CORN DRY-MILLING: EFFECTS OF FIRST-TEMPER MOISTURE, SCREEN PERFORATION, AND ROTOR SPEED ON BEALL DEGERMINATOR THROUGHPUT AND PRODUCTS[1]

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ABSTRACT

A statistically planned series of pilot-plant experiments on a single lot of yellow dent, hybrid corn provided quantitative data on effects of three variables upon degerminator throughput, product yields, and product characteristics. The largest screen perforations (18/64 vs. 16/64 or 14/64 in.) gave highest throughput, maximum yield of −3½+6-mesh grits, and minimum yield of fractions in the −6+50-mesh range, but gave a high fat content for the −3½+6 grits. Increasing the first-temper moisture (24 vs. 21 or 18%) also increased throughput and hull release but lowered the fat content and yield of the −3½+6 grits while increasing the amount of undesirable fines. High throughput came with the highest rotor speed (880 vs. 785 or 690 r.p.m.) but at reduced yields of −3½+6 grits. The recommended level of each variable for desired yield and characteristic of specific fractions is given.

The experiments were made with a No. 0 Beall degerminator fitted with three screens and driven by a 10-h.p. motor. The corn was tempered at room temperature; no second temper was used.

Screen perforation, rotor speed, and first-temper moisture affect not only hourly throughput of a Beall degerminator but also yields and characteristics of degerminator products. No information has been published on the quantitative effect each variable has on the various factors which a corn dry-miller must consider in selecting his process conditions. This series of experiments, statistically planned and analyzed, on the effects these three variables have at three levels each, should help corn dry-millers select on a more scientific basis the best processing conditions for their operations.

Materials, Equipment, and Methods

A single lot of yellow dent, hybrid corn, a mixture of Doubet varieties D25 and D41 from the 1959 crop, dried as ear corn by natural ventilation, was obtained. It was grown at Elmwood, Illinois, on a silt-loam soil with 175 lb. per acre of 12-12-12 fertilizer applied at the time of planting. The corn contained (% m.f.b.) oil, 4.70; crude fiber, 2.04; ash (600°C.), 1.37; and protein, 9.44. Its test weight was 58.3 lb. per bu. with 70 and 95% (wt.) of the kernels retained on U.S. No. 3 and 3½

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[2] Biometrician, Biometrical Services, Plant Industry Station, ARS, Beltsville, Md.

sieves, respectively. According to the "floaters test," the corn was "average" in hardness (9). Experimental milling was carried out 12 to 15 months after the corn was harvested, and during this period its initial moisture content for the individual runs varied between 14.3 and 15.2%.

Oil content of the corn and of the various fractions was determined by the AOCS Official Method Ba 3-38 with the following modifications: 6-hr. extraction, use of Whatman filter paper No. 1 and heating for 16 hr. at 80°C. in vacuum oven for solvent removal (1). AOAC procedures were used for crude fiber, ash, and protein analyses (2). For the protein determination, a 4% boric acid solution and a mixed indicator (methyl red and bromcresol green) were used. Moisture in whole corn was determined by a two-stage drying procedure: the sample (about 25 g.) was dried for 4 hr. in a forced-draft oven at 50°C. and loss in weight determined; after the sample was ground in a Wiley laboratory mill, about 2 g. of the meal were dried for 16 hr. in a vacuum oven at 80°C., weight loss determined, and total moisture loss calculated.

The size No. 0 Beall degerminator, rated at 10 to 20 bu. per hr. capacity by the manufacturer, was driven by a 10-h.p. electric motor loaded 100%. The degerminator set-up included: Three perforated screens in the cage, flapper-type tail gate above the rotor shaft, rotor in 50% closed position, and "blunt" rotor studs. To obtain a reasonable amount of recycle stock in each experiment, the tail-gate loading had to be varied according to the first-temper moisture, screen perforation, and rotor speed used. The loading directly affects the amount of work done on the corn and thus influences the throughput rate, yields, and characteristics of the products (3). The loading, based upon a visual inspection of the tailing stream, was varied to give some recycle stock (material, largely whole corn, retained on a 3½-mesh U.S. sieve). The recycle fraction usually ran between 1 and 4% of the gross feedstock with increases to 7.5 and 11.5% in two tests for an over-all average of 3.2%. Experience gained only recently indicates that a higher level, 5 to 10%, is more desirable because of increased net throughput. In no case was a recycle stream added to the degerminator feed stream.

