$5.00

WHEAT in LIVESTOCK and POULTRY FEEDS

PROCEEDINGS of an
International Symposium
June 18-19, 1970

Oklahoma State University
Stillwater, Oklahoma 74074

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INTRODUCTION

In June, 1970 Oklahoma State University sponsored an international Symposium on "Wheat in Livestock and Poultry Feeds." At this Symposium fourteen internationally known scientists presented papers on the production, chemical and physical properties, and the feeding values of wheat for livestock and poultry.

The proceedings of the Symposium should fill a long desired need for a single publication which will present a comprehensive review on the feeding of wheat.

Oklahoma State University feels fortunate in having been able to assemble this distinguished group of scientists on our campus. We are proud to be able to offer these papers in the form of this proceedings for all to use.

It is through the cooperation of the Oklahoma Wheat Commission, who helped finance the Symposium, that this proceedings is possible.

DONALD R. GILL
ROLLIN H. THAYER
EDWARD SMITH
Program Chairmen

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Opportunities and Obstacles in Wheat Production and Improvement

LOUIS P. REITZ

Availability of Wheat for Feed

The amount of wheat grain that is fed to livestock varies widely from year to year but it is a relatively small portion of the total crop. Even so, the tonnage is considerable. Since 1964, the average has been about 110 million bushels per year (Table 1) or 3,300,000 tons. Possibly, 200 million bushels of the 1969 crop will be fed (31). In the case of corn, one-half of the crop is fed on the farm where grown; however, only about one-thirtieth of the wheat crop is so utilized. In the Atlantic States (but nowhere else in the United States) about 10% of the wheat has been fed on the same farm where produced. States where more than 3 million bushels of home-grown wheat were fed in 1968 include Pennsylvania, Ohio, Indiana, Michigan, Missouri, Kansas, Montana, and Idaho (6).

The byproducts of milling — mainly bran and shorts — must be added to the quantity of grain that is fed to express the total impact of wheat as feed. The byproducts have been estimated at about 4,500,000 tons annually (Table 1) (1). This is 25% more in total weight than the grain that is fed. Hence, the combined estimates show that wheat annually contributes nearly 8 million tons to the feed supply.

Louis P. Reitz is Research Agronomist and Leader of Wheat Investigations, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland 20705.

Table 1. Wheat: Supply, distribution and prices, average 1964-68 and Annual 1966-69.

(From Wheat Situation 211)

Item	Year beginning July				
	Average 1964-68	1966	1967	1968[1]	1969 Projected
	Million bushels				
Supply					
Beginning carryover	643.6	535.2	425.0	539.4	819
Production	1,401.9	1,311.7	1,522.4	1,576.2	1,459
Imports[2]	1.2	1.7	.9	1.1	1
Total supply	2,046.7	1,848.6	1,948.3	2,116.7	2,279
Domestic disappearance					
Foods[3]	513.1	501.9	519.2	519.8	525
Seed	67.8	78.4	71.5	61.6	55
Industry	.1	.1	.1	.1	---
Feed (residual)[4]	110.2	98.9	57.0	172.5	200
On farms where grown	(40.1)	(26.1)	(42.9)	(58.6)	
Total	691.2	679.3	647.8	754.0	780
Available for Export and Carryover	1,355.5	1,169.3	1,300.5	1,362.7	1,499
Exports[2]	728.4	744.3	761.1	544.1	600
Commercial, incl. barter	(322.6)	(438.8)	(366.9)	(293.2)	
Total disappearance	1,419.6	1,423.6	1,408.9	1,298.1	1,380
Ending carryover	627.1	425.0	539.4	818.6	899
Privately owned—"Free"	(194.5)	(223.7)	(216.2)	(202.9)	
Wheat millfeeds (1,000 tons):	4,700.	4,499	4,490	---	---
	Dollars per bushel				
Price Support					
National average loan rate	1.26	1.25	1.25	1.25	1.25
Average certificate payment	.50	.59	.48	.55	.65
Season Average Price Received					
By non-participants	1.39	1.63	1.39	1.24	1.23
By program participants	1.89	2.22	1.87	1.79	1.88

[1] Preliminary.

[2] Imports and exports are of wheat, including flour and other products in terms of wheat.

[3] Used for food in the United States and U.S. territories, and by the military both at home and abroad.

[4] Assumed to roughly approximate total amount used for feed, including amount used in mixed and processed feed.

[5] Average is for 1962-67. Data from 1969 Suppl. to USDA Stat. Bull. 410.

Statistics on feed use of wheat must be used with caution. USDA values of grain fed are derived partially as a residual after other uses have been apportioned and, therefore, are subject to several unknown factors.

The feeding of wheat depends upon how useful it is for various classes of animals and whether supplies of wheat are available at competitive prices. All my life I have been told that wheat was too dear a product to feed to livestock. This, obviously, is not quite the case. Wheat as feed has been a secondary use; the margin of price and hence, choice, generally has gone in favor of corn, sorghum, barley, and oats, all traditional feed grains.

Table 2. Grain Crop Production in the United States, 1960-69

(From CRPR 2-1 69).

CROP PRODUCTION, UNITED STATES[1], 1960-69

Year	Corn, grain	Oats	Barley	Sorghum grain	Feed grains[2]	Rye
	1,000 bushels				1,000 tons	1,000 bushels
1960	3,906,949	1,153,332	429,005	619,954	155,503	33,108
1961	3,597,803	1,010,314	392,441	480,208	139,768	27,336
1962	3,606,311	1,012,197	427,726	510,284	141,725	40,698
1963	4,019,238	965,510	392,833	585,394	153,806	29,178
1964	3,484,253	852,257	386,059	489,796	134,174	32,476
1965	4,084,342	926,851	392,279	672,698	157,443	33,223
1966	4,117,355	801,327	393,186	714,992	157,563	27,775
1967	4,760,076	789,196	372,898	755,936	176,025	24,154
1968	4,393,273	939,228	422,959	739,695	168,902	23,365
1969	4,577,864	949,874	417,156	743,124	174,197	31,405

	Wheat						
Year	Winter	Durum	Other spring	All	Buckwheat	Rice	Food grains[1]
	1,000 bushels					1,000 cwt.	1,000 tons
1960	1,111,403	34,361	208,945	1,354,709	847	54,591	44,318
1961	1,074,807	21,339	136,213	1,232,359	864	54,198	40,467
1962	822,887	70,260	198,811	1,091,958	828	66,045	37,221
1963	914,090	51,427	181,304	1,146,821	952	70,269	38,758
1964	1,020,987	68,146	194,238	1,283,371	1,020	73,166	43,092
1965	1,017,085	69,866	228,662	1,315,613	[3]	76,281	44,212
1966	1,062,493	62,638	186,571	1,311,702	---	85,020	44,380
1967	1,206,808	66,443	249,131	1,522,382	---	89,379	50,816
1968	1,235,063	99,501	241,687	1,576,251	---	104,075	53,146
1969	1,147,646	106,319	204,907	1,458,872	---	91,303	49,210

[1] Does not include Alaska and Hawaii.

