CORN: THE RELATIONSHIP OF GROWING, HARVESTING, AND HANDLING CONDITIONS ON FEEDING VALUE

Kim B. Koch, Ph.D.
Northern Crops Institute
North Dakota State University

INTRODUCTION

Corn (*Zea mays* L), "the only significant cereal crop native to North America" (Farnham, et al 2003) has become the number one valued crop in the United States, worth more than $23 billion in 2003. In 2003 the U.S. produced 42% of the world's corn and the feed sector used 57% of that production; 30.3% in beef production, 29.5% in poultry production, 23.5% in swine production and 16.7% in dairy production (World of Corn, 2004).

Corn is categorized as; dent, flint, flour, sweet, pop or pod, based on its kernel characteristics. The majority of corn grown in the U.S. is yellow dent, which has kernels with vitreous horny endosperm (starch granules contained within a protein matrix) at the sides and back, and a central core of soft floury endosperm (mostly starch granules). As the kernel dries the floury central core collapses on itself producing a dent or sunken area on the top of the kernel. Average composition for this type of corn is 61% starch, 19.2% protein and fiber, 16% water and 3.8% oil (World of Corn, 2004).

Corn production has been described as a race against time. A properly selected hybrid, planted on time has only a 50% (5 out of 10 years) chance of reaching maturity before frost (Farnham et al, 2003). For corn to achieve physiological maturity, requirements for growing degree units (GDUs), moisture and temperature must be fulfilled. Too few GDUs and development stops before maturity is reached. Too little or too much moisture at critical growth stages can be a serious growth deterrent and yield limiting factor. Similarly, too low or too high temperatures result in delayed growth and reduced yields.

Having achieved physiological maturity the emphasis is on maintaining quality. There are two areas of concern; kernel moisture content and kernel integrity. In a normal season, kernel moistures of mature corn at harvest will range from 25-17% wet basis. At these levels the kernel is at risk to fungal attack, so some form of preservation must be utilized; drying, oxygen limitation (ensiling) or chemical preservative. Of added concern is mechanical damage to the kernels. Hellevang and Wilcke (1996) stated that mechanical damage to kernels is minimized during harvest when moisture content is about 22%, with increased damage observed above and below that level. Mechanical damage, either from threshing or handling, results in ruptured or cracked pericarp that can lead to further lost quality during forced-air drying, handling and storage.

Corn in commercial channels is assigned an official grade based on a set of quality descriptors; minimum test-weight (weight per unit of volume), maximum limits of damaged kernels (heat damage and total damage) and broken corn and foreign material (BCFM) (Ag. Marketing Service, 1996). Relating these physical descriptors to end-use value in livestock feeding or industry is very difficult. Bern et al (2002) suggested that the USDA test for BCFM (all matter passing through a 4.76 mm round hole sieve) was not sensitive enough to give an accurate description of the pericarp ruptures and cracks, caused by mechanical damage.

Reports describing the utilization of damaged or stressed corn have followed unusual growing season weather events. The events have tended to be extremes of temperature or moisture that retarded development and resulted in frost on an immature corn crop. The harm to the corn is related to the severity of the frost and the developmental stage of the corn. Maier and Parsons (1996) supplied these general statements about frost damaged corn. Corn that was frozen in the milk stage will have ears that are difficult to pick and shell, resulting in very low yield potential with very chaffy grain, and is perhaps best suited to green chopping. Corn that was frozen in the dough stage will have reduced yields, test weights ranging from 44 to 64 kg/hL and kernel moistures of about 60%. Field drying to tolerable harvest moisture of 35% is possible, but brings the associated risk of additional losses due to stalk breakage, ear drop, perhaps ear molds if warm temperatures follow the freeze and thresher damage to kernels. Corn frozen in the dented stage will have reduced test weights and kernel moisture will be about 55%. If the corn was in late dent stage (already black-layered) it was physiologically mature and the freeze had negligible effect on physical characteristics.

