. This is much the same conclusion that was reached by Williams (1989).

As far as rewetting is concerned, chemicals make no apparent difference for rewetting rates. Therefore, if one would so choose to use them, they would not increase rewetting rates. Furthermore, this study did reveal one interesting observation; that corn dried at a temperature of 38° C and a relative humidity of 26% rewet faster than corn dried at 21 or 49° C. Additional study on rewetting properties of corn as a function of the drying temperature and relative humidity would better explain the results of the rewetting study.

CONCLUSIONS

This study concluded that drying rate constant (k) values for untreated corn samples were not significantly different from those of corn samples that were treated with either distilled water or aqueous solutions containing various levels of fatty acid esters. Secondly, k values significantly increased as drying temperature increased and relative humidity of drying air decreased. Finally, rewetting rate constants for all corn samples were not significantly affected by chemical treatments applied to the corn prior to drying.

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