[2] Corn for grain, oats, barley, and sorghum grain.

[3] Estimates discontinued.

[4] Wheat, rice, rye, and buckwheat.

My objective is to present background, outline the status of the problem of feeding wheat, and discuss improvement in terms of supplies, yields, costs, and production.

U.S. wheat producers serve four markets: 1) domestic food; 2) export; 3) feed; and 4) industry. In a long view of opportunities, Palmby (18) concluded that "if we are to make anything like full use of our present capacity to produce wheat, we will have to market increasing amounts as livestock and poultry feed." He emphasized feed usage both domestically and as a part of our exports of wheat.

We can grow much more wheat than we can use for food or export. Our allotment this year is down to 45.5 million acres. As recently as 1967, we harvested 58.7 million acres and in 1949 we harvested 75.9 million acres. The average acre yield for the U.S. has more than doubled in the last 50 years. The fact is inescapable that we have a very great potential for wheat production. Only four wheat crops in the last 25 years

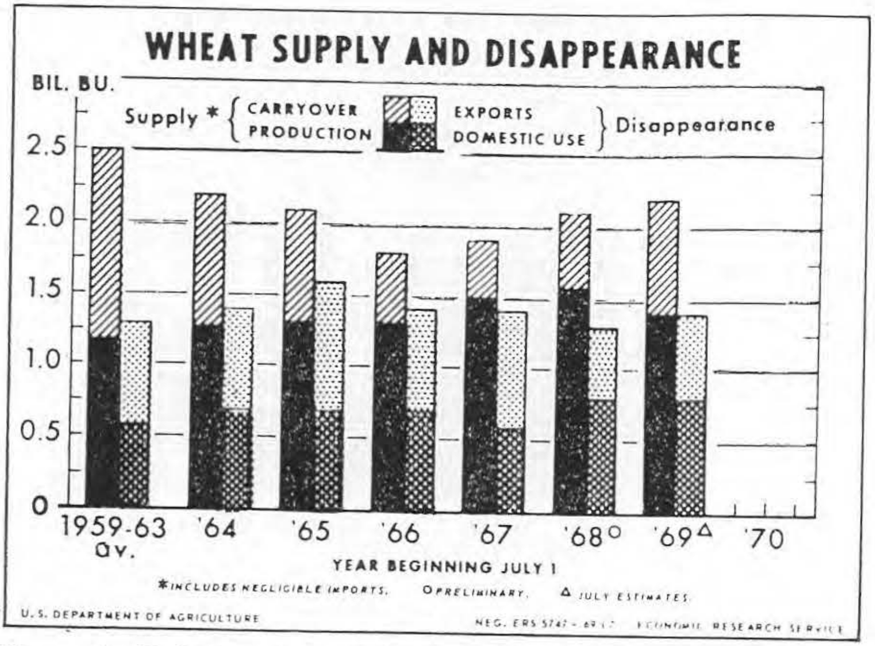


Figure 1. U. S. Supply and Disappearance of Wheat, 1959-1969.
(From Wheat Situation 209).

have fallen below a billion bushels. The last three averaged more than 1.5 billion bushels. By contrast, we have grown feed crops in large amounts as follows: corn, 4.5 billion bushels; oats, 0.9 billion; barley, 0.4 billion; and sorghum, 0.7 billion. Bushels converted to their ton equivalents were 174 million tons in 1969 for feed grains combined and 49 million tons for food grains. The latter includes wheat, rice, and rye. Wheat *vs* feed grains for 1960 to 1969 is shown in Table 2 (23). A return to former acreages of wheat could readily increase output 50% in the United States.

The relationship between wheat and feed grains is complicated by commodity programs. This has been discussed at length by many competent people. Hadwiger (11) says: "Every bushel of wheat not used for food is a potential addition to feed grain supply. Therefore, programs for reducing wheat production and for increasing food outlets for wheat have been of direct concern to feed grains producers. — Assuming a surplus of wheat on the cash food market, wheat growers have had even more reason than feed grains producers to be concerned about the relationship of feed grains and wheat, because the price of the entire production of wheat in a free market would in that event be its feed value."

The wheat supply and disappearance situation is summarized in Figure 1 (31) and Table 1. The combined production and carryover

