Small Grains for Livestock

A Meta-Analysis

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December 22, 2017

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Small Grains for Livestock: Executive Summary

There are clear agronomic and ecosystem services advantages to increasing diversity of crops grown in the U.S. Cornbelt. Small grains—oats, barley, wheat, rye, triticale—are obvious candidates for a third crop in a corn-soybean rotation. Small grains that cannot be marketed directly as human food products will be fed to livestock, but many livestock nutritionists have little practical experience using these products. Although small grains were once widely grown and used, early career nutritionists in the US are most likely to have gained all of their experience in a feed landscape dominated by overwhelmingly abundant supplies of corn grain and soybean meal. This report is a review of peer-reviewed, English language work comparing animal performance (dairy, beef, pork, broilers, and layers) when fed diets based on corn grain as compared to oats, barley, wheat, rye, or triticale.

This report is divided into four sections. The first provides a brief overview of plant carbohydrates and summarizes energy and nutrient concentration of representative feed grains. Section two reviews small grain use in beef and dairy cattle, while section three summarizes research in pigs and poultry. Section four introduces potential health and environmental impacts of increasing dietary fiber fed to pigs and poultry. This report presents recommended upper limits for small grain inclusion in dairy, beef, pork, and poultry diets that have been demonstrated to support animal performance at a level comparable to corn grain when fed as part of a complete and nutritionally balanced diet. On-going work in plant breeding and applied animal nutrition will likely result in further nuancing of these recommendations as new information becomes available. However, based on the available literature of feeding small grains to cattle, pigs, and poultry there is considerable opportunity to increase the use of these feedstuffs in livestock diets without sacrificing animal performance or product quality.

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December 2017

Chapter 1. Introduction to Carbohydrates

Carbohydrates are the major source of energy in all livestock diets. Carbohydrates are diverse in terms of structure and solubility based on a number of factors. Cereal grains are concentrated sources of readily digestible carbohydrates (like starch) but also contain variable levels of less digestible carbohydrates (like cellulose). The value of small grains as livestock feed is essentially dependent upon the nature and the concentration of different carbohydrate fractions found in the grain and the animal's ability to utilize those fractions. Two recent publications (NRC, 2012; NASEM, 2016) provide an excellent review of how livestock nutritionists analyze, classify, and consider carbohydrates. Table 1 provides a simplified schematic of plant carbohydrates as they relate to small grain utilization by livestock. Tables 2 and 3 summarizes concentration of major nutrients and selected carbohydrate fractions for corn, barley, oats, rye, triticale, and wheat.

Net energy (NE) is the quantity of energy in a feedstuff that can be digested, absorbed, and put to useful purpose by an animal. Useful purposes include maintaining the animal (NE_M), growing body tissue (NE_G), and producing milk aka lactation (NE_L). Digestibility and utilization of feedstuffs depends on species as well as development of individual livestock. Thus net energy value of feedstuffs will vary between different classes of livestock. Table 4 summarizes net energy values of selected feed grains for beef cattle and pigs.

Citations

NASEM–National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle. Eighth revised edition. Washington, DC: The National Academies Press. doi 10.17226/19014.

NRC–National Research Council. 2012. Nutrient Requirements of Swine. Eleventh revised edition. Washington, DC: The National Academies of Press. doi. 10.17226/13298.

Table 1. Simplified Schematic of Important Plant Carbohydrates in Small Grains[1]

<table>
<tr><th>Compound</th><th>Digestion and Fermentation[2]</th><th>Energy end product</th></tr>
<tr><td>Starch</td><td>Easily digested by mammalian enzymes of small intestine; very quickly fermented by gut microbes (seconds to minutes)</td><td>Glucose in nonruminants
Volatile fatty acids for ruminants</td></tr>
<tr><td>Resistant Starch[3]</td><td>Resists digestion by mammalian enzymes of small intestine; quickly fermented by gut microbes (minutes)</td><td>Volatile Fatty Acids for all species[4]</td></tr>
<tr><td>β-glucans[5]</td><td>Not well digested by mammalian enzymes of small intestine; less quickly fermented by gut microbes (minutes to hours)</td><td rowspan="3">Volatile Fatty Acids for all species</td></tr>
<tr><td>Hemicellulose</td><td rowspan="2">Not digested by mammalian enzymes, complete fermentation by gut microbes requires hours to days</td></tr>
<tr><td>Cellulose</td></tr>
<tr><td>Lignin[6]</td><td>Indigestible and not fermented by gut microbes within normal limits</td><td>None; high levels inhibit utilization of other fractions</td></tr>
</table>

[1] Based on NRC 2012 and NASEM 2016

[2] Fermentation rates are relative estimates.

[3] Naturally occurring in grain but also influenced by processing and storage

[4] Volatile Fatty Acids (VFA's) are critical sources of energy for ruminant animals and certain nonruminants that retain feed for extended periods of time. Small amounts of VFA's can be beneficial to nonruminants with relatively short feed retention times such as poultry and growing pigs but extensive utilization of fibrous feeds is generally not viable under commercial conditions in North America.

[5] β-glucans tend to increase viscosity of ingesta and can thus reduce digestibility of other components of feedstuffs.

[6] Lignin is technically not a carbohydrate but is almost always associated with naturally occurring plant cellulose and hemicellulose and is routinely included in analysis of dietary fiber

Table 2. Simplified nutrient concentration of selected grains[1]

	Nutrient Fraction, % Dry Matter[2]			
Grain	Protein	Fat	Ash	Carbohydrate
Corn grain	9	4	1	82
Barley	13	2	4	75
Oats	13	6	3	70
Rye	11	1	2	73
Triticale	12	2	2	75
Wheat	14	2	2	74

[1] Based on NRC 2012 and NASEM 2016

[2] Nutrients are presented on a dry matter basis and will not total 100% due to variance in available data

[3] Carbohydrates = Starch + NDF; NDF = cellulose + hemicellulose + lignin

Table 3. Selected carbohydrate fractions of corn and small grains[1,2]

	Carbohydrate Fraction[3], % of total Dry Matter			
Grain	Starch	Hemicellulose	Cellulose	Lignin
Corn grain	72	6	3	1
Barley	57	11	5	2
Oats	44	13	10	3
Rye	58	8	6	2
Triticale	61	10	3	2
Wheat	62	8	2	2

[1] Based on NASEM 2016

[2] Nutrients are presented on a dry matter basis and may not match table 2 due to rounding

[3] Concentration of resistant starch is influenced by storage and processing while β-glucans will vary greatly between variety of grain within a species. Because these fractions are not routinely measured or reported including them in this general comparison is not feasible.

Table 4. Net energy value of corn and small grains for beef cattle and swine

	Beef Cattle[1]		Swine[2]
Grain	NE_M, Mcal/kg	NE_G, Mcal/kg	NE, Mcal/kg
Corn grain	2.17	1.49	2.67
Barley	2.06	1.40	2.33
Oats	2.03	1.37	1.89
Rye	1.97	1.32	2.46
Triticale	2.02	1.37	2.51
Wheat	2.15	1.47	2.47

[1] NASEM 2016; NE_M = Net Energy for Maintenance, NE_G = Net Energy for Growth

[2] NRC 2012; NE = Net Energy, currently there is no differentiation between NE used for maintenance or growth in swine

Chapter 2. Small Grains for Cattle

Microbes that reside in the rumen of ruminant animals such as cattle alter ingested feedstuffs prior to the small intestine where feed is enzymatically digested. It is through this microbial fermentation that ruminant animals are able to sustain growth and performance when fed fibrous carbohydrates that are not well digested by mammalian enzymes. Grains and other concentrates also undergo microbial fermentation in the rumen. Because rumen microbial fermentation fundamentally alters ingested feed prior to delivery to the small intestine, practical considerations for feeding small grains to ruminant animals like dairy and beef cattle are fundamentally different than guidelines for feeding small grains to nonruminants such as pigs and poultry. Beef cattle on feedlot and lactating dairy cattle are the primary ruminant consumers of grain in the U.S. During these stages of production, the animal's energy requirements generally exceed what can be met through forage alone and so these cattle regularly receive grain of some kind.

