Wax Yield of Grain Sorghum (Sorghum bicolor) as Affected by Mechanical Harvesting, Threshing, and Handling Methods

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TECHNICAL NOTES:

WAX YIELD OF GRAIN SORGHUM (*SORGHUM BICOLOR*) AS AFFECTED BY MECHANICAL HARVESTING, THRESHING, AND HANDLING METHODS

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ABSTRACT. *Wax is found on the outer layer of the grain sorghum (*Sorghum bicolor*) kernel. Current harvesting and handling techniques cause abrasion and breakage, thereby potentially reducing wax yield from sorghum kernels. The purpose of this study was to determine wax yield of sorghum after mechanical harvesting and handling and to compare wax yield of whole and broken sorghum kernels. Combine threshing and auger conveying of grain caused abrasion and breakage, which reduced the wax yield by 5%. The monitored process in this experiment included a cleaning system which reduced the amount of broken kernels and sorghum particles, increasing wax yield after cleaning and bagging. Additionally, the monitored process had a limited amount of augering and other handling included. In the second experiment, artificially broken kernels were found to have a 25% reduction in wax yield.*

Keywords. *Materials handling, Bran, Pericarp, Damage, Combine, Auger.*

Grain sorghum (*Sorghum bicolor)* produces wax on the outer layer, or epicarp, of its kernel which is similar to carnauba wax (Kummerow, 1946a; Bunger and Kummerow, 1951; Cannon and Kummerow, 1957; Freeman and Watson, 1969; Weller et al., 1998). Extraction procedures using hexanes have been developed to remove and quantify this material (Freeman and Watson, 1969; Lochte et al., 1996; Weller et al., 1998). Sorghum wax has a high melting point of approximately 80°C (175°F) (Kummerow, 1946a,b; Hubbard et al., 1950; Cannon and Kummerow, 1957; Dalton and Mitchell, 1959; Freeman and Watson, 1969; Saraiva, 1995; Weller et al., 1998) and has potential to be removed as a co-product of commercial sorghum processing. Eventually it may be used in place of or with carnauba wax in car, shoe and floor polish, as a paper coating or as a confectionery coating (Saraiva, 1995).

Studies have shown that the amount of wax available for recovery is affected by the pre-treatment of the kernel and kernel integrity. Lochte et al. (1996) found when using a TADD (Tangential Abrasive Dehulling Device), as much as 40% of total recoverable kernel wax can be removed in 20 s of abrasive run time. Additionally, preliminary results have shown that when a large percentage of sorghum kernels to be extracted were broken into small pieces, as much as a 25% reduction in wax yield of the sample occurred.

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Quick and Montgomery (1974) compiled a list of references which discuss grain quality as a result of combine harvesting. During mechanical harvesting and handling, kernels of various crops experience damage (Haman, 1978) such as abrasion, checking, and breakage. Large amounts of abrasion and breakage may occur as a result of threshing, augering, and impaction when harvested by combine, followed by transfer from combine to grain truck with subsequent transfer to farm storage or local grain elevator. After drying in farm storage or at a local elevator, grain would be transferred to a grain truck or rail car for transport to the final end use point or further storage. Handling at each transfer causes kernels to break or crack. As pericarp layers shear apart, the wax matrix is also disrupted, allowing wax particles to break or flake off the kernel.

The objectives of this study were: (1) to determine the effect of a selected mechanical harvesting, threshing, and handling method on wax yield of grain sorghum kernels; and (2) to compare sorghum wax recovery amounts from artificially broken kernels versus whole kernels.

MATERIALS AND METHODS

KERNEL PREPARATION

Two experiments were performed with samples of the sorghum variety, NC+ 7R37E. In the first experiment, samples were procured during harvest on 18 October 1996 from a University of Nebraska Foundation Seed Division field at the Mead Research Center. Samples were collected: (1) by hand harvesting from field; (2) from combine bin; (3) from grain cart/drying wagon; (4) after cleaning; and (5) after bagging. At stage 2, a Gleaner A-II combine with cylindrical thresher was used to mechanically harvest sorghum from the field. At stage 4, an air-screen cleaner (Clipper M2B Cleaner, AT Ferrell Co.) was used for cleaning of sorghum. The scalper and finishing screens were 0.556-mm (0.219-in.) round hole and 0.20-mm (0.077-in.) × 1.3-mm (0.5-in.) slotted screen, respectively.

Samples collected by hand from the combine bin and from the grain cart were dried from 21% MC_{wb} to less than 12% MC_{wb} in a forced air dryer at 38°C (100°F). Samples collected after cleaning and after bagging were dried in the grain cart/drying wagon which had a perforated bottom for airflow, to less than 12% MC_{wb} before cleaning and bagging. All samples were then stored at 5°C (40°F) until washed.