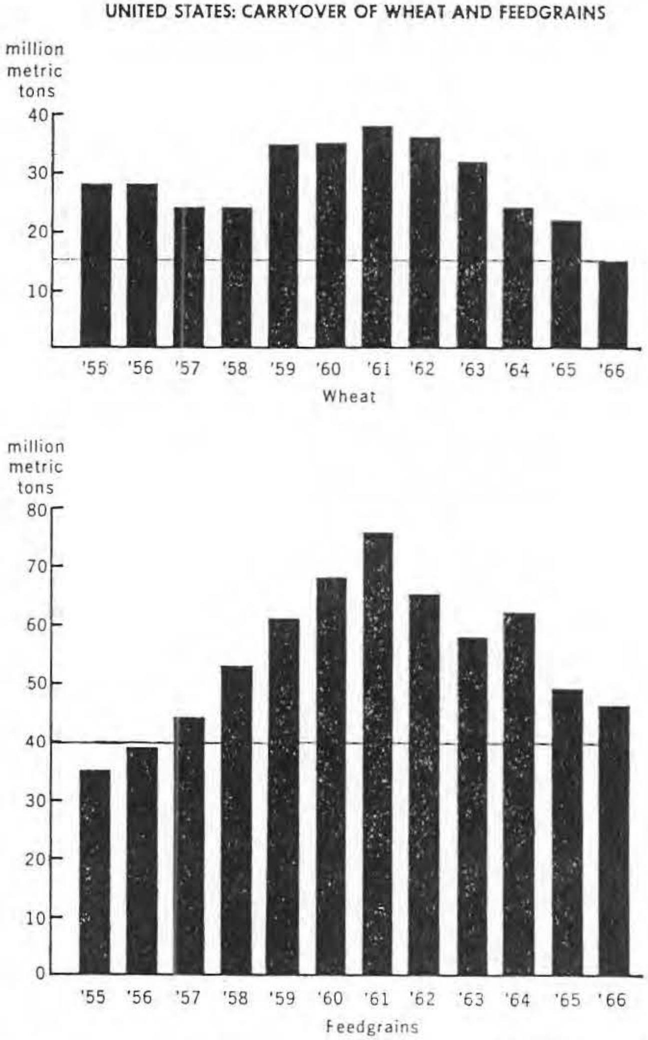
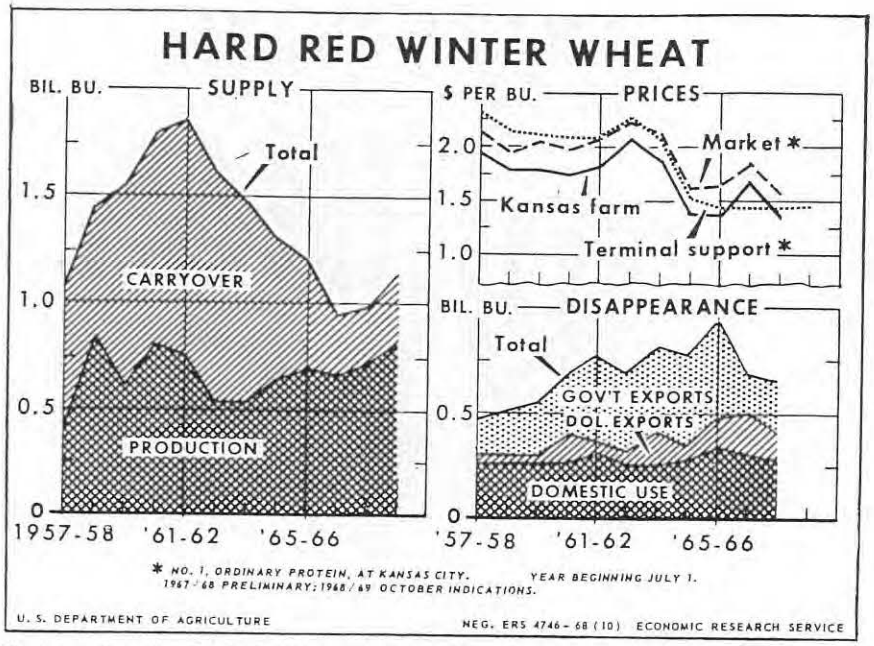


Figure 2. Carryover of Wheat and Feedgrains in the U.S., 1955-1966.
(Freeman).

have approached or exceeded 2 billion bushels in most years and reached 2.5 billion in one year. This was during years when exports were at an all-time high. Feed grains, likewise, have been carried over in substantial amounts. Figure 2 compares the carryover of wheat and feed grains (8). I do not know what amount should be carried over as a safety reserve. Some have said a one-year supply is needed. Sixteen million tons (600 million bushels) of wheat would be required and for feed grains 45 million short tons. If one draws a line from left to right perpendicular



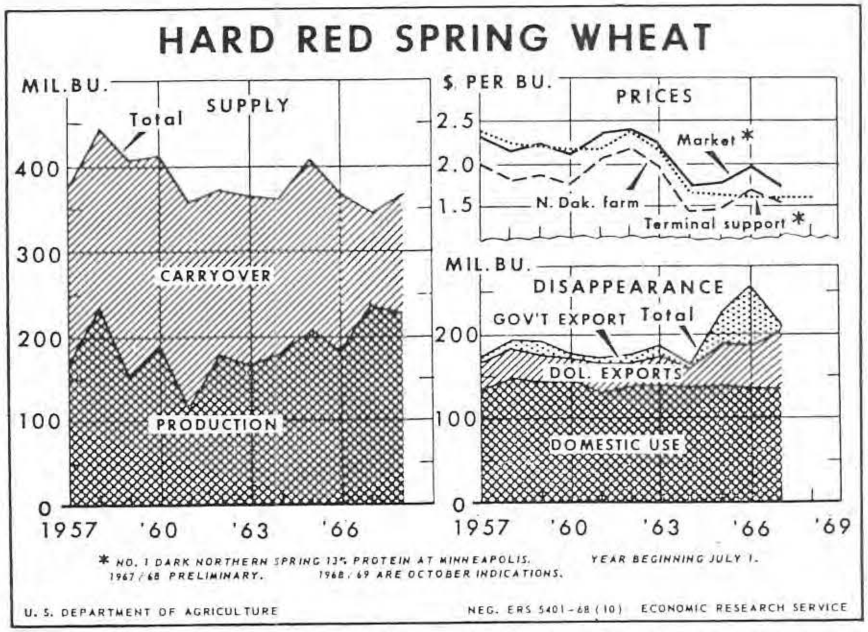
* NO. 1, ORDINARY PROTEIN, AT KANSAS CITY. YEAR BEGINNING JULY 1.
1967/68 PRELIMINARY; 1968/69 OCTOBER INDICATIONS.

U. S. DEPARTMENT OF AGRICULTURE NEG. ERS 4746-68 (10) ECONOMIC RESEARCH SERVICE

Figure 3. Hard Red Winter Wheat Production in the U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).

to the 15 million point for wheat and about 40 million for feed grains on Figure 2, we see that there was excess every year except one for wheat, and excess every year except two for feed grains. So, we are producing now at a moderate level commensurate with a regular outlet for wheat as feed. The amount of excess increased and declined in the same years which shows a competitive situation rather than a complementary one. There could be a great excess for feed in the United States with expanded acreage or reduced exports.