PHYSICAL CHARACTERISTICS AND NUTRIENT CONTENT

Thorton and co-workers (1969) reviewed reports from as early as 1904 and noted that decreased corn test weights were associated with drought, hail or frost damaged corn and that corn harvested after an early frost was described as “soft”, or immature. This suggested to them that a relationship between corn composition and test weight could be established using physiological development as the benchmark. They grew corn of a single variety, in a field of uniform soil type and fertility and hand-harvested at 84, 95, 109 and 145 days post-planting. Kernel development for the harvest dates was early milk, early dough, mid-dent, and mature. At harvest the corn was husked and placed into a forced-air drier at 55º C. After the last harvest date all the corn was hand-shelled. Results are presented in Table 1. Test weights and composition of the immature corn agreed with reports of harvesting frost damaged corn.

Table 1. Characteristics of corn harvested at four stages of kernel maturity.

	Stage of kernel maturity			
Description	**early milk**	**early dough**	**mid dent**	**mature**
Date of harvest	8/12	8/23	9/6	10/12
Test-weight, kg/hL	45.1	60.6	70.9	74.7
Kernel dry matter, %	20.9	35.7	55.5	76.6
Crude protein, %	16.6	12.5	10.7	10.9
Ether extract, %	3.0	4.0	4.8	4.9
Starch, %	47.7	55.0	58.7	63.7
Crude fiber, %	5.4	3.3	2.5	2.1
Ash, %	2.8	2.3	1.7	1.5

To characterize energy values Lilburn and Dale, (1989) contrasted low test-weight to high test-weight corn. They secured two samples, one a 60.6 kg/hL short-season yellow dent variety and the other 69.6 kg/hL yellow dent commodity corn. Results are presented in Table 2. The differences in composition of the low (60.6 kg/hL) and commodity (69.6 kg/hL) corn agreed with the findings of Thorton et al (1969), but very little difference was observed in the TME values, leading the authors to state that test-weight does not affect ME to the degree many had assumed.

Table 2. Characteristics of corn harvested at four stages of kernel maturity.

	Test-weight, kg/hL	
Description	**60.6**	**69.6**
Kernel moisture, %	12.4	12.4
Crude protein, %	9.3	8.4
Ether extract, %	3.0	3.4
Fiber, %	2.4	2.1
Ash, %	1.3	1.3
Energy, kcal/g DM	3.8	3.8

Baidoo and co-workers (1991) reported that corn produced in southern Alberta, Canada has kernels of low test-weight because it is often subjected to low rainfall, a shortened growing season and the likelihood of frost prior to maturity. The authors explored the relationship of test-weight to available energy content. Results, presented in Table 3, showed that test-weight, crude protein, ether extract, crude fiber, ash and starch were similar to those described by Thorton et al (1969) and Lilburn and Dale (1989). However, even with large differences in test-weights there were negligible differences in gross energy contents. Positive relationships were established for TMEn and kernel density using White Leghorn roosters, and AMEn using broiler chicks. However, large differences in test-weight showed only small differences in TMEn or AMEn values, which in the authors view precluded the use of test-weight as an estimator.

Table 3. Characteristics and composition of corn produced in Alberta, Canada

	Test-weight, kg/hL				
Description	**60.0**	**62**	**68**	**71**	**72**
Kernel dry matter, %	86.80	87.60	88.60	86.40	86.90
Crude protein, %	12.20	11.20	10.10	9.80	10.70
Ether extract, %	3.90	4.00	4.50	4.30	3.90
Starch, %	65.50	66.90	69.20	71.50	73.10
Crude fiber, %	3.20	3.00	2.90	2.30	2.30
Ash, %	1.90	1.80	1.90	1.40	1.30
Energy, kcal/g DM	4.45	4.53	4.53	4.52	4.52
AME	3.54	3.64	3.66	3.72	3.68
TME	3.68	3.88	3.90	3.95	3.96

Dale, (1994) evaluated the protein and metabolizable energy contents of 26 samples of yellow corn with test weights that varied form a minimum of 54.1 kg/hL to a maximum of 77.3 kg/hL.

