Effect of Pump Rate and Table Slope on Starch Recovery for a 100-g Laboratory Wet-Milling Procedure

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ABSTRACT

A replicated full-factorial experiment with four starch table slopes (0.0052, 0.0104, 0.0156, and 0.0208 cm/cm) and five pump rates (40, 45, 50, 55, and 60 ml/min) was used to determine the relationship between the table parameters of slope and slurry pumping rate and starch yield and the protein content of starch for a 2.44-m × 5.08-cm aluminum channel used as a starch table in a 100-g laboratory wet-milling procedure. The tests showed that both starch yield and the protein content in the starch decreased with increasing table slope and pumping rate. The rate of starch yield loss with increasing table slope and pumping rate was approximately linear. However, protein content of starch was relatively unaffected by table slope at slopes >0.0104 cm/cm. The lowest table slope (0.0052) had significantly more protein in the starch than did the other three table slopes tested. Selection of the appropriate table slope and pumping rate for use with the 100-g laboratory wet-milling procedure was based upon starch yield and protein in starch results from tabling the same starch slurry on an 8.3-cm × 6.1-m table as performed in a 1-kg laboratory wet-milling procedure. A table slope of 0.0104 cm/cm and a pumping rate of 50 ml/min was the combination that gave the starch yield (81.8 vs. 80.0%) and protein content in starch (0.50 vs. 0.52%) closest to those of the 1-kg tabling procedure.

The density separation of starch and protein in the corn wet-milling process is currently accomplished using a series of continuous centrifuges and hydrocyclones (Watson 1984, Blanchard 1993). However, up until approximately 40 years ago, corn starch was separated from protein in industrial processes by pumping the starch slurry onto sloped wooden troughs called starch tables. Starch would settle on the table, while the protein remained suspended in the water and would be carried off the end of the table. The tables were typically 0.6-m wide and 40-m long with a slope of ≈0.0052 m/m (Kerr 1950). Factors affecting the performance of the industrial starch tables included the table slope, specific gravity of the starch-protein slurry, temperature of the slurry, table length, and pump volume per unit width of table (Berkhout 1976).

Three methods have been used in laboratory and pilot-size wet milling to separate starch from protein: 1) batch centrifugation (Hassanean and Abdel-Wahed 1986, Steinke and Johnson 1991); 2) hydrocyclone (Rubins 1990, Singh and Eckhoff 1995); and 3) starch tabling (Watson et al 1951; Eckhoff et al 1993; Pelshenke and Lindemann 1954; Anderson 1957, 1963; Weller 1987; Wehling et al 1993). There has been no direct comparison between the three procedures, although Singh and Eckhoff (1995) compared the hydrocyclone with the starch table. They found that at the conditions they operated the hydrocyclone, starch yield was reduced and protein content in the starch was higher for starch recovered by the hydrocyclone procedure. They felt that further refinement of the procedure, including recycling of the protein overflow, would yield acceptable results. Results from the references above and other literature (Eckhoff and Tso 1991, Steinke et al 1991, Fox et al 1992, Wang and Johnson 1992, Fox and Eckhoff 1993, Rausch et al 1993, Shandera et al 1995) indicate that all three methods appear to be capable of giving starch yields near industrial levels with low starch protein content and with low standard deviation between replicates, although not all research studies achieved the same level of accuracy and precision.

Each of the three methods appear to have different advantages. The batch centrifugation and the hydrocyclone are faster than tabling, but tabling has fewer subjective steps in its operation and requires less expensive equipment. Centrifugation and use of a hydrocyclone more closely emulate the current separation technology in the industry, take up less floor space, and are more adjustable for working with hard-to-separate starch samples. However, the hydrocyclone does not appear to be adaptable to sample sizes much less than 1 kg.

Pelshenke and Lindemann (1954) used a short starch table to separate starch and protein following a two-stage centrifugal washing procedure for a 100–200 g sample procedure. They did not report basic information on the slope of the table, the slurry flow rate, or the specific gravity of the slurry, but they were able to achieve good separation as indicated by a high starch yield, low protein content in the starch, and a high degree of precision in measuring starch yield.

In developing a laboratory wet-milling procedure that uses a 100-g sample size, Eckhoff et al (1996) used a 2.44-m × 5.08-cm aluminum channel as a starch table. There is no scientific data available on the relationship between the various parameters for tabling such as slurry temperature, slurry specific gravity, table length, table slope, and slurry pumping rate. In laboratory practice, it is possible to hold slurry temperature, slurry specific gravity, and table length constant. It is necessary to know the relationship between the starch quality and starch yield and the table slope and slurry pumping rate. The objective of this research was to determine the relationship between table slope, the pumping rate onto the table, and the resulting starch yield and starch protein content for a 2.44-m × 5.08-cm aluminum starch table to be used for starch-protein separation in a 100-g laboratory wet-milling procedure.