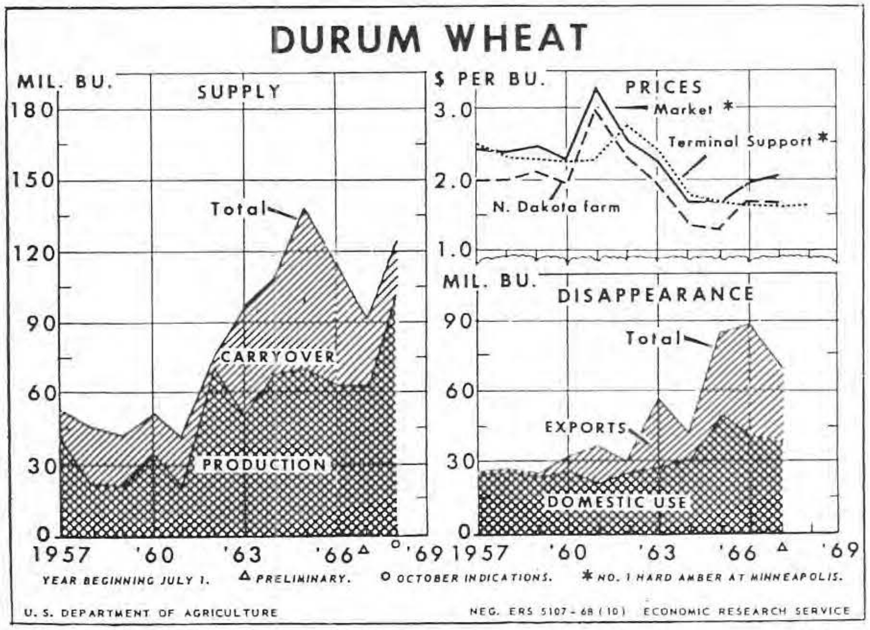
Where have our supplies of wheat come from? A series of graphs will show this clearly. Hard red winter is the concern in Figure 3, hard red spring is shown in Figure 4, durum in Figure 5, eastern soft in Figure 6, and western in Figure 7 (9). The current situation is summarized in Table 3 for 1969 and an estimate is given for 1970 (31). Hard red winter wheat grown mainly in the central and southern Plains, has amounted to about three-fourths of the total carryover. It is also the major export class, with more shipped than all other classes combined. This class has also tended to dominate the price determination. Western wheat is very active also in export; only about one-sixth of the western wheat produced is used domestically. Hard red spring wheat mainly grown in the North-central states, is normally in great demand domestically and for dollar



* NO. 1 DARK NORTHERN SPRING 13% PROTEIN AT MINNEAPOLIS. YEAR BEGINNING JULY 1.
1967/68 PRELIMINARY. 1968/69 ARE OCTOBER INDICATIONS.

U. S. DEPARTMENT OF AGRICULTURE NEG. ERS 5401-68 (10) ECONOMIC RESEARCH SERVICE

Figure 4. Hard Red Spring Wheat Production in the U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).



YEAR BEGINNING JULY 1. △ PRELIMINARY. ○ OCTOBER INDICATIONS. * NO. 1 HARD AMBER AT MINNEAPOLIS.

U. S. DEPARTMENT OF AGRICULTURE NEG. ERS 5107-68 (10) ECONOMIC RESEARCH SERVICE

Figure 5. Durum Wheat Production in the U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).

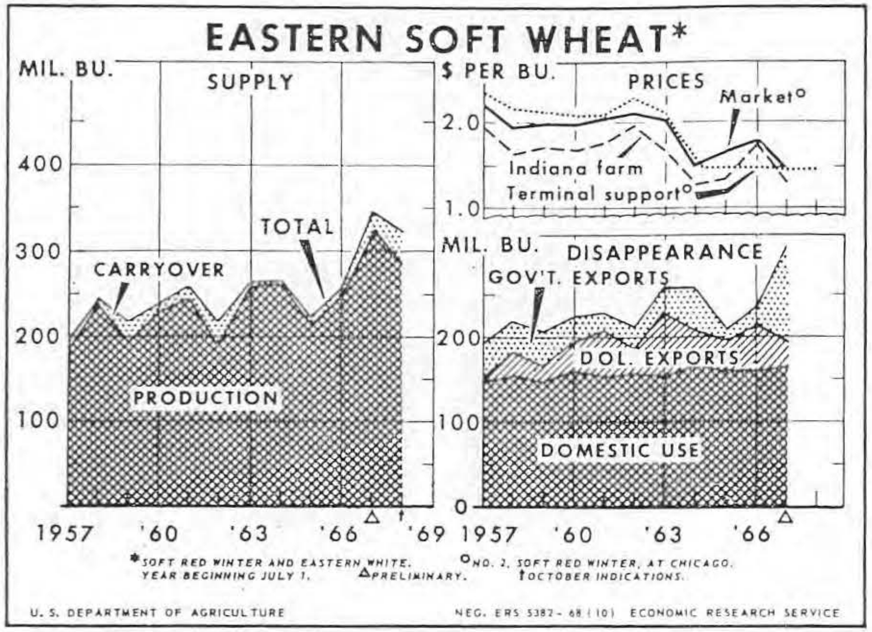


Figure 6. Eastern Soft Wheat Production in the U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).

exports. Only in recent years has there been an excess of durum, a kind of wheat also grown mainly in the Northcentral states. The eastern soft wheat has generally been utilized domestically, partly because of its physical position in heavy-consuming areas and because it has been used liberally for feed (10).

Average U.S. crop yields in pounds per acre harvested for the 10 years 1960-1969 are as follows: rice, 4045; corn, 3920; sorghum, 2682; barley, 1820; wheat, 1583; oats, 1504; rye, 1169 (23). 8hese weights include hulls in the case of rice (about 20%), barley (about 15%), and oats (about 25%). Corn and rice tend to be grown under the most uniformly favorable circumstances; the cultural conditions for the others are highly variable.