Small Grains for Dairy Cattle

In a 1998 survey of dairy nutritionists in the U.S., it was reported that cereal grains commonly comprise up to 30% of a lactating dairy cow's ration (Mowrey and Spain, 1999). Maximum inclusion rates of four cereal grains were reported as 45% for corn grain, 26% for barley, 20% for oats, and 20% for wheat (Mowrey and Spain, 1999). A later survey of U.S. dairy producers reports that 90% of dairy farms feed corn grain to their animals while approximately 23% feed oats, 15% feed barley, and 9% feed wheat (USDA, 2014). Use of other small grains such as rye or triticale and inclusion rates of grain in typical dairy cattle rations was not reported by either study (Mowrey and Spain, 1999; USDA, 2014).

Oats

Early work in Washington state demonstrated that when fed as part of a balanced ration with alfalfa hay, wheat, corn, oats, or barley equally support total milk yield and fat corrected milk (FCM) production (Tommervik and Waldern, 1969). Fat corrected milk is a widely accepted performance measure for lactation which standardizes total milk production based on fat concentration. Dairy cattle fed rations containing 60% corn grain consumed more feed and out produced cattle fed 72% oats, however differences in protein, fat, and fiber contents of the experimental diets likely contributed to reported performance differences (Fisher and Logan (1969). In a comparison of regular oats (14.5% CP) and high protein oats (17.6% CP) to corn grain, it was demonstrated that FCM was not different between grain sources but that high protein oats supported milk production without supplementation of soybean meal (Schingoethe et al. 1982). Later work demonstrated that FCM production was superior when cattle were fed rations containing 60% oat grain as compared to 60% barley or wheat (Moran, 1986).

Barley

When dairy cows were fed complete, balanced, rations containing corn versus barley, fat corrected milk production was not different (McCarthy et al. 1989). Further work has demonstrated that when processed similarly and fed as part of a balanced ration, replacing corn grain with barley does not affect fat corrected milk production (Beauchemin and Rode 1997; Beauchemin et al. 1997; Grings et al. 1992). More recently, it has been demonstrated that when dairy cows are fed a complete ration, barley can be used as a partial or total replacement for corn grain (Kargar et al. 2014).

Wheat

It is well established that when fed as part of a balanced dairy ration, wheat grain will support total milk yield and FCM (Tommervik and Waldern, 1969; McPherson and Waldern 1967; Cunningham et al. 1970; Faldet et al. 1989). McPherson and Waldern (1967) demonstrated that when dairy cows were fed forage and grain concentrate in a ratio of 55:45, the grain portion of the diet could include up to 93% wheat without any negative impact on cow health, diet digestibility, or FCM. Both normal (14% CP) and high protein (18% CP) wheat can replace up to 33% of the corn grain in a lactation ration without negative impact (Cunningham et al. 1970). Replacing 66% of the corn grain in a lactation ration reduced FCM as compared to lower levels, however differing ratios of concentrate and forage in the final rations makes it difficult to ascertain if the effect was due to higher levels of wheat or the reduced levels of fiber occurring in the high wheat diets (Cunningham et al. 1970). When dairy cows were fed rations of 55% concentrate and 45% forage, increasing levels of wheat (0, 40, or 60%) in the concentrate mix resulted in a linear reduction in FCM (Faldet et al. 1989) but again it is unclear if the effect was due to higher levels of wheat or accompanying changes in dietary fiber and protein levels of the ration.

Rye

Less work has been published comparing rye to other grains in dairy rations. Feeding more than 30% rye to growing Holstein calves has been shown to reduce intake and gain but not efficiency of gain (Sharma et al. 1981). Roasting the rye improved palatability and performance of growing calves (Sharma et al. 1981). Up to 25% rye could be included in the concentrate mix fed to lactating dairy cows without impacting intake or performance, however when rye accounted for 50% or more of the concentrate mix intake was reduced (Sharma et al. 1981). Fat corrected milk production was not impacted when rye accounted for 25% of the concentrate mix, but when rye accounted for 50% of the concentrate mix, FCM was reduced (Sharma et al. 1981).

Triticale

One study demonstrated that replacing barley with triticale in the concentrate mix fed to dairy cows in addition to alfalfa silage does not impact FCM (McQueen and Fillmore 1991). Later work reported that dairy cows fed a concentrate mix containing 70% corn out performed dairy cows fed a concentrate mix containing 70% triticale (Smith et al. 1994). When triticale was combined with corn grain such that triticale accounted for 66% of the grain in the concentrate mix lactation performance was similar to cows fed corn as their sole source of grain (Smith et al. 1994).

Small Grains for Beef Cattle

Grain consumption by beef cattle is highest during the feedlot phase of cattle finishing. Following a transition period, grain concentration in beef feedlot rations typically accounts for 60-90% of total dry matter intake (Samuelson et al. 2016). In two surveys of beef feedlot nutritionists, corn grain wass the most widely used cereal grain in feedlot rations (Vasconcelos and Gaylean, 2007; Samuelson et al. 2016). Wheat, barley, and sorghum were also reported to be fed to some cattle, generally as a secondary grain to corn (Vasconcelos and Gaylean, 2007; Samuelson et al. 2016). Neither survey specifically reported regular use of oats, rye, or triticale in feedlot rations (Vasconcelos and Gaylean, 2007; Samuelson et al. 2016).

Feed grains are often processed prior to feeding to feedlot cattle (Vasconcelos and Gaylean, 2007; Samuelson et al. 2016). Dry rolling and steam flaking are common feed processing methods (Vasconcelos and Gaylean, 2007; Samuelson et al. 2016) and both can improve the utilization of small grains by beef cattle (Mathison 1996; Owens et al. 1997). Considerably more research has been published examining the impact of different processing techniques within a given species of grain than studies comparing two species of grains that have been uniformly processed (Owens et al. 1997). However when growing beef cattle are fed appropriately balanced diets growth rate and efficiency can be supported equally by barley, wheat, oats, or corn (Dion and Seoane, 1992; Owens et al. 1997).

<u>Oats</u>

Oats are well established as a starter feed for growing beef cattle but are generally less effective in finishing rations due to their comparatively lower energy value (Comerford, 2017). Zinn (1993) demonstrated that growth rate and carcass merit of cattle was superior when fed steam-flaked corn compared to dry rolled oats. Steam processing and rolling of oats improved the energy value of oats for beef cattle (Zinn, 1993). Dion and Seoane (1992) demonstrated that finishing cattle fed balanced rations containing either 54% rolled oats or 54% cracked corn performed similarly.

<u>Barley</u>

Barley is regularly fed to beef cattle in areas where it is commonly grown and is widely recognized as an excellent cattle feed. Finishing cattle fed complete rations containing either 78% rolled corn or 78% rolled barley for 90 days prior to harvest grew similarly with no differences in carcass quality (Mathison and Engstrom, 1995). This is in agreement with an earlier study comparing growth and performance of feedlot cattle fed either 54% cracked corn or 55% rolled barley (Dion and Seonae, 1992). In a 172 day finishing trial cattle fed rations containing 74% steam-flaked corn grew at the same rate as cattle fed rations containing 74% dry rolled or steam flaked barley (Zinn 1993). Dry matter intake was higher for barley fed cattle and thus feed efficiency was slightly reduced for barley fed cattle as compared to corn fed cattle but carcass weights were larger for barley fed cattle (Zinn 1993). It was later demonstrated that finishing steers performed similarly when fed either 70% corn grain or barley in combination with corn silage and supplements (McEwen et al. 2007).

Wheat

Wheat is a well-established feed for beef cattle with growth performance and carcass characteristics of wheat-fed animals being similar to those fed either corn grain or barley (Owens et al. 1997). Dion and Seoane (1992) demonstrated that finishing cattle fed balanced rations containing either 55% wheat or 55% rolled barley performed similarly. Wheat starch is digested faster by rumen microbes than starch in corn or barley and thus may alter rumen pH more quickly (Herrera-Saldana et al. 1990). For this reason wheat is often limited to around 50% in feedlot diets to avoid digestive disturbance (Owens et al. 1998). In an 84-day experiment, 160 crossbred steers performed similarly and produced carcasses of equivalent quality when fed balanced rations containing either 89% barely or 88.4% wheat (Moya et al. 2015).