METHODS AND MATERIALS

A quantity of starch-protein slurry was obtained, all at one time, from the feed to the primary centrifuge, in a wet-milling facility. Commercial starch-protein slurry was utilized in the test to minimize variability that would occur from repetitive laboratory wet milling to produce starch-protein slurry. The slurry was refrigerated to prevent deterioration of the starch until the random duplicated tests were performed. When running a test condition, the slurry was well mixed, a representative sample withdrawn, warmed to room temperature, and adjusted to a 1.04

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specific gravity (≈9.8% solids) by the addition of distilled water before tabling. Three 100-ml samples of the slurry were used for solid determination by the two-stage air-drying procedure (AACC 1983).

Samples (1,000 ml) of the prepared mill starch with a specific gravity of 1.04 were tabled at each of 20 combinations of table slope and pump rate in a duplicated full-factorial experimental design comparing four table slopes (0.0052, 0.0104, 0.0156, and 0.0208 cm/cm) and five pump rates (40, 45, 50, 55, and 60 ml/min.). Dry, empty aluminum starch tables were initially tared by suspending the table between two balances, one located on each end of the starch table. The initial tared weight was the sum of the weight measured by the two balances. Slurry was pumped on the table at the designated flow rate and table slope, and the overflow was recovered as the protein fraction. After all of the slurry was pumped on the table, 150 ml of distilled water used to rinse the bucket was pumped over the starch on the table to wash the starch surface. The starch table was allowed to sit undisturbed for at least 6 hr to air dry the starch, after which the starch table was weighed across two balances to give a wet weight of starch. Starch on the table was then immediately scraped off into tared aluminum sample cups, and moisture was measured using a 2-hr 135°C forced-air oven procedure (AACC 1983). The overflow (protein fraction) volume was measured, three 75-ml representative samples were placed in tared aluminum sample cups, and the total solids content of the protein fraction was measured using a two-stage forced-air oven procedure (AACC 1983). Protein in starch (N × 6.25) was determined using a micro Kjeldahl procedure (AOAC 1984).

As a control, duplicate 6,000-ml representative samples were pumped on a 6.1-m × 8.3-cm table using the guide lines of the 1-kg laboratory corn wet-milling procedure of Eckhoff et al (1993). Slurry (6,000 ml) was chosen as representative of the volume of slurry tabled during use of the 1-kg procedure. The table was set at a slope of 0.0093 cm/cm with a pumping rate of 300 ml/min. The percentage yield of starch, gluten, and the starch protein content were determined.

RESULTS AND DISCUSSION

The average starch yield and protein content in the starch for the 1-kg procedure controls was 80.0 and 0.52%, respectively. This is ≈85% recovery of the starch in the starch-protein slurry. This is a low recovery by commercial standards, but it may be due to excessive recycling of middling material or other in-plant situations. The protein content in the starch was at the high end of values reported when using the 1-kg procedure. Eckhoff et al (1993) reported a value of 0.32%; Tso and Eckhoff (1991) also reported 0.32%. Singh and Eckhoff (1995) reported 0.42% protein in the starch they recovered using the 1-kg procedure, while Anderson (1963), using a similar procedure, reported a value of 0.54%. The higher than desired protein content in the starch is consistent with the lower starch recovery, indicating that the particular commercial slurry sample is difficult to separate.

Starch yield on the 100-g procedure table decreased with increasing pump rate and table slope (Fig. 1). Holding slope or pumping rate constant gave similar results in that at all pumping rates tested the starch yield decreased with increasing table slope, and at all table slopes tested, the starch yield decreased with increasing pumping rate. The maximum starch yield of 88% was at the lowest pumping rate and table slope (40 ml/min and 0.0052 cm/cm). The rate of starch yield decrease was greatest for the lowest and highest table slopes (0.0052 and 0.0208 cm/cm) with decreases of 6.9 and 7.3% starch yield. The middle two table slopes (0.0104 and 0.0156 cm/cm) had decreases in starch yield of 4.3 and 4.2%, respectively.