The yield comparisons for four grain crops are made for six States in Figure 8. Corn and sorghum lead in productiveness in all six States. Wheat and barley are about equal unless the hulls of barley are deducted. Even within States, the circumstances for culture often differ so much that valid crop-yield comparisons are impossible from such data. In Kansas, for example, the corn acreage is largely in a rainfall belt exceeding 30 inches and most of the wheat is grown in the area with less than that amount. The acreage of corn in North Dakota is small and in Washing-

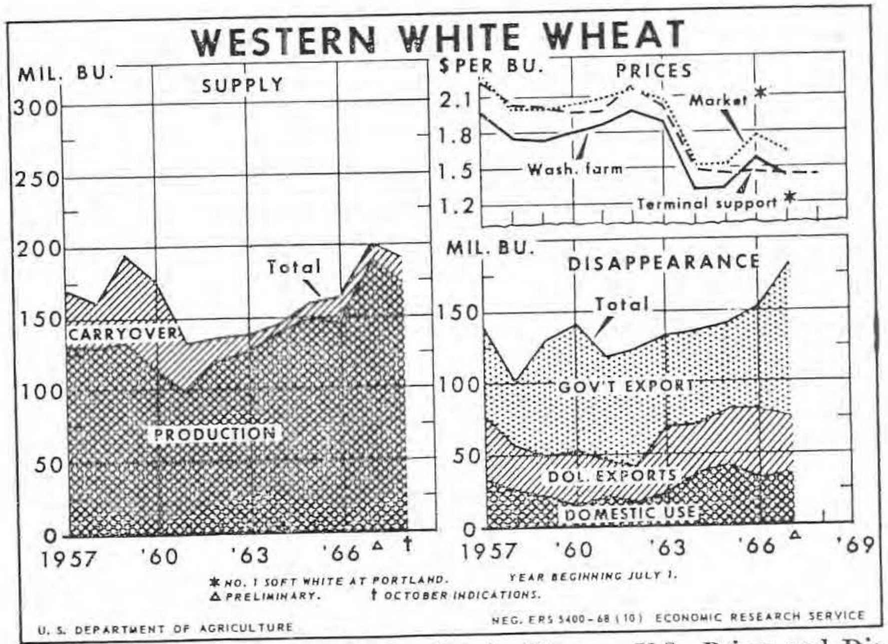


Figure 7. White Wheat Production in Western U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).

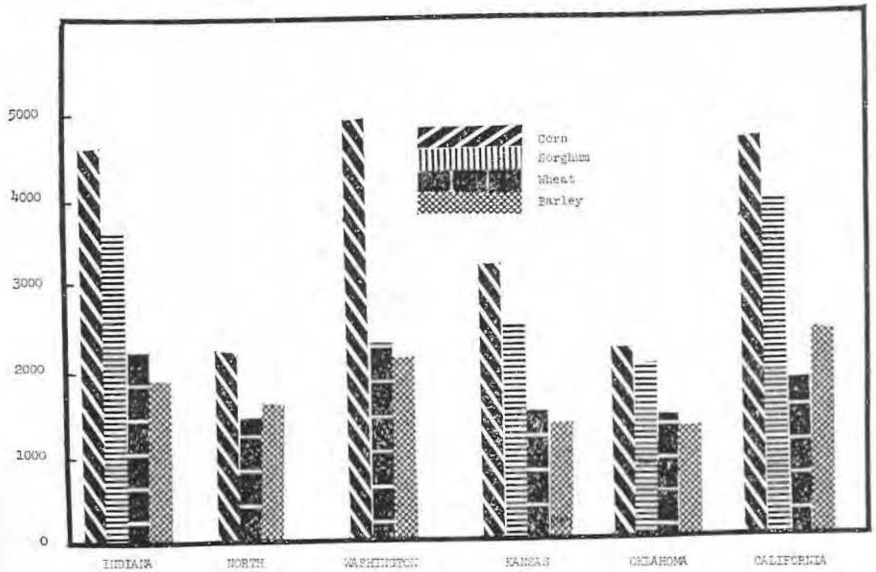


Figure 8. Average Yield (pounds) per Harvested Acre of Four Grain Crops in Designated States, 1960-1969.
(SRS, USDA).

Table 3. June Carryovers of Various Classes of Wheat, 1969 and 1970 Estimates.
(From Wheat Situation 211, p. 7).

Item	June 30 1969	June 30 1970
	Million bushels	
Hard red winter	547	640-660
Soft red winter	33	20-25
Hard red spring	140	95-105
Durum	41	65-75
White	58	50-60
Total	819	899

Table 4. U.S. Average Prices of Wheat and Corn; also Wheat Fed. Nine Months in 1968-69.
(Wheat Situation 208, p. 6).

1968/69	Farm price per cwt. Wheat	Farm price per cwt. Corn	Wheat relative to corn	Wheat fed
		Dollars		Million bushels
July-Sept.	2.00	1.81	+.19	115
Oct.-Mar.	2.12	1.88	+.24	45

ton very small and is confined to the areas with the highest number of heat units, higher rainfall, or which are under irrigation. The fact remains, however, that when a choice is warranted, corn and sorghum get the nod for high yielding feed grain acres. Even when wheat grain yields would indicate the crop was not competitive, farmers for other reasons may grow it. The grazing value alone may be decisive. In fact, two-thirds of the wheat in Kansas, Oklahoma, Texas and the Southeast is grazed to some extent in most years.

Prices and Competitive Values

The price of wheat has declined in recent years for all of the market classes reviewed above. This has caused numerous management questions to be raised. One of these is: Has the price of wheat been reduced to a level at which its value for feed will be a dominant factor? The relationship of wheat to corn prices in 1968-69 is compared in Table 4 (31). The spread is narrow.

A recent compilation of break-even points for Pacific Northwest wheat and three feed grains for five classes of animals shows that under present barley-wheat supplies and prices, the PNW is in a very favorable position relative to livestock feed costs in other regions (except lamb) (Table 5) (17). Prices of $40 and $50 per ton for wheat represent $1.20 and $1.50 per bushel, respectively.