Rye

Ryelage—a forage feedstuff made by chopping and harvesting the entire cereal rye plant (and immature seed head)—is probably the most common use of cereal rye in the Midwest United States. Rye grain is not a common livestock feed in North America, but European work demonstrates that it can be fed successfully. Current recommendations for rye inclusion based on work summarized by Meyer et al. (2017) are 20% of the concentrated feed or approximately up to 2.2 lb of rye/day during finishing.

Triticale

Early work comparing triticale to sorghum in finishing cattle reported reduced intake and growth rate in triticale fed cattle (McCloy et al. 1971). However the study by McCloy et al. (1971) compared rations containing 92% triticale or 83.1% sorghum + 7.6% cottonseed meal + 1.2% urea. Although both diets were isonitrogenous, the differences in performance cannot truly be attributed to differences in grain source alone. In another study researchers compared 70% corn + 6% soybean meal to 38% corn + 38% triticale or 38% corn + 38% barley and demonstrated that both triticale and barley could successful replace corn and supplemental protein fed to finishing cattle (Hill and Utley, 1989). Growth rate, feed intake, and feed efficiency of cattle fed rations containing 90% triticale versus 90% barley were not different in a 120-day feeding trial (Zobell et al. 1990).

Conclusion

Small grains can support efficient production by both dairy and beef cattle. A major consideration when formulating rations is the relative cost of different sources of nutrients. Typical market conditions in the U.S. usually support feeding corn grain over other cereal alternatives. Maintaining rumen function and health through including adequate fiber is essential regardless of the type of grain fed to cattle. If rations including small grains are formulated to provide adequate nutrition to the animal while maintaining rumen health there is little evidence to suggest small grains are not appropriate for inclusion in rations fed to dairy or beef cattle. Tables 5 and 6 summarizes the ability of small grains to replace corn in rations for dairy and beef cattle while maintaining performance. In all cases it is assumed that toxin free grains that are processed equivalently will be fed and that rations will include appropriate levels of forage. It is further expected that rations will be balanced using supplemental sources of protein, minerals, and vitamins as needed.

Citations

Beauchemin, K. A. and L. M. Rode. 1997. Minimum versus optimum concentrations of fiber in dairy cow diets based on barley silage and concentrates of barley or corn. Journal of Dairy Science. 80:1629–1639. doi: 10.3168/jds.S0022-0302(97)76094-6

Beauchemin, K. A., L. M. Rode, and W. Z. Yang. 1997. Effects of non-structural carbohydrates and source of cereal grain in high concentrate diets of dairy cows. Journal of Dairy Science. 80:1640–1650. doi: http://dx.doi.org/10.3168/jds.S0022-0302(97)76095-8

Comerford, J. 2017. Feeding small grains to beef cattle. Penn State University Extension. Available online at http://extension.psu.edu/animals/beef/nutrition/articles/feeding-small-grains-to-beef-cattle Accessed 6-19-2017.

Cunningham M. D., J. L. Albright, and W. T. Howard. 1970. Percent protein and amounts of soft red winter wheat for lactating cows. Journal of Dairy Science. 53:1787–1790. doi: http://dx.doi.org/10.3168/jds.S0022-0302(70)86480-3

Dion, S. and J. R. Seoane. 1992. Nutritive value of corn, barley, wheat and oats fed with medium quality hay to fattening steers. Canadian Journal of Animal Science 72:367–373.

Faldet, M. A., T. Nalsen, L. J. Bush, and G. D. Adams. 1989. Utilization of wheat in complete rations for lactating cows. Journal of Dairy Science. 72:1243–1251. doi: 10.3168/jds.S0022-0302(89)79229-8

Fisher, L. J., and V. S. Logan. 1969, Comparison of corn and oat based concentrates for lactating dairy cattle. Canadian Journal of Animal Science. 49:85–90. doi 10.4141/cjas69-012

Grings, E. E., R. E. Roffler, and D. P. Deitelhoff. 1992. Evaluation of corn and barley as energy sources for cows in early lactation fed alfalfa-based diets. Journal of Dairy Science. 75: 193–200. doi: http://dx.doi.org/10.3168/jds.S0022-0302(92)77753-4

Herrera-Saldana, R. E., J. T. Huber, and M. H. Poore. 1990. Dry matter, crude protein, and starch degradability of five cereal grains. Journal of Dairy Science. 73:2386–2393

Hill, G. M. and P. R. Utley. 1989. Digestibility, protein metabolism and ruminal degradation of Beagle 82 triticale and Kline barley fed in corn-based cattle diets. Journal of Animal Science. 67:1793–1804

Kargar, S., G. R. Ghorbani, M. Khorvash, A. Sadeghi-Sefidmazgi, and D. J. Schingoethe. 2014. Reciprocal combinations of barley and corn grains in oil-supplemented diets: Feeding behavior and milk yield of lactating cows. Journal of Dairy Science. 97:7001–7011. doi: http://dx.doi.org/10.3168/jds.2013-7850

Mathison, G. W. 1996. Effects of processing on the utilization of grain by cattle. Animal Feed Science and Technology. 58:113–125. doi: https://doi.org/10.1016/0377-8401(95)00878-0

Mathison, G. W. and D. F. Engstrom. Ad libitum versus restricted feeding of barley- and corn-based feedlot diets. Canadian Journal of Animal Science.75: 637–640. doi: https://doi.org/10.4141/cjas95-095

McCloy. A. W., L. B. Sherrod, R. C. Albin, and K. R. Hansen. 1971. Nutritive value of triticale for ruminants. Journal of Animal Science 32.534–539

McCarthy, R. D., Jr., T. H. Klusmeyer, J. L. Vicini, and J. H. Clark. 1989. Effects of source of protein and carbohydrates on ruminal fermentation and passage of nutrients to the small intestine of lactating dairy cows. Journal of Dairy Science. 72: 2002–2016. doi: http://dx.doi.org/10.3168/jds.S0022-0302(89)79324-3

McEwen, P. L., I. B. Mandell, G. Brien, and C. P. Campbell. 2007. Effects of grain source, silage level, and slaughter weight endpoint on growth performance, carcass characteristics, and meat quality in Angus and Charolais steers. Canadian Journal of Animal Science. 87: 167–180. doi:

McPherson, R. G. and D. E. Waldern. 1967. Pacific northwest soft white wheat for lactating dairy cattle. Journal of Dairy Science. 52:84–89. doi: http://dx.doi.org/10.3168/jds.S0022-0302(69)86506-9

McQueen, R. E., and A. E. Fillmore. 1991. Effects of triticale (cv. Beaguelita) and barley-based concentrates on feed intake and milk yield by dairy cows. Canadian Journal of Animal Science. 71:845-853 doi: 10.4141/cjas91-099

Meyer, A., W. von Gagern, T. Schwarz, M. Pieszka, M. Lopuszanska-Rusek, M. Kamyczek, and C. H. Heuer. 2017. Rye in pig and cattle feed. Available online at http://www.ryebelt.com/fileadmin/Redakteure/RYE_BELT/UK/RyeBelt_Fuetterungsbrosch%C3%BCre_eng_web.pdf

Moran, J. B. 1986. Cereal grains in complete diets for dairy cows: A comparison of rolled barley, wheat, and oats and of three methods of processing oats. Animal Production 43:27–36. doi: 10.1017/S0003356100018316

Moya, D., M. L. He, L. Jin, Y. Wang, G. B. Penner, K. S. Schwartzkopf-Genswein, and T. A. McAllister. 2015. Journal of Animal Science. 93:3091–3100. doi: 10.2527/jas2014-8680

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. Journal of Animal Science. 75:868–879

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. Journal of Animal Science. 76:276–286

Samuelson, K. L., M. E. Hubbert, M. L. Gaylean, and C. A. Löest. 2016. Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech University survey. Journal of Animal Science. 94:2648–2663. doi. 10.2527/jas2016-0282

Schingoethe, D. J., H. H. Voelker, and F. C. Ludens 1982. High protein oats grain for lactating dairy cows and growing calves. Journal of Animal Science. 55:1200–1205. doi:10.2527/jas1982.5551200x

Sharma, H. R., J. R. Ingalls, J. A. McKirdy, and L. M. Sandord. 1981. Journal of Dairy Science. 64: 441–448. doi: http://dx.doi.org/10.3168/jds.S0022-0302(81)82591-X

Smith, W. A., G. S. duPlessis, and A. Griessel. 1994. Replacing maize grain with triticale grain in lactation diets for dairy cattle and fattening diets for steers. Animal Feed Science and Technology. 49:287-295. doi: http://dx.doi.org/10.1016/0377-8401(94)90053-1

Tommervik, R. S. and D. E. Waldern. 1969. Comparative feeding value of wheat, corn, barley, milo, oats, and a mixed concentration ration for lactating cows. Journal of Dairy Science. 52: 68–73. doi: 10.3168/jds.S0022-0302(69)86503-3

Vasconcelos, J. T. and M. L. Gaylean. 2007. Nutritional recommendations of consulting feedlot nutritionists: The 2007 Texas Tech University survey. Journal of Animal Science. 85:2772–2781. doi: 10.2527/jas.2007-0261

Zinn, R. A. 1993. Influence of processing of the comparative feeding value of barley for feedlot cattle. Journal of Animal Science 71: 3–10.