Representative samples of degerminator product streams (throughs and tailings, not combined) were fractionated by a laboratory procedure employing screening for size separation, followed by aspiration for hull recovery, and flotation for germ recovery. Yield of grits of various particle sizes, germ and hull as percentage of feedstock (corn processed) was calculated on the basis of air-dry weights of the recovered fractions and percentage of throughstock or tailstock. A portion of the −4+6 grits obtained by coning and quartering was examined for attached hull, attached germ, and checked grits. The remainder of these grits and the entire portion for other grits were ground and submitted for chemical analysis. Other details of this fractionation procedure and of the experimental installation have been described previously by Brekke *et al.* (4).

The three variables were studied at the following levels: (a) round-hole screen perforations of 14-, 16-, and $^{18}/_{64}$-in. diameter; (b) rotor speeds of 690, 785, and 880 r.p.m.; and (c) first-temper moisture levels of 18, 21, and 24%. Tempering was conducted at room temperature, and time was varied between 3.1 and 4.3 hr. except for 5.0 hr. in one test. No second temper was employed.

With the 3^3 factorial statistical design used, the effect of the three main variables, the best level of each, and the effect of all two-way combinations of these variables (first-order interactions) could be determined (5,6). The three-way combination, or second-order interaction, had to be used as the error term, as tests were not replicated. Because a number of the first-order interactions were not significant, this decision was justified statistically as well as economically.

Results and Discussion

Processing data treated statistically by the analysis of variance included gross throughput; net throughput adjusted to 15% moisture basis (net throughput is gross throughput less +3½-mesh recycle stock); yields of the various fractions, including the amount of germ and hull released; oil contents of the −3½+4, −4+6, and −6+8 grit fractions; and attached hull, attached germ, and checking noted on the −4+6 grits.

The statistical procedure is illustrated in summary form in Table I for yield and oil content of the −4+6 grits. All three variables had either a significant or highly significant influence on the yield and oil content of the −4+6 grits. One interaction, perforation × moisture, had a significant effect on yield.

Not only does a miller need to know if a variable has a significant effect, but also he must know the direction and extent of any expected change. Information about which variables had a significant effect on throughput and other factors, along with a quantitative evaluation of the effect noted and the recommended level for each variable, is given in Table II. The values in each column under the three variables are

TABLE I

ANALYSIS OF VARIANCE FOR YIELD[a] AND OIL CONTENT OF −4+6 GRITS AS INFLUENCED BY SCREEN PERFORATION, FIRST-TEMPER MOISTURE, AND ROTOR SPEED

SOURCE OF VARIATION	DEGREES OF FREEDOM	YIELD		OIL CONTENT	
		Mean Square	F[b]	Mean Square	F[b]
Total	26	...	..	....	..
Perforation	2	233.20	83**	0.2965	74**
Moisture	2	99.37	35**	.2326	58**
Speed	2	55.55	20**	.0211	5.28*
Perforation × moisture	4	19.21	6.86*	.0019	<1
Perforation × speed	4	6.84	2.44	.0061	1.53
Moisture × speed	4	1.04	<1	.0082	2.05
Pooled error (perforation × moisture × speed)	8	2.80	..	0.0040	..

[a] Based on net feedstock, e.g., gross feed less +3½-mesh recycle stock.

[b] To be significant (designated by *), F (the variance ratio) must equal or exceed 4.46, and to be highly significant (designated by **), it must equal or exceed 8.65.

an average of nine experimental determinations; in addition, oil contents for the −4+6 and −6+8 grits were determined in duplicate.

A column is also included for the minimum significant difference at the 95% level. For a pair of values within each group of the three means (perforation, etc.) to vary by a "significant" amount in a statistical sense, they must differ by at least this minimum (8). In borderline cases, the recommended conditions are based upon Duncan's procedure for testing differences (7).

Perforation and rotor speed have a highly significant effect on both gross and net throughput, and for maximum throughput the largest perforation and highest rotor speed are recommended. These values are the figures underlined in Table II. An increase in first-temper moisture from 18 to 21% had no effect, but because the 24% level increased throughput by a highly significant amount, this level is recommended. The data also reveal that perforation had the greatest effect, rotor speed had the second greatest, and first-temper moisture the least.