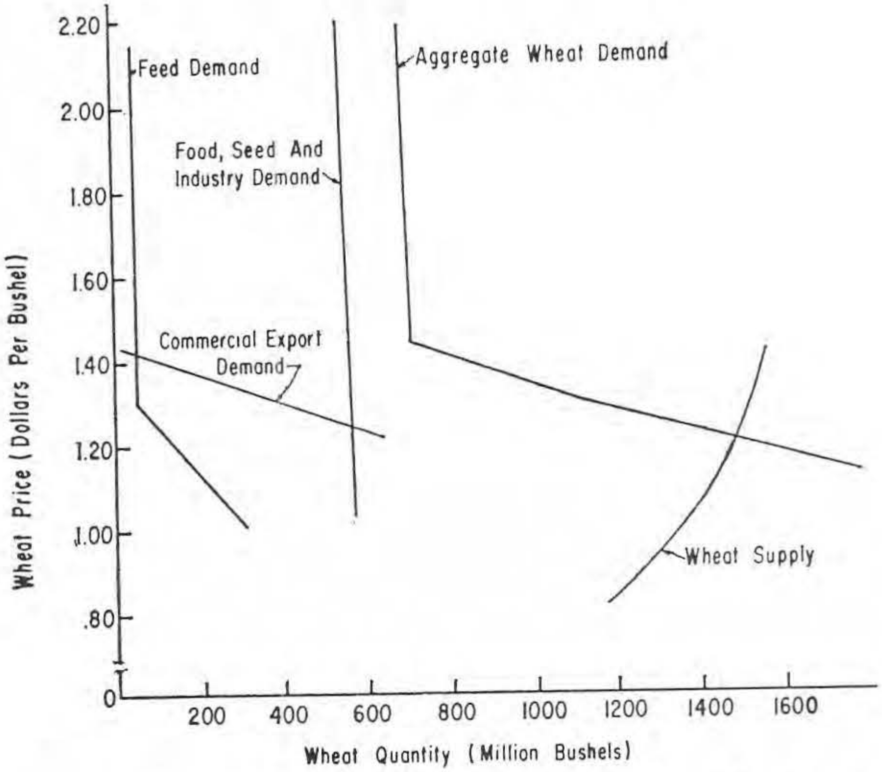


Figure 9. Estimated U.S. Aggregate Wheat Supply, Demand and Three Major Demand Components for 1967.
(From Tweeten, p. 15).

Price has a slight, almost negligible, effect on the amount of wheat used for food. The same is true for seed although these two uses are quite independent. In contrast, the demand for wheat used for feed is

Table 5. Break-even Western Soft White Wheat Prices to Give Nutritional Equivalent at Various Sorghums, Corn, and Barley Prices.

Grain;	$ Per T	Feeder Cattle	Dairy Cattle	Hogs	Lamb	Poultry
Sorghum:	$42	$47	$42	$42	$40	$38
	44	49	44	44	42	40
Corn:	$42	44	42	42	38	38
	44	46	44	43	40	40
Barley:	$42	47	42	47	40	47
		49	44	49	42	49

SOURCE: Issues and Alternatives in Wheat Production and Marketing. Oregon State University, Corvallis, Oregon. Jan. 1970, 23 pages.

highly responsive to price; export demand is a mixed response to dollar markets and government stimuli. The Oklahoma Agricultural Experiment Station published a study on these relationships which I commend to you (30). One of the models (Figure 9) is a brief summary. It will be seen that the demand for feed changes but little at moderate prices but increases rapidly after the price reaches a low, critical, presumably competitive point. The commercial export demand may vary over a wide quantity. Food, seed and industry uses are inelastic at something just below 600 million bushels. The autonomous government demand (about 100 million bushels) is not shown but is included in the aggregate. Where the line for aggregate demand intersects the supply arc (Figure 9), we see approximately free market equilibrium prices and quantities as follows: $1.20 per bushel; 565 million bushels for food, seed, and industry; 135 million for feed; and 780 million for export (total 1,480,000,000 bushels). The model requires many rigid assumptions but it illustrates interactions of some of the factors involved and helps assess how society may obtain the greatest net benefits from various kinds of programs.

There are, of course, economic limits to the production of wheat. Net returns are closely related to yield level when total inputs remain about the same. Increased operations representing improved technology generally mean increased costs which can only be recouped if the total returns are increased substantially above costs. Size of operation is often thought to be related to efficiency but a balanced set of machinery and manpower can introduce stability into the cost per bushel beyond which an increase in size of units may not show further savings. This is illustrated by a study in western Nebraska (33) wherein the cost per bushel did not change after a size class of 250-300 acres of wheat was reached up to 1000-acre units.

A major element of concern in planning to use wheat for feed is the regularity of supply at the regional, local, and farm level. Wheat yields vary widely, especially in the Plains (13), as can be seen from Figure 10a (26). More stability is noted in the Pacific Northwest and the eastern States. Corn yields also vary, and in a similar manner although corn is not grown so extensively in the higher risk areas (Figure 10b). The percentage of the wheat acreage abandoned reaches high levels in some years and when adverse weather is the main cause, large areas in several states may be affected in the same year. A graph illustrating this situation appears as Figure 11 (15). Of course, all feed is in jeopardy over wide areas when severe weather occurs. Livestock men are familiar with this problem and the disruptive consequences of it. Feed reserves, dependence on alternative feed sources, and herd thinning are resorted to for relief.

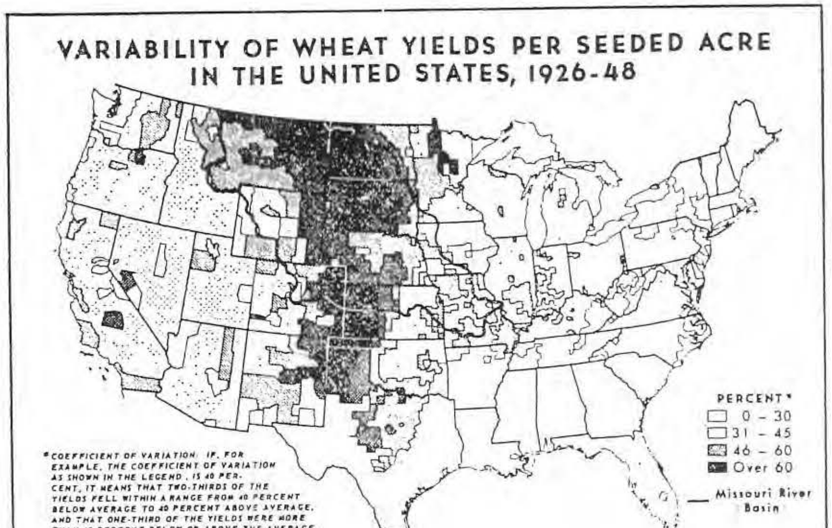


Figure 10. Variability of Wheat (a) and Corn (b) Yields.
(From Nebraska Bulletin 422, pp. 32-33).