Results are summarized in Table 4. The samples were submitted by grain companies and poultry producers from the U.S. and Canada. Results agreed with other reports showing no significant relationship for test-weight and gross energy. However, a slight, but significant positive relationship for test-weight and TMEn was found. The author supplied two explanations; lighter test-weight kernels are reported to have a lower fat content, and lighter test-weight kernels are reported to be smaller in size with a proportionally greater amount of low digestible seed coat, both factors contribute to decreased TMEn values. The author concluded that corn nutritive values could not be evaluated solely from corn test-weights.

Table 4. Characteristics of corn with different test-weights.

	Test-weight (kg/hL)					
Description	**54 - 57**	**58 - 61**	**62 - 64**	**66 - 68**	**70 - 72**	**73 - 77**
Gross energy, kcal/kg	4,049.50	3,882.00	3,922.40	3,934.00	3,899.00	3,930.00
TMEn, kcal/kg	3,389.00	3,324.70	3,367.20	3,416.60	3,371.60	3,450.60

The 1993 growing conditions in the Upper Midwest of the U.S. were characterized as cool and wet, with an early frost. Concerned that the nutritive value of corn would be affected, Hsu and Sell (1995) investigated light test-weight corn for growing turkeys using diets that contained either 55 kg/hL, or 70 kg/hL corn. The diets were fed to male turkey poults (Nicholas Large White) from 1 to 20 days of age and body weight gain, feed efficiency, nutrient retention were observed, and MEn for the diets and corn was determined. Results are shown in Table 5. Authors noted a slight, but significant depression of growth during day 1-7 for the low test-weight corn diet. Protein content of the low test-weight corn was reported as "inordinately low" and not in agreement with other reports relating test-weight to nutrient value. Other factors exhibited little difference between the low and normal test-weight corn diets.

Table 5. Results of feeding corn of different test weights.

	Test-weight, kg/hL	
Description	**55**	**70**
Production year	1993	1991
Dry matter, %	85.5	88.2
Protein, %	6.6	8.5
Ether extract, %	3.1	3.6
MEn corn, kcal/kg	3,221.00	3,245.00
MEn diets, kcal/kg	2,790.00	2,797.00
BWG, g, day 1-7	82.0*	92.0*
BWG, g, day 7-14	199	208
BWG, g, day 14-21	230	239
Feed efficiency day1-7	1.01	0.96
Feed efficiency day 7-14	1.24	1.25
Feed efficiency day 14-21	1.6	1.58
Retained nitrogen, %	56.4	55.2
Retained energy, %	37	36.9

PHYSICAL CHARACTERISTICS AND ANIMAL PERFORMANCE

Heidenreich and Wilson (1952) reported that South Dakota researchers in the nineteen forties had demonstrated that on a dry matter basis, soft corn, with a moisture content of 24-34%, was approximately equal to hard corn in feeding value for swine. In 1951 much of the corn harvested in South Dakota had moisture contents of 40% or greater and was immature. The authors wanted to know the impact of feeding this corn to swine. Results are summarized in Table 6. The authors concluded that on a dry matter basis immature, "soft" corn was approximately equal to the commercial, "hard" control corn as a feed for growing- fattening swine. That on a cost of gain basis the immature corn was superior, due to its low purchase cost. That drying immature corn was cost affective.

In a companion study Jordan, (1952) stated, "there was little or no market for the 1951 South Dakota corn crop and feeding it was the only means of realizing anything" from it. He conducted a feeder lamb study using the same corn as his fellow researchers Heidenreich and Wilson. Results are summarized in Table 7. He concluded that immature corn had more feeding value than was generally believed and emphasized the gain and cost of gain values for the lambs fed the immature corn by saying, "livestock is the best corn-crib for wet corn".

Table 6. Feeding immature corn to growing-fattening swine.

Description	Mature corn	Immature dried corn	Immature wet corn
Test-weight, kg/hL	70.9	38.6	42.5
Avg days on feed	63.5	66.3	68.1
Avg daily gain, kg	0.84	0.78	0.76
Avg total gain, kg	53.3	51.7	51.7
Cost of gain, $/kg	$0.27	$0.24	$0.15

Table 7. Feeding immature corn to feeder lambs.