Yield of recycle stock is influenced by not only the three variables studied but the tail-gate loading, as explained earlier. For this reason, recycle stock yields are included for informational purposes only and no statement can be made as to the effect of each variable. While the amount of through stock is also influenced by tail-gate loading, the data given in Table II indicate that moisture and rotor speed had no influence and that screen perforation had a pronounced effect. In normal commercial practice the throughs stream usually constitutes 60% or less of the corn processed.

The broad statistical evaluation indicates that all three variables had a highly significant effect on the yield of −3½+4 grits. A closer

TABLE II

EFFECTS OF SCREEN PERFORATION, FIRST-TEMPER MOISTURE, AND ROTOR SPEED
(Underlined values indicate recommended level for each variable)

FACTOR	DESIRED LEVEL	MIN. SIGNIF. DIFF., 95% LEVEL	STATISTICAL EVALUATION			PERFORATION			FIRST-TEMPER MOISTURE			ROTOR SPEED (R.P.M.)		
			Perforation	Moisture	Speed	14/64 in.	16/64 in.	18/64 in.	18%	21%	24%	690	785	880
THROUGHPUT:														
Gross throughput, bu./hr., as is	max.	2.0	**	**	**	12.42	20.86	27.55	19.18	19.30	22.79	17.43	20.25	23.60
Net throughput, bu./hr., 15% M	max.	1.8	**	**	**	11.63	18.56	24.93	17.63	17.55	19.94	15.57	18.19	21.36
YIELDS:														
+3½ Recycle stock, % G.F.S.[a,b]	ca. 5%	2.1	..	..	..	(2.5)	(4.2)	(3.0)	(4.8)	(2.2)	(2.7)	(4.0)	(3.1)	(2.6)
Through stock, % G.F.S.	..	4.5	**	..	..	66	73	91	76	78	75	77	75	77
−3½+4 grits, % N.F.S.[c]	max.	0.8	**	**	**	3.8	4.0	7.3	6.5	4.4	4.2	6.0	5.2	3.9
−4+6 grits, % N.F.S.	max.	2.3	**	**	**	38.8	43.6	48.9	47.4	43.2	40.8	46.2	43.9	41.3
−6+8 grits, % N.F.S.	max.	1.9	**	*[d]	**	20.9	17.5	11.7	15.6	17.4	17.1	15.1	16.3	18.7
−8+25 grits, % N.F.S.	max.	0.9	**	**	**	10.5	9.1	7.2	8.1	9.3	9.5	8.1	9.0	9.7
−25+50 stock, % N.F.S.[e]	min.	1.0	*	*	*[d]	7.3	6.3	5.8	7.1	6.6	5.7	6.3	6.1	7.1
−50 fines, % N.F.S.[e]	min.	1.6	..	**	..	4.4	4.2	3.6	2.9	3.7	5.5	3.8	4.7	3.7
Hull fraction, % N.F.S.	max.	1.2	..	**	..	5.0	5.4	5.6	2.7	5.6	7.7	5.3	5.5	5.5
Germ fraction, % N.F.S.	max.	1.3	..	..	..	9.4	10.1	9.9	9.9	9.9	9.6	9.4	9.7	10.3
Oil in germ, % m.f.b.	max.	1.3	..	**	*	26.3	25.8	26.5	25.0	26.4	27.2	26.4	26.8	25.3
Potential oil recovery, lb./bu.[f]	max.	0.11	*	*	..	1.27	1.30	1.37[g]	1.25	1.34	1.35	1.28	1.33	1.33
OIL CONTENTS, % m.f.b.														
−3½+4 grits	min.	0.33	**	**	..	0.94	1.52	2.23	2.00	1.43	1.26	1.43	1.59	1.67
−4+6 grits	min.	0.08	**	**	*	0.45	0.65	0.82	0.82	0.61	0.50	0.68	0.65	0.59[g]
−6+8 grits	min.	0.12	**	**	*	0.74	0.85	0.94	0.87	0.92	0.74	0.81	0.93	0.78
−4+6 GRITS, % (wt.)														
Attached hull	min.	14	...	**	..	66	65	72	96	77	30	66	69	67
Attached germ	min.	4+	**	*	..	3	5	10	9	4	6	5	7	7
Checked grits	min.	11	*[d]	**[h]	..	17	25	28	26	30	15	23	25	23

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[a] Gross feedstock.