The protein content in the tabled starch also decreased with increasing pump rate and table slope as anticipated (Fig. 2). Most noticeable was that there was a large difference between the protein content of the starch tabled at 0.0052 cm/cm and the other three table slopes, with significantly more protein being retained on the table. There was no significant difference ($\alpha = 0.05$) between the protein content in the starch samples recovered at rates greater than 50 ml/min except at the lowest table slope. Zipf et al (1950) found a similar decreasing trend for the protein content in starch.

Selection of an appropriate table slope and pumping rate for use with the 100-g laboratory wet-milling procedure was based on conditions that give a protein content in starch and a starch yield similar to what would be expected from tabling using the 1-kg procedure. Protein content in starch levels >0.5% was not considered acceptable, based upon industrial specifications. The protein content in the starch decreased <0.5% at a table slopes and pumping rates combinations >0.0104 cm/cm and 50 ml/min. The best starch yield from the 100-g procedure for starch with <0.5% protein was 81.8% at a 50 ml/min pump speed and 0.0104 table slope, which was comparable to the values for the control samples (80.0% starch yield and 0.52% protein in starch).

Although selection criteria for determining the table slope and the pumping rate were based on comparison with results from the 1-kg procedure, there is no guarantee that numerical results will always be highly correlated between the two procedures. Because

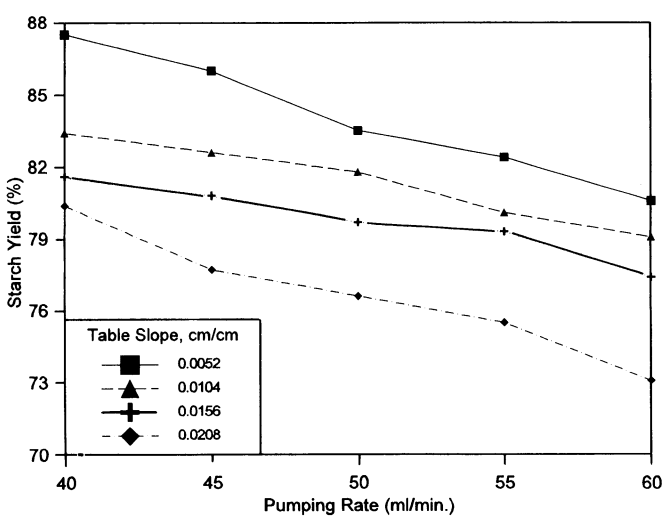

Fig. 1. Yield of starch as affected by table slope and slurry pumping rate.

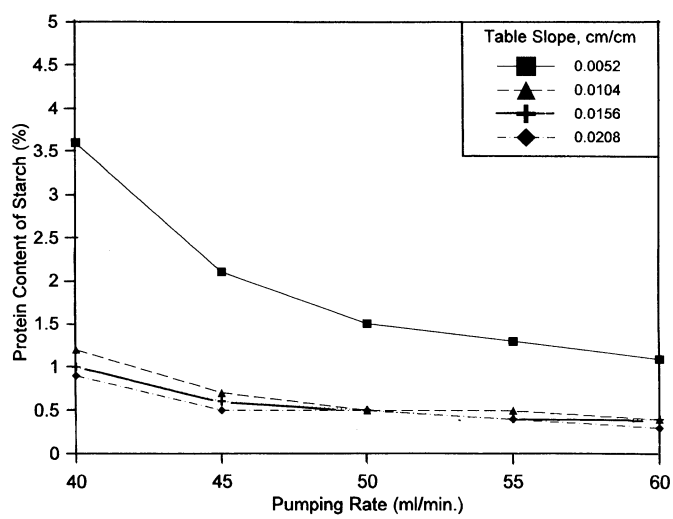

Fig. 2. Protein content of tabled starch as affected by table slope and slurry pumping rate.

the table slopes are different (0.0104 cm/cm vs. 0.0093 cm/cm) and the flow rate per cross-sectional area are not the same (10 ml/min/cm vs. 36 ml/min/cm), relative ranking of hybrids will correlate between the two procedures, but numerical yield values may be different.

CONCLUSIONS

Both starch yields and protein content in the starch decreased with increasing table slope and pumping rate. The combination of table slope and pumping rate that resulted in a starch yield and starch protein content similar to that observed for the 1-kg tabling procedure on the same slurry was 0.0104 cm/cm and 50 ml/min.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 44-18, Method 44-19. The Association: St. Paul, MN.

AOAC. 1984. Official Methods of Analysis. Association of Official Analytical Chemists. Method 7.025. AOAC: Washington, DC.

ANDERSON, R. A. 1957. A pilot plant for wet-milling. Cereal Science Today 2(4):78-80.