Zinn, R. A. 1993. Influence of processing on the feeding value of oats for feedlot cattle. Journal of Animal Science. 71:2303–2309.

Zobell, D. R., L. A. Goonewardene, and D. F. Engstrom. 1990. Potential of triticale as a feed for finishing heifers. Canadian Journal of Animal Science. 70:325–328.

Table 5. Small grain replacement of corn in balanced rations fed to lactating dairy cows[1,2]

Small Grain[3]	Fat Corrected Milk Production
Oats	100%
Barley	100%
Wheat[4]	100%
Rye	Inclusion up to 25% of concentrate mix can support performance
Triticale	Inclusion up to 66% of concentrate mix can support performance

[1] Replacement that have been demonstrated to support equivalent fat corrected milk production

[2] Rations will include appropriate levels of forage and will be balanced using supplemental sources of protein, minerals, and vitamins as needed.
[3] Toxin free grains that are processed equivalently
[4] Wheat is equivalent to corn when cattle fed rations containing 55% forage and 45% concentrate. Performance is reduced when cattle fed 45% forage and 55% concentrate.

Table 6. Small grain replacement of corn in balanced rations fed to finishing beef cattle[1,2]

Small Grain	Performance[1]
Oats	90%
Barley	100%
Wheat[4]	100%
Rye	Inclusion of up to 20% can support performance
Triticale[4]	100%

[11] Replacement that have been demonstrated to support equivalent growth rate, feed consumption, and feed efficiency
[2] Rations will include appropriate levels of forage and will be balanced using supplemental sources of protein, minerals, and vitamins as needed.
[3] Toxin free grains that are processed equivalently
[4] Wheat and triticale have been demonstrated to be equivalent to barley

Chapter 3. Small Grains for Poultry and Pigs

Feedstuffs that are ingested by pigs and poultry do not undergo microbial fermentation prior to the small intestine where feed is enzymatically digested. Thus pigs and poultry are fundamentally less able to achieve peak levels of muscle growth, egg production, and reproduction when fed diets rich in fermentable carbohydrates or nonstarch polysaccharides that may support cattle performance. Historically nonstarch polysaccharides were considered antinutritional compounds that should be minimized in pig and poultry diets. Today as knowledge of the gut microbiome evolves, nutritionist are recognizing that fermentable carbohydrates do play an important role in supporting gut health and thus animal performance. However, the majority of energy in practical pig or poultry diets is derived from starch and thus there may be greater limits on inclusion of small grains in pig and poultry diets that support commercial levels of production as compared to cattle rations.

Small Grains for Poultry

Although both broilers and layers are the same species *(G. gallus)* there are major differences in the feeding strategy and production cycle of domestic chickens kept to produce eggs (layers) and those raised for meat (broilers). These differences are summarized in various production guides readily available from commercial breeding companies (Cobb-Vantress Inc., 2012 and Hy-Line LLC, 2016). Although the U.S. leads the world in turkey production, total turkey meat production is less than 15% of the total broiler meat production (USDA-NASS 2017). Although turkey production is not an insignificant sector, published research examining the nutrition of turkeys is less widespread compared to studies involving chickens, pigs, or cattle. Thus the following review of feeding small grains to poultry focuses on chickens with limited discussion of turkey production when supported by available literature. Genetic selection and subsequent rate of improvement in chickens is much faster than other livestock. In 1925 the typical broiler chicken as 112 days of age and weighed 2.5 lb at slaughter while in 2015 the typical broiler chicken was only 48 days of age but weighed 6.24 lb (National Chicken Council, 2016). Similar advancements have been made in egg production (American Egg Board, 2014). Rapid genetic improvement and dramatic changes in husbandry practices within the poultry industry makes drawing direct comparisons between historic feeding comparisons and current production systems challenging. Perhaps more so than other species there is a definite need for revalidation of suggested inclusion rates for small grains in poultry diets. Table 7 summarizes recommendations for upper limits of small grain inclusion in poultry diets.

<u>Oats</u>

Early work demonstrated that "heavy test weight" oats could replace 20% of the corn grain in diets fed to growing chicks without adversely impacting growth rate or feed efficiency (Carrick and Roberts,1948). Later it was shown that broilers fed a balanced diet consuming 45% oats performed similarly to those fed 0% oats in two replicated trials involving 3,000 birds (Beacom, 1963). Similarly, Petersen (1969) found no difference in growth rate of broilers fed diets containing 67.3% corn or 50% oats + 17.3% corn., but feed efficiency was reduced in the diet containing oats. Feeding oat-based diets (>59% oats) for layer hens resulted in similar performance to corn-based diets (Lillie and Denton, 1967).

Traditional oats (*Avena sativa)* typically include a robust hull that remains with the grain and dilutes the starch and protein fractions of this feedstuff. Varieties oat with a loosely attached hull that is easily winnowed off as it is harvested—aka Naked oats (*Avena nuda)*— have been developed and have higher starch and protein and lower fiber as compared to traditional oats, making them a more attractive feed for poultry. It was demonstrated that layers could be fed diets containing up to 60% naked oats without reducing egg yield or production as compared to a corn-soybean meal diet (Cave et al. 1989). Naked oats partially replaced both corn and soybean meal in the experimental diets, while maintaining bird performance (Cave et al. 1989). Maurice et al. (1985) demonstrated that broiler chickens could be fed balanced diets containing up to 40% naked oats and perform similarly to broilers fed the corn-soybean meal control diet. Balanced diets containing 66% naked oats have also been reported to support performance in turkeys (MacLean et al. 1993). Leeson and Summers (2005) recommends maximum inclusion rate of naked oats at 40% for broiler and 50% for layers.

Barley

Arscott et al. (1955) demonstrated that broilers fed a corn-soybean diet could include 15.25% barley while maintaining growth and performance. Growth rate and feed efficiency was reduced in broilers fed a diet containing 50% barley + 17.3% corn as compared to broilers fed a diet containing 67.3% corn (Peteren 1969). In that study diets were not formulated to be equivalent in energy and amino acids and so the diets containing barley had reduced energy concentration as compared to the corn based diets (Petersen 1969). Growth and performance of broilers fed balanced diets containing 30% barley was similar to broilers fed corn-soybean meal diets but litter conditions deteriorated when birds were fed more than 20% barley (Brake et al. 1997). When birds were supplemented with an enzyme complex with xylanse and protease activity it was demonstrated that barley could replace all corn in broiler diets (Gracia et al., 2003).

Compared to broilers, turkeys have a more expansive gastro-intestinal tract which may improve utilization of barley by turkeys as compared to broilers. Growing turkeys performed similarly when fed diets containing either corn or barley from week 8-20 (Moran and McGinnis

1966). Turkeys fed 70-86% barley had wetter litter, but this was alleviated when birds were fed diets supplemented with an enzyme complex (Moran and McGinnis, 1966).