There are two ways to think about wheat as a feed grain: 1) an incidental use of the crop or 2) planned as a regular part of the feed supply. In either case, basic nutritional and economic factors about the

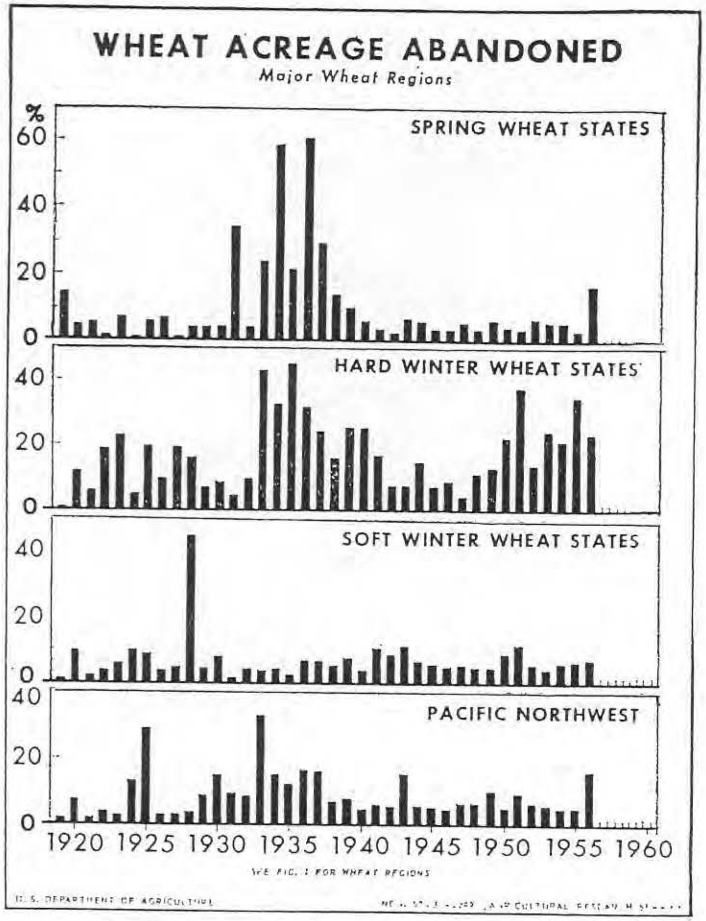


Figure 11. Percentage of the Wheat Acreage Abandoned in Four Regions of the U.S., 1919-1956.
(From Nauheim et al, p. 22).

use of wheat in rations of many kinds are needed and it is indeed appropriate to have the known information summarized. Millfeeds have always been in the second category while direct use of grain for feed has tended to be intermittent. Even when supplies have been burdensome and prices depressed, a need to supply other nations, borne of humanitarianism, opportunism in marketing, or defense have drained away the supplies often at attractive prices. Farmers, the grain trade and government programs have all tended to hold supplies away from feeders, either by the hope for good prices, by various guarantees, or by the position where the grain is stored. Some efficiency in marketing wheat for feed is thereby lost.

It has been argued that varieties should be bred specifically for feed. This may be valid when we learn what to breed for but as of now breeders have nothing to guide them toward a type not also compatible with normal objectives for food usage. It has been suggested that feed wheats be marked a distinctive color such as green, blue or purple. This could be done but it would impede the movement of such wheat into other appropriate markets. There are no convincing data that high yields, good milling and baking quality, and satisfactory feed values are incompatible objectives.

Planning for the production of wheat for feed involves availability of efficient practices and responsive varieties which together lead to high yields and low costs. Except for the constraint of milling and baking quality, most of the requirements and decisions for producing wheat for feed and food are the same. In fact, when specific information about the feed quality requirements of wheat become known, both quality constraints may about balance out. Some understanding of the problems associated with producing wheat seems pertinent.

Improved Yields by Cultural Practices

The culture and improvement of wheat have been discussed by so many workers that only a partial review can be achieved here. The excellent treatments of cultural problems by Schlehuber and Tucker (22), Leonard and Martin (14), Peterson (19), and Nielsen (16) provide a good basis for understanding the problems, methods, and opportunities for improving the yield and stability of wheat production through cultural practices in North America. A still broader view of dryland wheat production has recently been published (5).

Under humid conditions in North America, or with irrigation, wheat is generally grown in rotation with a legume or grass sod crop or with one or more intertilled crops such as corn and soybeans. In the Southeast, much interest has been shown in a two-crop-per-year system by which a summer crop of soybeans or corn is followed by a winter crop of wheat. The success of rotations is related not so much to the fact that a sequence of crops was grown but to the total return from the diverse crops in contrast to monocrop culture. The specific response of wheat is related to weed and other pest control, availability of plant nutrients and soil moisture, not overlooking subsoil moisture. Wheat after sweetclover or alfalfa frequently is disappointing. One cause for disappointment is a dry subsoil. Continuous wheat, often decried, is a practical way to grow wheat, and the yields may be maintained, even increased, over time by proper soil fertilization, moisture conservation, and weed control. Seventy-two years of continuous wheat in the Magruder plots at Oklahoma State University prove this point (22). In the dryer areas an alternate crop and fallow system, or two years in crop and one of fallow, are widely used. Acreage control programs have induced farmers to fallow more of their land for wheat production. The use of fallow, however, is of great concern to agronomists for, while they see short-term yield benefits, some long-range objectives are sacrificed. The exposure of the soil surface to long periods without vegetative cover favors wind and water erosion. New systems of continuous crop husbandry are being sought by our soil and crop management specialists whereby greater precision in use of fertilizer and other inputs will result in avoidance of the depletive consequences of fallow. These systems are not expected to increase the average yield per harvested acre but should add a degree of permanence to our agriculture.