Samples were washed to remove chaff and dirt. Washing consisted of placing kernels in a plastic container, adding tap water to a minimum level of 3.8 cm (1.5 in.) over kernels, followed by hand agitation, and skimming off floating material. A U.S. Standard Testing Sieve No. 40 was used to capture sorghum, which was rinsed before drying. The whole washing process for each sample was completed in less than 10 min. Sorghum kernels were then dried in a forced air dryer at 38°C (100°F) to again below 12% MC_{wb} and stored at 5°C (40°F) until wax extraction. Samples for moisture content determination were taken at the same time wax extractions were performed. Moisture content was determined in duplicate using AOAC method 925.10 (AOAC, 1990).

For the second experiment, sorghum kernels were taken from three different bagged samples collected in Experiment 1. Samples were hand-separated into whole and broken kernels, with additional kernels “artificially” broken. Artificial breaking of kernels was done by placing approximately 100 g (3.5 oz) of whole kernels in a commercial blender (Model 9011, Waring Products Division, New Hartford, Conn.) and running the blender for approximately 15 s on high speed. Approximately 500 g (17.5 oz) was needed for wax extraction, therefore the process of “artificially” breaking the kernels was repeated until enough sample was prepared for wax extraction from each bag.

WAX EXTRACTION

Wax was extracted from samples using a solvent containing a minimum of 95% n-hexane (Product No. N169-01, J.T. Baker, Phillipsburg, N.J.). Hexanes and sorghum fractions were refluxed together for 30 min at approximately 65°C (150°F) at a ratio of 125 mL (4 oz) hexanes to 125 g (4 oz) of grain sorghum. After refluxing, the sorghum/hexanes mixture was vacuum filtered through a Whatman No. 2 filter paper on a Büchner funnel. The filtrate was stored at –5°C (20°F) for 24 h, allowing wax to precipitate. After cold storage, the solution was vacuum filtered through a Whatman No. 50 filter paper using a Büchner funnel. This process of cold storing and filtering was repeated two more times.

The filter paper with precipitated hexanes extract or wax was removed and allowed to dry at room conditions, 25°C (75°F) and 30% RH, for 24 h. The dried wax and filter papers were then weighed to the nearest 0.1 mg (3.5×10^{-6} oz).

Five wax extractions were performed for each sampling location, for a total of 25 extractions for Experiment 1. For Experiment 2, wax extraction was performed in duplicate on both whole kernels and broken kernels for each of the three bags sampled, for a total of 12 wax extractions.

CALCULATION OF WAX YIELD

Wax mass for each extraction was determined as the total mass gain for the three Whatman No. 50 filter papers. Wax yield (% wax_{db}) was calculated as:

$$\%\,wax_{db} = \frac{\text{total wax mass (g)}}{\text{sorghum mass initially extracted (g)}} \times \frac{1}{100 - \%\,MC_{wb}} \times 100\% \qquad (1)$$

where $\%MC_{wb}$ is the percent moisture content on a wet basis of sorghum initially extracted.

SIEVE ANALYSIS OF SORGHUM GRAIN

Four samples of 100 g (3.5 oz) from each harvest-handling point, 20 samples total, were sieved to determine kernel integrity. Samples were shaken for 7 min using a standard sieve shaker (Ro-Tap Testing Sieve Shaker No. 1506, The W.S. Tyler Co., Cleveland, Ohio) with U.S. Standard Testing Sieves No. 6, No. 8, No. 10, No. 12, No. 14, and catch pan. Material retained above No. 8 sieve with 2.36-mm (0.0929-in.) spacing was considered to be whole kernel or largely whole kernel material. Percent of damaged whole kernels was reported for material retained above the No. 8 sieve and determined by manually counting the damaged kernels retained above No. 8 sieve divided by the total number kernels retained above No. 8 sieve, times 100%. Material which fell through the No. 8 sieve was determined to be over 95% damaged and multiple particles accounted for a single kernel. Therefore, the weight of material which fell through No. 8 sieve was reported as fragmented material in table 1.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

Experiment 1 was conducted as a completely randomized design. Wax yield was the dependent variable and harvest location was the independent variable. Five wax extractions were performed for each sampling location: hand-harvested, combine-harvested, grain cart, after cleaning, and after bagging; for a total of 25 extractions performed in random order. Whole kernel size distribution and damaged kernel content was measured and averaged on four sub-samples per harvest-handling sample location. Pair-wise t-tests were used to compare significant ($p < 0.05$) main effect treatment means.

Experiment 2 was conducted as a randomized complete block design with two treatments (whole versus artificially broken) and three blocks. Each bag served as the blocking factor. Two replications per bag were extracted for a total of 12 samples. Wax yield was analyzed as the dependent variable using PROC GLM (SAS, 1996). Pair-wise t-tests were used to compare significant ($p < 0.05$) main effect treatment means.