Mohammed et al. (2010) demonstrated that barley can replace 50% of the corn in a layer hen diet while maintaining egg quality and production (barley inclusion rate of 30% in final diet). Balnave (1970) demonstrated that layers could be fed barley-based diets (55% inclusion rate) balanced for linoleic acid content while maintaining hen development, egg production, and feed efficiency similar to those obtained with corn-based diets. Barley (50% inclusrion rate) can replace 90% of the corn in layer hen diets without impacting egg production or feed efficiency, but was associated with a higher incidence of dirty eggs (Lázaro et al. 2003). Supplementing barley-based diets with xylanse and ß-glucanase improved feed efficiency and egg production while reducing incidence of dirty eggs (Lázaro et al. 2003). Adding enzymes to water also enhanced utilization of barely in layer hen diets (Mohammed et al. 2010). Benabdeljelil and Arbaoui (1994) reported that improved utilization of barley-based diets by laying hens with enzyme supplementation of feed. Feeding barley-based diets (57.8% inclusion rate) supported egg production but reduced feed efficiency as compared to a corn-based diet (Coon et al. 1988). No enzymes were fed in this study and diets were not balanced for linoleic acid content (Coon et al. 1988). In contrast, when enzyme-supplemented barley-based diets (45% inclusion) containing sufficient linoleic acid were fed to layer hens, egg production, egg quality, and feed efficiency was similar to the corn-based control (Pérez-Bonilla et al. 2011). Leeson and Summers (2005) recommends maximum inclusion rate of barely at 10% for birds younger than 4 weeks and 15% for birds older than 4 weeks. If barley-based poultry diets are supplemented with β-glucanase enzymes, barley can account for 30–40% of the total diet (Leeson and Summers, 2005).

Wheat

Gardiner (1973) demonstrated that some varieties of wheat were equal to or superior to corn in supporting broiler chick performance. In contrast, growth rate and feed efficiency was reduced in broilers fed a diet containing 50% wheat + 17.3% corn as compared to broilers fed a diet containing 67.3% corn (Peteren 1969). In that study diets were not formulated to be equivalent in energy and amino acids and so the diets containing wheat had reduced energy concentration as compared to the corn based diets (Petersen 1969). When diets were formulated to be equivalent in energy and amino acids, broilers fed wheat-based diets (52% of total) performed as well as broilers fed a corn-based diet (49% of total) (Gardiner et al. 1981). Recent work has demonstrated that wheat can substitute for corn in broiler diets and that supplementation with xylanase improves utilization of wheat based diets (Chiang et al. 2005). Rodríguez et al. (2011) also demonstrated that supplementing a wheat and barley-based diet with xylanse and ß-glucanase improved utilization in broiler chickens with performance of birds fed the supplemented diet being equivalent to those fed a corn-based diet.

Wheat can replace corn in balanced diets fed to growing turkeys without negatively impacting growth or performance (Waldroup 1967; Hulet et al. 1993). Harper et al. (1981) demonstrated that wheat could also replace corn in diets fed to breeding turkeys. Odetallah et al. (2002) demonstrated improved utilization of wheat-based diets by turkeys when diets were supplemented with xylanse and ß-glucanase.

Lillie and Denton (1968) reported that wheat can replace corn in layer diets when diets are balanced for protein. Balnave (1970) demonstrated that layers could be fed wheat-based diets (55% inclusion rate) balanced for linoleic acid content while maintaining hen development, egg production, and feed efficiency similar to those obtained with corn-based diets. Later work has confirmed that if diets are balanced appropriately, wheat can replace corn in layer hen diets without impacting performance (Liebert et al. 2005; Saffa et al. 2009). When enzyme-supplemented wheat-based diets (45% inclusion) containing sufficient linoleic acid were fed to layer hens, egg production, egg quality, and feed efficiency was similar to the corn-based control (Pérez-Bonilla et al. 2011). Replacing corn with wheat in layer hen diets did not impact egg production or feed efficiency, but was associated with a higher incidence of dirty eggs (Lázaro et al. 2003). Supplementing wheat-based diets with xylanse and ß-glucanase improved feed efficiency and egg production while reducing incidence of dirty eggs (Lázaro et al. 2003). Leeson and Summers (2005) recommends maximum inclusion rate of wheat at 20% for birds younger than 4 weeks and 25% for birds older than 4 weeks. If wheat-based poultry diets are supplemented with appropriate enzymes, wheat can account for 40–50% of the total diet (Leeson and Summers, 2005).

Rye

Broiler growth and performance can be supported by diets containing 10% rye (Proudfoot, 1977). Feeding diets containing 18% or more rye reduced broiler performance as compared to a barley and wheat-based control diet (Boros et al. 1995). Broilers fed rye-based diets (>50% inclusion) grew slower and less efficiently as compared to broilers fed wheat based diets (Józefiak et al. 2007 and Lázaro et al. 2004). Supplementing rye-based diets with xylanase improved utilization by broilers, but performance still lagged behind birds fed wheat- based diets (Józefiak et al. 2007; Lázaro et al. 2004). Recently it was demonstrated that feeding 5-10% rye to growing broilers had little impact on animal performance but may improve immune competence by impacting gut morphology, microbiota, and gene expression (van Krimpen et al. 2017).

Layer diets can contain up to 45% rye without impacting egg production or feed efficiency, but higher levels negatively impact performance as compared to wheat-based layer diets (Campbell and Campbell 1989). Diets containing 35% rye grain can support egg production or feed efficiency in layer hens, but were associated with a higher incidence of dirty eggs (Lázaro et al. 2003). Supplementing rye-based diets with xylanse and ß-glucanase improved feed efficiency and egg production while reducing incidence of dirty eggs (Lázaro et al. 2003).

Triticale

Broiler growth and feed efficiency was similar when fed corn-soybean diets containing 0, 5, 10, or 15% triticale (Hermes and Johnson 2004). It has been reported that broiler diets can contain up to 40% triticale without impacting growth rate or feed efficiency as compared to a corn-soybean meal control (Vieira et al. 1995). In contrast, broilers fed triticale-based diets grew slightly slower and less efficiently than broilers fed a wheat-based diet (Korver et al. 2004). In a third study, broilers fed triticale-based diets (> 60% inclusion) grew similarly to broilers fed wheat based diets (Józefiak et al. 2007). Differences across studies are likely due to using differences in broiler genetics and management, as well as varieties of grain and other dietary factors. Xylanase supplementation has been shown to improve utilization of triticale-based diets fed to broiler chickens (Józefiak et al. 2007; Mendes et al. 2013).

Fernandez et al. (1973) demonstrated that layer performance was similar when birds were fed either triticale-based (85% inclusion rate) or corn-based diets. Layer diets containing 42% triticale supported egg production as well as a corn-soybean meal control diet (Kim et al. 1976). Çiftci et al. (2003) demonstrated that triticale can be substituted for wheat in layer diets up to 60% without impacting egg production or quality. Egg yolk color was lighter when triticale was fed alone, but when mixed with corn grain (30% triticale + 33% corn) egg yolk color improved

(Çiftci et al., 2003). Later work showed that egg production was maintained on diets containing 30% triticale but yolk color was reduced as compared to layers fed the corn-soybean meal control diet (Hermes and Johnson 2004).

Small Grains for Pigs

Recommended upper limits of usage for feed ingredients in swine diets have been presented (Sullivan et al. 2005 and Reese et al. 2010) and are summarized in table 8. More so than other species upper limits have been examined and tested in pigs at various weights and production phases. The weight based recommendations incorporate physiological changes in the gastrointestinal tract and shifting nutritional requirements of pigs at different stages of production. Because further review of previous feeding trials examining small grains in pigs would be redundant (see table 8), this review will focus on work examining the two grains—oats and rye—that have the lowest recommended inclusion rates

Oats

As with other grains, quality of the oats fed is an important consideration when evaluating animal performance (Jensen et al. 1959). In a South Dakota study, 96 pigs were fed balanced diets containing 0, 20, 40, or 60% oat grain from 60–200 lb (Wahlstrom and Libal, 1975). Heavy test weight (33 lb/bushel) oats were used in this study and no differences in growth rate, feed intake, or feed efficiency were detected across treatments (Wahlstrom and Libal, 1975). More recently, Fortin et al. (2003) demonstrated that finishing pigs could be fed up to 70% oats in a balanced ration and performed similarly and produced carcasses comparable to pigs fed a control diet that used wheat and barley as the main source of carbohydrate energy.

Rye

Enzyme supplementation is a strategy that can enhance utilization of small grains by pigs (Woyengo et al. 2008 and Owusu-Asiedu et al 2012). However results are variable based on specific enzyme used, activity of that enzyme, and other dietary factors. Xylanase supplementation alone did not improve nutritional value of rye in growing pigs (Lærke et al. 2015 and Nørgaard et al. 2016). However, feeding an enzyme complex with both xylanase and multiple β-glucanse activities enhanced utilization of rye-based diets fed to pigs using a liquid feeding system (Villca et al. 2016). European work summarized by Meyer et al. (2017) reports that feeding balanced diets containing up to 50% rye grain can support finishing pig growth and performance with lower levels being recommended for smaller pigs and lactating sows.