Description	Mature corn	Immature dried corn	Immature wet corn
Test-weight, kg/hL	70.9	38.6	42.5
Avg days on feed	70	70	70
Avg daily gain, kg	0.18	0.21	0.17
Avg total gain, kg	12.2	14.5	11.8
Cost of gain, $/kg	$0.34	$0.23	$0.21

Corn purchased for use in beef cattle feedlots is priced based on USDA grade #2 yellow corn, with a minimum test-weight of 69.5 kg/hL. When the test-weight falls below the standard, feeders will incrementally discount the price, in response to a perceived loss of nutrient value. Wagener, (1995) had this to say about low test-weight corn, "feeding low test-weight corn is an excellent opportunity for producers to salvage a low-value crop or to reduce production costs and improve the profitability of their beef cattle feeding operations". Drawing upon the reports from South Dakota in the 1940s and 1950s and more recent ones he stated, "evidence suggests only minimal differences in energy for light test-weight corn as compared to normal corn. Whenever possible blend normal test-weight with light test-weight corn to minimize any differences".

Rush et al, (1996) used low test-weight corn from consecutive crop years, 1992-93, in feeding trials for growing and finishing steers. The results are summarized in Table 8. Years one and two were combined for the growing-finishing phases and carcass data. There were no demonstrated differences in the growing or finishing phases. There was a significant positive affect for light test-weight corn on hot carcass weights. There were no significant differences for other carcass traits.

Table 8. Performance data for light test-weight corn fed to growing steers.

	Test Weight	
Combined data (2 yrs), growing phase	61.4 kg/hL	72.8 kg/hL
Avg daily gain, kg	1.14	1.12
Feed DM/day, kg	7.8	7.62
Feed /gain	6.9	6.8
	Test Weight	
Combined data (2 yrs), finishing phase	61.4 kg/hL	72.8 kg/hL
Avg daily gain, kg	1.46	1.42
Feed DM/day, kg	9.3	9.57
Feed /gain	6.4	6.8
	Test Weight	
Combined data (2 yrs), carcass	61.4 kg/hL	72.8 kg/hL
Hot carcass weight, kg	372.4	363.78
Dressing percent	63.7	63.5
Marbling score	6	6

It is not at all unusual to find corn in the Upper Midwest of the U.S. that has lesser test-weight than commercial grade #2 corn and discountable moisture contents. This is often the result of delayed development terminated in a frost. The feeding value of this corn has been questioned many times. Continued research has provided a clearer picture of nutrient content and a better understanding of nutrient utilization. Birkelo et al, (1994) determined the effect of light or normal test-weight corn on energy portioning and net energy (NE) estimates of finishing diets fed to cattle and found that low test-weight corn is not inherently lower in NE than normal corn. Pritchard (2005) commented that growing conditions affect the value of grain and that this is reflected in the cost of gain for cattle. He further stated that high moisture corn grain that has been properly processed and ensiled can be fed to cattle for economic advantage. Schoonmaker and Anderson (2005) compared mature dry corn to immature high moisture corn in finishing diets for beef cattle. The high moisture, immature corn was supplied by a commercial feedyard and had been processed with a tub grinder, piled and packed and averaged 54.1 - 56.7 kg/hL, with 28% moisture. Dry mature corn came from commercial channels and was 69.6 kg/hL with 14% moisture. Cattle were fed for 118 days, from early December 2004 until marketed in late March 2005. Results are summarized in Table 9. Cattle had similar gains, consumption and efficiencies regardless of corn type. This similarity of performance was repeated in carcass data, with only a significant difference being cattle fed dry rolled corn had greater percentage of kidney, pelvic and heart fat. The authors concluded there was an economic advantage gained in feeding immature high moisture corn.

In a related study Larson (2005) used corn with three different test-weights in a beef cattle finishing diets and determined cost of gain values. The corn was from the 2004 North Dakota crop year. Results are summarized in Table 10.

Table 9. Effect of corn type on performance and carcass characteristics of steers.