RESULTS AND DISCUSSION

WAX YIELD AFTER HARVESTING AND HANDLING

Harvesting, threshing, and handling significantly ($p < 0.05$) influenced wax yield. Samples collected from the combine bin and grain cart yielded 5% less wax than kernels collected by hand harvesting, after cleaning, and after bagging (table 1). Sieve analysis and manual counting of damaged kernels for samples collected from the combine bin and grain cart found damaged kernel content retained above the No. 8 sieve was 4.0 and 7.6%, respectively; with 2.3 and 3.4%, respectively, of total material falling through the No. 8 sieve. For samples collected after cleaning and after bagging, the amount of damaged kernels retained above the No. 8 sieve decreased to 2.1 and 3.1%, respectively; and the percent of material which fell through the No. 8 sieve was 1% of the total sieved for both samples (table 1). Sorghum kernels experienced abrasion and breakage resulting in wearing and fracturing of wax on the outer layer, or epicarp, of the kernel as a result of combine threshing with subsequent transfer by auger to the grain cart. During cleaning, broken pieces of pericarp were removed, thereby leaving less-damaged whole kernels for wax extraction and resulting in increased wax yield as compared to wax yield of samples collected from the combine bin and grain cart. Bagging of samples apparently did not cause as much damage to wax yield as mechanical harvesting and conveying.

Wax Yield from Whole and Artificially Broken Kernels

Increased percentages of damaged kernels decreased wax yield. A significant ($p < 0.01$) difference in wax yield was found for artificially broken kernels as compared to whole kernels, 0.16% to 0.20%, respectively. Bag effect was significant ($p < 0.05$) and most likely a result of the "artificial" method of creating damaged kernels in the blender. Differences in blender run time and mass of blended kernels probably affected the amount of damage caused by the blender blades. The wax yields of broken kernel fractions for bags 1, 2, and 3 were 0.13%, 0.17%, and 0.17%, respectively. Visual inspection after sieving of whole and broken samples for bag 1 found over 90% of kernels retained above the No. 8 sieve were damaged with 32% of material falling through the No. 8 standard sieve (table 1).

When kernels were damaged, a fraction of the pericarp broke away with or without attached endosperm. It was speculated that as the pericarp broke away, wax on the outer layer flaked off as well. During removal of wax from filter papers, it was noticed that wax particles easily clung to other surfaces such as plastic or metal. Likely, as wax separates from sorghum kernels, it becomes lost in the harvesting and handling system by adhering to system surfaces.

Table 1. Wax yield and sieve analysis of kernels for each harvest-handling sample location, and for whole and artificially broken kernel samples

		Sieve Analysis†		
Sample Location or Treatment	Wax Yield* (%)	Passed Through No. 8‡ (%, w/w)§	Retained Above No. 8 (%, w/w)§	Damage to Retained Material (%)
Exp. 1 — Harvest Location	SE — 0.002	0.6	0.25	*0.25*
1) Hand harvested	0.197 b‖	0	100	0
2) Combine bin	0.186 a	2.3	97.7	4.0
3) Grain cart	0.188 a	3.4	96.6	7.6
4) After cleaning	0.195 b	1.0	99.0	2.1
5) After bagging	0.199 b	1.1	98.9	3.1
Exp. 2 — Kernel Integrity	SE — 0.004	1.9	1.5	*1.5*
Whole kernels	0.198 b	0.1	99.9	0.4
Artificially broken kernels	0.156 a	32.6	67.4	90.4

* Mean of 5 samples (Experiment 1) and 6 samples (Experiment 2).
† Sieve analysis (mean of 4 samples) used Standard Sieve no. 8 with 2.36 mm (0.0929 in.) spacing. Material retained above Standard Sieve No. 8 determined as whole kernels. Material passing through Standard Sieve No. 8 determined to be fragmented or particulate.
‡ All material passing through Standard Sieve No. 8 considered to be > 95% damage and particulate in nature.
§ % w/w of total material sieved.
‖ Wax yield means with the same letter for each experiment are not significantly ($p > 0.05$) different from each other.

Conclusions

Mechanical harvesting and handling mechanisms analyzed in this study significantly ($p < 0.05$) decreased wax yield. Only small amounts of augering and handling of the grain with a cleaning step was used in this study. To what extent a more severe commercial harvesting and handling system would affect wax yield is unknown. As seen when comparing whole versus artificially broken kernels, a large amount of damage significantly reduced the wax yield by as much as 25%. Determination of wax loss as a result of abrasion or breakage with analysis of commercial harvest and handling systems would help to define an allowable level of damage without large wax losses. Quite possibly a rapid test such as the fast green dye test could be used to establish levels of damage. Analysis of wax yield from farm through end use should give specific attention to the amount of augering or screw conveying performed, length of conveyors, diameters of any tubing in such systems, capacity in conveying systems, rotational speed of augers, types of conveyor, auger or elevator, and abrasiveness of surfaces. Knowledge of where the largest amount of original wax is lost in the harvest/handling process would allow commercial wax recovery systems to recover a maximum amount of wax.

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