Conclusion

Small grains can support efficient production in broilers, layers, turkeys, and pigs. Typically replacing corn with small grains in corn-based diets for nonruminants will also enable reduced use of protein supplements such as soybean meal. The type and quantity of fermentable carbohydrates varies in grain. Differences in performance by nonruminant animals when fed diets formulated to be balanced for energy and nutrients may be attributed to the differences in fermentable carbohydrates found in various feedstuffs and the subsequent impact on dietary energy and nutrient availability. The use of exogenous enzymes can be beneficial particularly when feeding wheat and barley to broilers and young pigs, but the efficacy of enzyme supplementation tends to decrease as the animal matures and is not uniform across variety of grain or growing season. Partial replacement of corn with small grains in pig and poultry diets can result in nutritionally adequate diets that support animal performance. Tables 7 and 8 present recommendations for maximal inclusion rate of small grains in diets fed to poultry and pigs respectively.

Citations

American Egg Board. 2014. Fifty Year Study Documents U.S. Egg Industry Reduced Environmental Impact. American Egg Board, Park Ridge, IL. available online at http://www.aeb.org/images/PDFs/FoodManufacturers/WP-sustainability.pdf

Arscott, G. H. , L. E. Johnson, and J. E. Parker. 1955. The use of barely in high-efficiency broiler rations. 1. The influence of methionine, grit, and stabilized animal fat on efficiency of utilization. Poultry Science. 35:655–662.

Balnave, D. 1970. The influence of energy intake and dietary maize oil supplementation of layers' rations containing maize, wheat, or barley as the sole cereal ingredient. Poultry Science 49:1197–1202.

Beacom, S. E. 1963. The effects of including graduated levels of ground oats in growing rations for broilers. Canadian Journal of Animal Science. 43:9–15.

Benabdeljelil, K. and M. I. Arbaoui. 1994. Effects of enzyme supplementation of barley-based diets on hen performance and egg quality. Animal Feed Science and Technology. 48:325–334.

Boros. D., R. R. Marquardt, and W. Guenter. 1995. Rye as an alternative grain in commercial broiler feeding. The Journal of Applied Poultry Research. 4:341–351. doi: 10.1093/japr/4.4.341

Brake, J. D., D. E. Brann, and C. A. Griffey. 1997. Barley without enzyme supplementation in broiler grower and finisher diets. Journal of Applied Poultry Research. 6:422–431.

Campbell, G. L. and L. D. Campbell. 1989. Rye as a replacement for wheat in laying hen diets. Canadian Journal of Animal Science. 69:1041–1047.

Cave. N. A., R. M. G. Hamilton, and V. D. Burrows. 1989. Evaluation of naked oats (Avena nuda) as a feedstuff for laying hens. Canadian Journal of Animal Science. 69:789–799.

Carrick, C. W., R. E. Roberts. 1948. Studies on feed efficiency. II. The relative efficiency of corn and oats in chicken rations. Poultry Science 27:213–218.

Chiang, C. C., B. Yu, P. W.S. Chou. 2005. Effects of xylanse supplementation of wheat-based diets on the performance and nutrient availability of broiler chickens. Asian-Australian Journal of Animal Science. 18:1141–1146.

Çiftc, İ. E. Yenice, and H. Eleroglu. 2003. Use of triticale alone and in combination with wheat or maize: effects of diet type and enzyme supplementation on hen performance, egg quality, organ weights, intestinal viscosity, and digestive system characteristics. Animal Feed Science and Technology. 105:149–161.

Cobb-Vantress Inc. 2012. Cobb Broiler Management Guide. Cobb-Vantress Inc. Siloam Springs, Arkansas, USA. available online at: http://www.cobb-vantress.com/docs/default-source/management-guides/broiler-management-guide.pdf

Fernandez, R., S. M. Kim, J. L. Buenrostro, J. McGinnis. 1973. Triticale and rye as main ingredients in diets for laying hens. Poultry Science. 52:2244–2252. https://doi.org/10.3382/ps.0522244

Fortin, A., W. M. Robertson, S. Kibite, and S. J. Landry. 2003. Growth performance, carcass and pork quality characteristics of pigs fed oat-based diets containing different levels of ß-glucans. Journal of Animal Science. 81:449–456.

Gardiner, E. E. 1973. A comparison of corn, Glenlea, Pitic 62, and Neepawa wheats in broiler diets. Canadian Journal of Animal Science. 53:547–550.

Gardiner, E. E., S. Dubetz, and D. J. Major. 1981. Sorghum, wheat, and corn in diets for broiler chickens. Canadian Journal of Animal Science. 61:511–513.

Gracia, M. I., M. A. Latorre, M. Garcia, R. Lázaro, and G. G. Mateos. 2003. Heat processing of barley and enzyme supplementation of diets for broilers. Poultry Science 82:1281–1291.

Harper. J. A., G. H. Arscott, W. B. Roush, and M. P. Goeger. The comparative feeding value of corn and wheat with and without an enzyme supplement in turkey breeder rations. Poultry Science. 61:1183–1187.

Hermes, J. C. and R. C. Johnson. 2004. Effects of feeding various levels of triticale var. Bogo in the diet of broiler and layer chickens. Journal of Applied Poultry Research. 13:667–672. https://doi.org/10.1093/japr/13.4.667

Hy-Line LLC. 2016. Hy-Line Management Guide for Commerical Layers. Hy-Line North America LLC. Wilton, Iowa, USA. available online at: http://www.hyline.com/UserDocs/Pages/BRN_COM_ENG.pdf

Hulet, R. M. , D. M. Denbow, and L. M. Potter. 1993. Effects of lighting and dietary energy source on male market turkeys : 1. Growth performance data. Poultry Science. 72:1459–1466.

Jensen, A. H., D. E. Becker, and S. W. Terrill. 1959. Oats as a replacement for corn in complete mixed rations for growing-finishing swine. Journal of Animal Science. 18:701–709.

Józefiak, D., A. Rutkowski, B. B. Jensen, and R. M. Engberg. 2007. Effects of dietary inclusion of triticale, rye, and wheat and xylanase supplementation on growth performance of broiler chickens and fermentation in the gastrointestinal tract. Animal Feed Science and Technology. 132:79–93.

Kim, S. M., M. B. Patel, S. J. Reddy, J. McGinnis. 1976. Effects of different cereal grains in diets for laying hens on production parameters and liver fat content. Poultry Science, 55: 520–530. doi: 10.3382/ps.0550520

Lærke, H. N., S. Arent, S. Dalsgaard, and K. E. Bach Knudsen. 2015. Effect of xylanase on ileal viscosity, intestinal fiber modification, and apparent ileal fiber and nutrient digestibility of rye and wheat in growing pigs. Journal of Animal Science. 93:4323–4335. doi: 10.2527/jas2015-9096

Lázaro, R., M. García, M. J. Araníbar, and G. G. Mateos. 2003. Effect of enzyme addition to wheat-, barley-, and rye-based diets on nutrient digestibility and performance of laying hens. British Poultry Science. 44:256–265.

Lázaro, R., M. A. Latorre, P. Medel, M. Gracia, and G. G. Mateos. 2004. Feeding regimen and enzyme supplementationto rye-based diets for broilers. Poultry Science. 83:152–160.

Leeson, S. and J. D. Summers. 2005. Commercial Poultry Nutrition. 3rd Edition. Nottingham University Press.

Liebert, F., J. K. Htoo, and A. Sünder. 2005. Performance and nutrient utilization of laying hens fed low-phosphorus corn-soybean and wheat-soybean diets supplemented with microbial phytase. Poultry Science. 84:1576–1583. https://doi.org/10.1093/ps/84.10.1576

Lillie, R. J. and C. A. Denton. Evaluation of four cereal grains and three protein level combinations for layer performance. Poultry Science. 47:1000–1004.

MacLean, J., A. B. Webster, and D. M. Anderson. 1993. Naked oats in grower and finishing diets for male chicken roasters and female turkey broilers. Canadian Journal of Animal Science. 74:135–140.