ANDERSON, R. A. 1963. Wet milling properties of grains: Bench scale study. Cereal Science Today 8(6):190-195, 221.

BLANCHARD, P. H. 1992. Technology of Corn Wet Milling and Associated Processes. Elsevier: Amsterdam.

BERKHOUT, F. 1976. The manufacture of maize starch. In: Starch Production Technology. J. A. Radley, ed. Applied Science Publishers: London.

ECKHOFF, S. R., RAUSCH, K. D., FOX, E. J., TSO, C. C., WU, X., PAN, Z., and BURIAK, P. 1993. A laboratory wet-milling procedure to increase reproducibility and accuracy of product yield. Cereal Chem. 70:723-727.

ECKHOFF, S. R., SINGH, S. K., ZEHR, B. E., RAUSCH, K. D., FOX, E. J., MISTRY, A. K., HAKEN, A. E., NIU, Y. X., ZOU, S. H., BURIAK, P., TUMBLESON, M. E., and KEELING, P. L. 1996. A 100-g laboratory corn wet-milling procedure. Cereal Chem. 73:54-57.

ECKHOFF, S. R., and TSO, C. C. 1991. Starch recovery from steeped corn grits as affected by drying temperature and added commercial protease. Cereal Chem. 68:319-320.

FOX, E. J., and ECKHOFF, S. R. 1993. Wet-milling of soft-endosperm, high-lysine corn using short steep times. Cereal Chem. 70:402-404.

FOX, S. R., JOHNSON, L. A., HURBURGH, C. R., JR., DORSEY-REDDING, C., and BAILEY, T. B. 1992. Relations of grain proximate composition and physical properties to wet-milling characteristics of maize. Cereal Chem. 69:191-197.

HASSANEAN, A., and ABDEL-WAHED, A. 1986. A new method to short the steeping period of corn grains. Starch/Staerke 38:417-419.

KERR, R. W. 1950. Chemistry and Industry of Starch. Academic Press: Orlando, FL.

PELSHENKE, P. F., and LINDEMANN, E. 1954. Untershuchungen uber die eignung verschiedener maissorten fur die starkefabrikation. Staerke 6(8):177-182.

RAUSCH, K. D., SINGH, S. K., and ECKHOFF, S. R. 1993. Magnesium bisulfite and sodium bisulfite as alternative steeping agents for wet milling. Cereal Chem. 70:489-490.

RUBENS, R. W. 1990. A pilot plant for the wet milling of corn grain. Cereal Foods World 35:1166-1169.

SHANDERA, D. L., PARKHURST, A. M., and JACKSON, D. S. 1995. Interactions of sulfur dioxide, lactic acid, and temperature during simulated corn wet milling. Cereal Chem. 72:371-378.

SINGH, N., and ECKHOFF, S. R. 1995. Hydrocyclone procedure for starch-protein separation in laboratory wet milling. Cereal Chemistry 72:344-348.

STEINKE, J. D., and JOHNSON, L. A. 1991. Steeping maize in the presence of multiple enzymes. I. Static batchwise steeping. Cereal Chem. 68:7-12.

STEINKE, J. D., JOHNSON, L. A., and WANG, C. 1991. Steeping maize in the presence of multiple enzymes. II. Continuous counter-current steeping. Cereal Chem. 68:12-17.

WANG, C., and JOHNSON, L. A. 1992. Wet-milling characteristics of propionate-treated high-moisture maize. I. Yields and composition of products. Cereal Chem. 69:43-46.

WATSON, S. A., WILLIAMS, C. B., and WAKELY, R. D. 1951. Laboratory steeping used in a wet milling research program. Cereal Chem. 28:105.

WATSON, S. A. 1984. Corn and sorghum starches: Production. In: Starch Chemistry and Technology. R. L. Whistler, J. N. BeMiller, and E. F. Paschall, ed. Academic Press: Orlando, FL.

WEHLING, R. L., JACKSON, D. S., HOOPER, D. G., and GHAEDIAN, A. R. 1993. Prediction of wet-milling starch yield from corn by near-infrared spectroscopy. Cereal Chem. 70:720-723.

WELLER, C. L., PAULSEN, M. R., and STEINBERG, M. P. 1988. Correlation of starch recovery with assorted quality factors of four corn hybrids. Cereal Chem. 65:392-397.

ZIPF, R. L., ANDERSON, R. A., and SLOTTER, R. L. 1950. Wet milling of grain sorghum. Cereal Chem. 27:463-473.

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