	Dry rolled corn	High moisture corn	SE	P
Average daily gain, kg/d				
Overall	1.72	1.77	0.11	0.44
Dry matter intake, kg				
Overall	10.16	9.43	0.3	0.24
Feed efficiency				
Overall	5.89	5.57	0.18	0.08
Hot carcass weight, kg	325.9	329	5.8	0.42
Dress, %	60.5	60.5	0.4	0.97
Rib-eye area, cm^2	82.6	84.5	0.2	0.39
Fat thickness, cm	1.22	1.12	0.03	0.29
Kidney, pelvic, heart fat, %	2.43	2.23	0.05	0.04
Yield grade	2.8	2.6	0.1	0.24
Marbling score	385.9	404.2	10.1	0.25
Choice, %	38.2	42	4.7	0.59

Table 10. Results of feeding corn with three different test-weights.

	Test-weight, kg/hL		
Description	**50.4**	**60.4**	**68.9**
Starting weight, kg	445	448	447
Final weight, kg	610	613	610
ADG, kg/d	2.15	2.15	2.14
G:F	0.19	0.17	0.18
Hot Carcass Weight, kg	366	368	366
Longisimus area, cm^2	86.77	87.01	82.26
12^{th} Rib Fat, cm^2	1.1	1.17	1.15
KPH fat, %	1.9	1.9	2.07
Yield Grade	2.73	2.8	3.04
Marbling:12^{th} Rib Fat	370.08	368.45	347.14
Cost of Gain, dollars/kg[c]	0.50^x	0.45^x	0.31^y

[xy] Within a row, means without a common superscript are different (P <0.05).
[c] 68.9 kg corn $5.54/hL, 60.4 kg corn $4.97/hL, 50.4 kg corn $2.84/hL.

There were no differences were seen in growth, consumption and efficiency of the cattle no matter corn test-weight, likewise for carcass results. Cost of gain however demonstrated significant differences for each of the corn test-weights.

THE ROLE OF HARVEST AND HANDLING

The advent of forced air-drying has allowed corn producers to harvest at higher moisture levels (mature corn can have kernel moistures of 35%), which reduced field losses (Bern et al, 2002). However, this practice has increased the likelihood of ruptures or cracks in the pericarp and Kline (1972) reported that this increased the amount of broken corn. Gunasekaran and Paulsen (1985) found that generation of broken corn increased by a factor of ten when artificial drying temperatures were increased from 20º to 65º C. Corn is graded based partly on the level of broken corn and foreign material (BCFM) and high levels of BCFM can result in discounts in the commercial market. Anecdotal evidence suggests that the broken corn in corn properly stored does not alter animal performance, although broken corn may contribute to dust and fines in the bottom of feed bunks, so that constant vigilance is needed to keep bunks clean and feed fresh. Price discounts based on BCFM content may be to the feeder's advantage.

The rush to harvest at ever higher moisture contents has introduced new variables into the corn quality equation. Modern combines thresh corn kernels from the cob by accelerating and repeatedly hitting, rubbing and rolling the ears. The process cannot be described as steady state because other variables, such as ground speed, gathering height and feed rates change as the combine proceeds through the field. In general terms reduced kernel damage is seen when corn is harvested later in the season, when moisture levels are lower (Bern et al, 2002).

Each time a kernel is handled breakage takes place (Sands and Hill, 1971). Based on observations by Howie (2005) corn can be handled three times from harvest to feeding. Each time it is handled it is at risk of additional surface damage. Most on-farm conveyors are screw (auger) type and they rely on friction to move material. Operated full at relatively slow speeds kernel damage can be minimized, but operated less than full at relatively high speeds caused increased damage (Sands and Hill, 1971). Free-fall from heights greater than 12 meters was the greatest cause of damage to corn kernels (Fiscus et al, 1971). This may not be a problem for a custom feeder, but large shuttle-train facilities and other terminal elevators may be increasing BCFM values resulting in end-user complaints and dissatisfaction.

Schoonmaker and Anderson (2005) speculated that under certain conditions harvesting high moisture corn would allow a producer to better utilize his resources. They viewed high moisture corn as a less costly process than steam flaked corn, but with similar nutrient digestibility, growth potential and efficiency. They stated that pre-storage processing, either grinding or rolling was needed and that the corn needed to be properly ensiled. Also, because digestion of starch is shifted from the small intestine to the rumen they cautioned awareness of acidosis and strict attention to bunk management.