Maurice. D. V., J. E. Jones, M. A. Hall, D. J. Castaldo, J. E. Whisenhunt, and J. C. McConnell. 1985, Chemical composition and nutritive value of naked oats (Avena nuda L.) in broiler diets. Poultry Science. 64:529–535. https://doi.org/10.3382/ps.0640529

Mendes, A. R., T. Ribeiro, B. A. Correia, P. Bule, B. Maçãs, L. Falcão, J. P. B. Freire, L. M. A. Ferreira, C. M. G. A. Fontes, M. M. Lordelo. 2013. Low doses of exogenous xylanase improve the nutritive value of triticale-based diets for broilers. The Journal of Applied Poultry Research. 22:92–99. https://doi.org/10.3382/japr.2012-00610

Meyer, A., W. von Gagern, T. Schwarz, M. Pieszka, M. Lopuszanska-Rusek, M. Kamyczek, and C. H. Heuer. 2017. Rye in pig and cattle feed. Available online at http://www.ryebelt.com/fileadmin/Redakteure/RYE_BELT/UK/RyeBelt_Fuetterungsbrosch%C3%BCre_eng_web.pdf

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Mohammed, Kh. A., M. A. Toson, H. H. M. Hassanien, M. A. H. Soliman, and S. H. M. El-Nager. 2010. Effects of barley replacement and enzyme supplementation on performance and egg quality of laying hens. Egyptian Poultry Science. 30:731–745

Moran, E. T. Jr. and J. McGinnis. 1966. A comparison of corn and barley for the developing turkey and the effect of antibiotic and enzyme supplementation. Poultry Science. 45:636–639.

National Chicken Council. 2016. US Broiler Performance. National Chicken Council, Washington D.C. available online at http://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance/

Nørgaard, J. V., T. F. Pedersen, K. Blaabjerg, K. E. Bach Knudsen, and H. N. Lærke. 2016. Xylanase supplementation to rye diets for growing pigs. Journal of Animal Science. 94:91–94. doi:10.2527/jas2015-9775

Odetallah, N. H., C. W. Parks, and P. R. Ferket. 2002. Effect of wheat enzyme supplementation on the performance characteristics of tom turkeys fed wheat-based rations. Poultry Science. 81: 987–994.

Owusu-Asiedu, A., E. Kiarie, A. Péron, T. A. Woyengo, P. H. Simmons, and C. M. Nyachoti. 2012. Growth performance and nutrient digestibilities in nursery pigs receiving varying doses of xylanase and β-glucanase blend in pelleted wheat- and barley-based diets. Journal of Animal Science. 90:92–94. doi:10.2527/jas51323

Petersen. V. E. 1969. A comparison of the feeding value for broilers of corn, grain sorghum, barley, wheat, and oats and the influence of the various grains on the composition and taste of broiler meat. Poultry Science. 48:2006–2013. https://doi.org/10.3382/ps.0482006

Pérez-Bonilla, A., M. Frikha, S. Mirzaie, J. García, and G. G. Mateos. 2011. Effects of the main cereal and type of fat of the diet on production performance and egg quality of brown-egg laying hens from 22 to 54 weeks of age. Poultry Science. 90:2801–2810. https://doi.org/10.3382/ps.2011-01503

Proudfoot, F. G. 1977. Effects of different proportions of rye to wheat in the grain component of broiler finisher diets on general performance. Canadian Journal of Animal Science. 57:495–497.

Reese, D. E., E. van Heugten, H. H. Stein, J. M. DeRouchey, J. M. Benz, and J. F. Patience. 2010. Composition and usage rate of feed ingredients for swine diets. National Swine Nutrition Guide. U.S. Pork Center of Excellence. PIG 08-07-09.

Rodríguez, M. L. , A. Rebolé, S. Velasco, L. T. Ortiz, J. Teviño, and C. Alzueta. 2011. Wheat- and barley-based diets with or without additives influence broiler chicken performance, nutrient digestibility, and intestinal microflora. Journal of the Science of Food and Agriculture. 92:184–190.

Saffa, H. M., Jiménez-Moreno, V. M Frikha, M. P. Serrano, and G. G. Mateos. 2009. Effect of main cereal of the diet and particle size of the cereal on productive performance and egg quality of brown egg-laying hens in early phase of production. Poultry Science. 88:608–614. doi: 10.3382/ps.2008-00328

Sullivan, Z., M. S. Honeyman, L. Gibson, J. McGuire, and M. Nelson. 2005. Feeding small grains to swine. Iowa State University Extension PM 1994.

USDA-NASS. 2017. Poultry-Production and Value 2016 Summary. USDA, National Agricultural Statistics Service. Washington D.C. available online at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1130

van Krimpen, M. M., M Torki, and D. Schokker. Effects of rye inclusion in grower diets on immune competence-related parameters and performance in broilers. Poultry Science. pex152, https://doi.org/10.3382/ps/pex152

Vieira, S. L., A. M. Penz, Jr., A. M. Kessler, E. V. Catellan, Jr. 1995. A nutritional evaluation of triticale in broiler diets. The Journal of Applied Poultry Research. 4: 352–355. doi:10.1093/japr/4.4.352

Villca, B., R. Lizardo, J. Broz, J. Brufau, and D. Torrallardona. 2016. Effects of a carbohydrase enzyme complex on the nutrient apparent total tract digestibility of rye-based diets fed to growing-finishing pigs under liquid feeding. Journal of Animal Science. 94:230–233. doi: 10.2527/jas2015-9747

Waldroup, P. W., D. E. Greene, R. H. Harris, J. F. Maxey, and E. L. Stephenson. 1967. Comparison of corn, wheat, and milo in turkey diets. Poultry Science. 46:1581–1585

Wahlstrom, R. C. and G. W. Libal. 1975. Varying levels of high-protein oats in diets for growing-finishing swine. Journal of Animal Science 41:809–812.

Woyendo, T. A., J. S. Sands, W. Guenter, and C. M. Nyachoti. 2008. Nutrient digestibility and performance response of growing pigs fed phytase- and xylanase-supplemented wheat-based diets. Journal of Animal Science. 86:848–857. doi:10.2527/jas2007-0018

Table 7. Recommended upper limits of usage (% of diet) for small grain in poultry diets

Grain	Chicken		Growing
	Broilers	Layers	Turkeys
Barley	30[1]	50[1]	70[1]
Barley + Enzymes[2]	*	*	*
Oats	45[3]	60[3]	ND
Naked Oats[4]	40	50	65
Rye	10	35[5]	ND
Triticale	*[6]	30[7]	ND
Wheat	20	25	*
Wheat + Enzymes[7]	*	*	*

An * denotes no nutritional limit in a complete diet balanced for energy, essential amino acids, essential fatty acids, minerals, and vitamins

ND = insufficient peer reviewed data available to make recommendation

[1] Feeding barley at these levels supported performance but was associated with higher incidence of dirty eggs and/or wet litter. These issues can be alleviated through supplementing with xylanase and ß-glucanase

[2] Xylanase and ß-glucanase supplementation is recommended for barley-based diets

[3] Based on work prior to 1970, modern genetics and management systems may not support this level of inclusion

[4] *Avena nuda*

[5] Feeding 35% rye associated with dirty eggs unless supplemented with xylanase and ß-glucanase

[6] Supplementing triticale-based diets with xylanase has been shown to improve utilization by broilers

[7] Higher levels will support production but may be associated with lighter egg yolk color

[8] Xylanase and ß-glucanase supplementation is recommended for wheat-based diets

Table 8. Recommended upper limits of usage (% of diet) for small grains in pig diets[1]

	Growing Pig weight range, lb				Sow Production Phase	
Grain	<25	25-50	50-125	125-315	Gestation	Lactation
Barley	*	*	*	*	*	*
Oats[2]	15	30	35	40	*	10
Oat groats[3]	*	*	*	*	*	*
Rye	0	10	25	35	20	10
Triticale	20	30	*	*	*	40
Wheat	*	*	*	*	*	*

[1] Based on Reese et al. 2010.

An * denotes no nutritional limitations in a complete diet balanced for energy, essential amino acids, minerals, and vitamins.

[2]Research has demonstrated that if high quality oats are fed as part of nutritionally balanced diets, pig performance can be supported at higher levels than reported here (Wahlstrom and Libal, 1975; Fortin et al. 2003).