[b] Varies with tail-gate setting. Therefore, effect of perforation, moisture, and speed could not be determined independently. Values in parenthesis are given for information only and are not to be used for comparative purposes.

[c] Net feedstock, i.e., gross less +3½-mesh recycle stock.

[d] Probability = 0.92 rather than 0.95.

[e] Germ and hull particles were not removed from material passing a 25-mesh sieve.

[f] Based on gross feedstock and on 100% oil extraction from germ. Moisture content of germ ranged from 5 to 9% and approximated 6%.

[g] Probability = 0.92 that this value is significantly better than next value.

[h] Probability = 0.98 rather than 0.99.

examination of the data reveals, however, that no real differences existed between $^{14}/_{64}$- and $^{16}/_{64}$-in. perforations and between 21 and 24% moisture. Similar situations will be noted later for other factors. For maximum yield of –3½+4 grits, the $^{18}/_{64}$-in. perforation, 18% moisture level, and 690-r.p.m. rotor speed are recommended. These same levels gave the maximum yield of –4+6 grits, and as the three variables were shifted to the other end of the range, highly significant decreases in yield occurred. The conditions as noted for obtaining maximum yields of –4+6 grits gave minimum rather than maximum yields of –6+8 grits. For highest yields of both –6+8 and –8+25 grits, $^{14}/_{64}$-in. perforation, 21% moisture, and 880 r.p.m. are recommended. To obtain minimum production of –25+50 stock (hull and germ fragments were not removed from this or the –50 fines fraction) either $^{16}/_{64}$- or $^{18}/_{64}$-in. perforation, 24% moisture, and either 690- or 785-r.p.m. rotor speed appear best. Only first-temper moisture influenced the yield of fines (–50-mesh) and hull release; for minimum fines production either 18 or 21% moisture is best; 24% moisture is required for maximum hull release. None of the variables had a significant effect on the amount of germ released under the conditions tested; for germ of highest oil content, either 21 or 24% moisture and either 690 or 785 r.p.m. were best. For maximum oil recovery, the $^{18}/_{64}$-in. perforation and either 21 or 24% moisture were best, but the differences are borderline. The values given for oil recovery are based on 100% oil extraction and on gross rather than net feedstock, because the recycle stock was partially degerminated.

For minimum oil content of the three large-grit fractions, the $^{14}/_{64}$-in. perforation and 24% moisture are recommended. While certain rotor speeds are underlined, on the basis of statistical analysis, an inconsistency in these data becomes apparent because increasing the rotor speed did not produce a consistent change in fat content of the –6+8 grits. Note also in Table II that the conditions recommended for obtaining minimum oil content gave minimum rather than maximum yields of the –3½+4 and –4+6 grits.

Only moisture level influenced the proportion of hominy grits having attached hull fragments. For the lowest hull count, the highest moisture level, i.e., 24%, is required. For grits with a minimum amount of attached germ either $^{14}/_{64}$-in. or $^{16}/_{64}$-in. perforations and 21% moisture are recommended. For a minimum amount of checked grits, the $^{14}/_{64}$-in. perforation and 24% moisture are best with no choice in rotor speed. The analyses for attached hull, attached germ, and checked grits are based upon visual inspection and are highly dependent upon the analyst's judgment. Since it was not always feasible to have the same individual make these inspections, some variation in the results is natural.

Use of a second temper, as is often done commercially, will lower the attached hull count and possibly have some influence on attached germ count. This is well known in the industry. However, the present experimental series was planned to learn what effect first-temper moisture, screen perforation, and rotor speed in themselves have on degerminator performance without the masking effect of a second temper. Work is planned to learn what advantages accrue from a second temper.

Over-all, moisture has a significant effect on the largest number of factors; but from a quantitative standpoint, perforation has the greatest effect, moisture is second although much less effective, and rotor speed is third.

No one set of conditions will satisfy all requirements and, unfortunately, a miller must make a compromise based upon the relative weight he places on throughput, yield of certain fractions, and their characteristics. Presently a miller changes moisture level or temper time for the tempering step when changes in processing characteristics of the corn are noted in the mill. With comparative information now available on the effect of temper level, rotor speed, and screen perforation, he can better judge which variable to change and what results to expect.

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