LITERATURE CITED

Agricultural Marketing Service. 1996. United States Standards for Corn. United States Department of Agriculture. Subpart D: 1-3

Baidoo, S.K., A. Shires, and A.R. Robblee. 1991. Effect of Kernel Density on the Apparent and True Metabolizable Energy of Corn for Chickens. Poultry Sci. 70:2102-2107

Bern, J.B., G. Quick, and F.L. Herum. 2002. Harvesting and Postharvest Management. Corn Chemistry and Technology, P. J. White and L. A. Johnson editors, AACC Press.

Birkelo, C.P., R.H. Pritchard, M. Buhman, S. Grosch, and C. Williams. 1994. Net Energy of Finishing Diets Containing Light or Normal test-weight Corn. South Dakota Beef Report 94-2

Dale, N. 1994. Relationship Between Bushel Weight, Metabolizable Energy, and Protein Content of Corn from an Adverse Growing Season. J. Appl. Poultry Res. 3:83-86

Farnham, D.E., G.O. Benson, and R.B. Pearce. 2003. Corn Perspective and Culture. Corn Chemistry and Technology, P. J. White and L. A. Johnson editors, AACC Press.

Fiscus, D.E., G.H. Foster, and H.H. Kaufmann. 1971. Physical Damage of Grain Caused by Various Handling Techniques. Trans. ASAE 14:480-485, 491

Gunasekaran, S. and M.R. Paulsen. 1985. Breakage Resistance of Corn as a Function of Drying Rates. Trans. ASAE 28:2071-2076

Heidenreich, C.J. and R.F. Wilson. 1952. Feeding Immature Corn to Growing Fattening Pigs. 12th Annual Feeders Day Report, SDSU Ag Experiment Station. 11-14

Hellevang, K.J. and W.F. Wilcke. 1996. Maintaining Corn Quality for Wet Milling. North Dakota State University Extension Service. AE-1119.

Howie, M. 2005. Tool Based on HACCP. Feedstuffs June 20, 2005. page 20.

Hsu, Li-Wen and J.L. Sell. 1995. Nutritional Value for Growing Turkeys of Corn of Light Test Weight. Poultry Sci. 74:1703-1707

Jordan, R.M. 1952. Results of Feeding "Immature" Corn – Dried and Undried. 12th Annual Feeders Day Report, SDSU Ag Experiment Station. 38-42.

Kline, G.L. 1972. Damage to Corn During Harvest and Drying. Proc. Grain Damage Symp. ASAE and Dept. of Agric. Eng., The Ohio State University, Columbus. Pages 79-82

Larson, D.M. 2005. Feeding Three Different Test Weights of Corn to Finishing Cattle. Unpublished Data, Personal Communication.

Lilburn, M.S. and N. Dale. 1989. Research Note: Characterization of Two Samples of Corn that Vary in Bushel Weight. Poultry Sci. 68:857-860

Pritchard, R.H. 2005. Utilizing Dry and High Moisture Corn Efficiently. Available: http://www.beeflinks.com/DryHMCorn.pdf

Rush, I., B. Weichenthal, and B. Van Pelt. 1996. Feeding Value of Light Test Weight Corn for Growing and Finishing Steers. 1996 Nebraska Beef Report: 54-55

Sands, L.D. and G.E. Hall. 1971. Damage to Shelled Corn During Transport in a Screw Conveyor. Trans. ASAE 14:584-585, 589

Schoonmaker, J. and V. Anderson. 2005. Effects of Immature High-moisture Corn vs. Dry-rolled Corn in Feedlot Diets. Beef Feedlot Research Report and Beef Production Field Day Proceedings, North Dakota State University Extension Service. Volume 28:12-16

Wagener, J.J. 1995. Low Test-Weight Corn for Feedlot Cattle. South Dakota State University Extension Service, Extension Extra 2019

World of Corn. 2004. National Corn Growers Association. Available http://www.ncga.com