[3]Oat groats are whole oats that have been processed to remove the fibrous hull.

Chapter 4. Health and Environmental Impact of Dietary Fiber fed to Pigs and Poultry

Dietary fiber (DF) is a collective term that refers to carbohydrates and associated plant substances that are resistant to digestion and absorption in the small intestine but can be partially or completely fermented by microbes in the large intestine (AACC 2001, NRC 2012). High levels of DF reduce energy and organic matter digestibility of feedstuffs fed to pigs and poultry. However, a minimum level of dietary fiber has to be included in pig and poultry diets to maintain normal physiological function in the gastrointestinal tract (Wenk 2001, Kleyn 2013). As discussed in chapter 1 small grains have more dietary fat than corn and so one way to increase dietary fiber would be to include small grains in diets fed to livestock. This chapter briefly reviews the impact of dietary fiber on animal health and environmental impact when fed to pigs and chickens.

The results of 37 experiments in which multiple types and levels (0.5–29.7%) of dietary fiber were fed to weaned pigs have been summarized by Flis et al. (2017). Although increasing total DF decreased digestibility, moderate levels (1.5-8%) of insoluble DF resulted in increased feed intake and improved growth rate (Flis et al. 2017). Sources of insoluble DF include oat and barley hulls as well as corn and wheat bran. Feeding oat hulls (2-4% of total diet) to pigs resulted in improved fecal consistency and reduced incidence of post-weaning diarrhea and antibiotic intervention (Flis et al. 2017). An increase in the counts of beneficial gut microbiota and short chain fatty acids were stimulated by increasing DF and indicates that increasing DF may improve intestinal barrier function (Flis et al. 2017). Overall, the studies reviewed by Flis et al. (2017) suggest that feeding 2% oat hulls to weaned pigs would promote gut development and health while improving growth performance. Although there is variation among oat varieties, oat hulls may constitute up to 25% of the total weight of oat grain (Crosbie et al. 1984). If oats are 25% hulls by weight, than a 2% oat hull inclusion rate is equivalent to 8% oat grain.

Dietary fiber supports bacterial fermentation that shifts nitrogen excretion away from urine to feces. The stability of nitrogen is greater when it is incorporated into feces rather than urine and thus shifting nitrogen excretion away from urine to feces is associated with lower ammonia emissions from pig manure (Aarnink et al. 2007). As reviewed by Jha and Berrocoso (2016) inclusion of DF in pig diets is an effective strategy to alter nitrogen excretion pathways in the gut and minimize negative environmental consequences of pig production. Beet pulp fiber has been shown to result in enhanced bacterial fermentation and shift nitrogen excretion away from urine to feces when fed to growing pigs (Patráš, 2012). Similarly, when finishing pigs were fed diets containing 64.5% oats they harbored increased populations of beneficial microbes and had decreased manure odor emissions compared to those fed barley-based diets (O'Shea et al. 2010).

Neutral detergent fiber (NDF) is an analysis that is often used to quantify fiber content of livestock diets. Although not identical to DF, diets that contain increased levels of NDF are also likely to contain increased levels of DF. The effect of increasing dietary NDF concentration in layer hen diets was examined in two studies by Roberts et al. (2007a, 2007b). In those studies NDF was increased by approximately 16% through the inclusion of either corn DDGS, wheat middlings, or soybean hulls (Roberts et al. 2007ab). Regardless of source of the increase DF, egg production was maintained and ammonia emissions from layer-hen was reduced when layer hens were fed higher-fiber diets (Roberts et al. 2007ab).

Jimenéz-Moreno et al. (2009) examined the impact of moderate fiber inclusion in growing broilers. Birds fed diets containing 3% oat hulls had improved rate of gain and feed efficiency as compared to birds fed 0% oat hulls during the first twenty-one days of growth. Adding 3% oat hulls to the diets increased NDF by approximately 17% (Jimenéz-Moreno et al. 2009). This higher level of dietary fiber improved total tract digestibility of energy and nutrients and was also associated with beneficial decreases in pH of the gizzard contents (Jimenéz-Moreno et al. 2009). If oats are 25% hulls by weight, then a 3% oat hull inclusion rate is equivalent to 12% oat grain.

Recently the effects of rye inclusion in broiler diet on immune competence-related parameters was examined (van Krimpen et al. 2017). Broilers were fed 0, 5 or 10% rye were fed to pens of broilers for 14 days. Growth rate and litter quality were slightly reduced with increasing rye inclusion (van Krimpen et al. 2017). However gut morphology, microbiota composition, and gene expression profiles of intestinal tissue and contents were affected by dietary rye inclusion in ways that suggest improved immune competence (van Krimpen et al. 2017).

The diverse nature and concentration of dietary fiber constituents in various grains increases the challenge of identifying optimal levels of different ingredients in pig and poultry diets to maintain performance while supporting gut function. Beyond normal physiological function there is a growing body of evidence that moderately increasing dietary fiber concentration supports gut health and thereby maintains animal performance in the absence of growth promoting antibiotics. There is also evidence that moderately increasing dietary fiber is associated with reduced odor and enhanced stability of excreted nitrogen in animal manure. It is clear that increasing inclusion of small grains in the diets of pigs and poultry would generally increase dietary fiber level of the final diet. Although optimal inclusion rates remain to be determined, it is logical to suggest that increasing small grain inclusion in diets of pigs and poultry may allow capture of the demonstrated benefits of dietary fiber in pig and poultry diets.

Citations

Aarnink, A. J. A. and M. W. A. Verstegen. 2007. Nutrition, key factor to reduce environmental load from pig production. Livestock Production Science. 109:194–203.

American Association of Cereal Chemists. 2001. The definition of dietary fiber. Report of the Dietary Fiber Definition Committee to the Board of Directors of the American Association of Cereal Chemists. Cereal Foods World. 46: 112–126.

Crosbie, G. B., A. W. Tarr, P. A. Portman, and J. B. Rowe. 1984. Variation in hull composition and digestibility among oat genotypes. Crop Science. 25:678–680

Flis, M. W. Sobotka, Z. Antozskiewicz. 2017. Fiber substrates om the nutrition of weaned piglets-A review. Annals of Animal Science. 17:627–643. doi: 10.1515/aoas-2016.0077

Jimenéz-Moreno, E., J. M. González-Alvarado, D. González-Sánches, R. Lázaro, and G. G. Mateos. 2009. Effect of dietary fiber and fat on performance and digestive traits of broilers from one to twenty-one days of age. Poultry Science. 88:2562–2574. doi: 10.3382/ps.2009-0017

Kleyn, R. 2013. Chicken Nutrition. A guide for nutritionists and poultry professionals. Context Products Ltd. Leicestershire, England.

National Research Council. 2012. *Nutrient Requirements of Swine: Eleventh Revised Edition*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

O'She, C. J., T. Sweeney, M. B. Lynch, D. A Gahan, J. J. Callan, and J. V. O'Doherty. 2010. Effect of ß-glucans contained in barley- and oat-based diets and exogenous enzyme supplementation on gastrointestinal fermentation of finisher pigs and subsequent manure odor and ammonia emissions. Journal of Animal Science. 88:1411–1420. doi: 10.257/jas.2009-20015

Patráš, P., S. Nitrayová, M. Brestenský and J. Heger. 2012. Effect of dietary fiber and crude protein content in feed on nitrogen retention in pigs. Journal of Animal Science. 90:158–160. doi:10.2527/jas53837

Roberts, S. A., H. Xin, B. J. Kerr, J. R. Russell, and K. Bregendahl. 2007a. Effects of dietary fiber and reduced crude protein on ammonia emission from laying-hen manure. Poultry Science. 86:1625–1632

Roberts, S. A., H. Xin, B. J. Kerr, J. R. Russell, and K. Bregendahl. 2007b. Effects of dietary fiber and reduced crude protein on nitrogen balance and egg production in laying hens. Poultry Science 86:1716–1725.

van Krimpen, M. M., M. Torki, and D. Schokker. Effect of rye inclusion in grower diets on immune competence-related parameters and performance in broilers. Poultry Science. 96:3324–3337. https://doi.org/10.3382/ps/pex152

Wenk, C. 2001. The role of dietary fibre in the digestive physiology of the pig. Animal Feed Science and Technology. 90:21–33