The use of improved methods of tillage, soil management, and fallow have increased wheat yields and helped to stabilize them in our semi-arid areas. A recent summary of 27 years' trials in North Platte in western Nebraska (24) provides a good example. Alternate wheat and fallow gave a crop every year, whereas continuous wheat failed in 10, or 37% of the years. The average acre yield produced on fallow was over 3 times the average from the continuous wheat plots. However, this is a wider ratio of benefit than fallow usually shows. When N fertilizer was applied, the yield was consistently increased on continuous wheat, averaging 50% more than where no N fertilizer was applied; on fallow the yield was not always improved by N and the average increase was about 10%. Nitrogen in the grain was always increased by fertilization. Even so, the water-use efficiency was in favor of fallow both with and without N. In fact, water use on fallow without N was 40% more efficient than continuous wheat with N in years of 25 to 60 cm precipitation, and was about 80% more efficient when annual precipitation was less than 43 cm. These results suggest that where moisture is erratic, as in the Great Plains, approximately 58 cm or more annual precipitation plus N fertilizer are needed for continuous wheat. The average precipitation-evaporation index is 25.6 with a range of 16 to 31 at this test location.

Also, in these and other trials, it has been shown that plowing, disking, subsoiling, and several other initial tillage practices all give about the same average yields. Stubble mulch is consistently superior to bare fallow when the depression of available N, often associated with stubble-mulch tillage, is corrected. More precision in timing the operations and procedures to obtain the same net results at lower costs are reasonable expectations from present research. Increasing moisture uptake seems paramount.

A farmer has four general ways to increase the use of the rainfall:

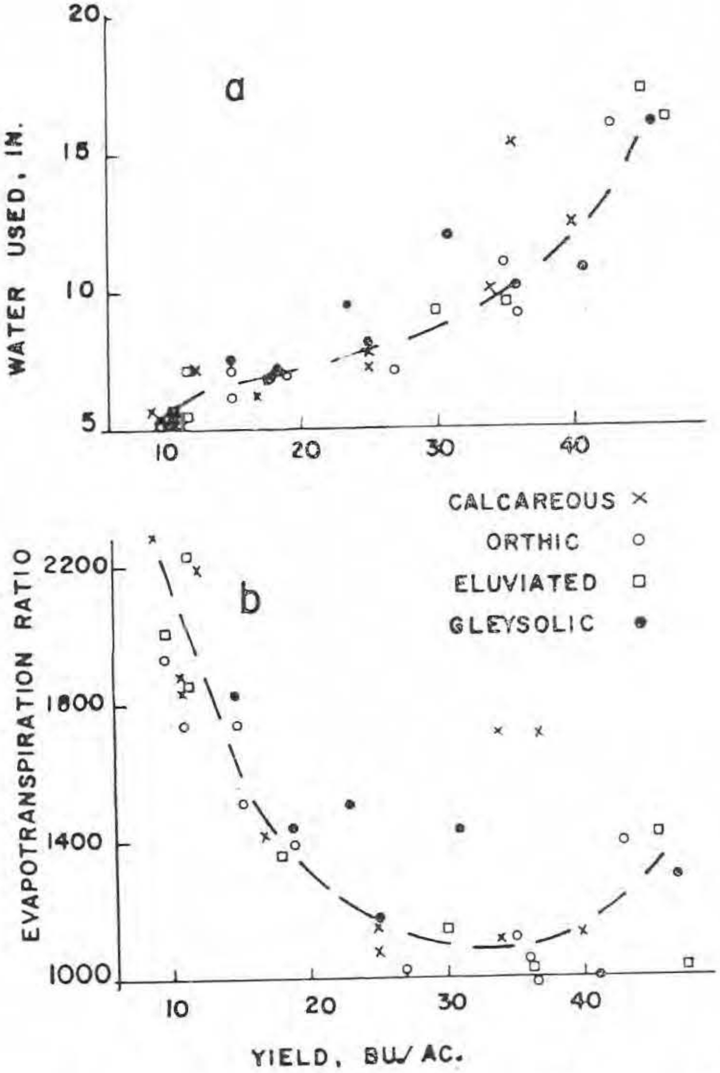


Figure 12. Relationship Between Water Use and Yield (a) and Evapotranspiration Ratio and Yield (b) for Thatcher Wheat in Central Saskatchewan (12).

1) alter the surface to increase infiltration; 2) provide more time for water to infiltrate; 3) manage his cropping system to take advantage of the seasonal distribution of the rainfall; and 4) irrigate.

In the southern Great Plains, about 7½ inches of water are used before any wheat grain can be realized, and each additional inch of water produces about two bushels of wheat. ("Inches of water" means water removed from soil and net of precipitation during the life of the crop.) Five inches and 3.4 bushels are approximate values for Saskatchewan (7, 12) (Figure 12).

In the Pacific Northwest it is said that 4" of water are needed to grow the plant before it produces any seed. Each remaining inch produces seven bushels of wheat in the case of Gaines and Nugaines — six bushels for other varieties. Hence, varietal efficiency can be an important variable. Likewise, fertility may be limiting even under semi-arid conditions, and soil type may be related to both water uptake and storage, and to parent fertility (12).

The predominant loss of water in the Great Plains occurs by evaporation. At the present time, there is no economic method of controlling evaporation for the production of the crops that are normally grown. If conservation practices are to be properly accomplished, an economic method for controlling evaporation for this important agricultural area is badly needed.

Numerous ways to increase the efficiency of precipitation have been investigated. These include ways to reduce runoff and increase penetration, such as stubble and subsurface mulch tillage, contour tillage and terracing, subtilling, etc., and these procedures are beneficial under the right conditions. Chemical fallow is being studied. Chemical weed control in the seeded crop is a wide-spread economical practice. Balancing the available plant nutrients with the expected moisture for the crop is receiving considerable attention and promises to increase yields with greater efficiency, and hopefully, give us more control over protein levels. No other practical means to induce wheat plants to use water more efficiently has been found. Some research is promising with barley and other plants (27, 34). Drought hardening in some wheat varieties has been noted (29).

It is common for a wheat crop to exhaust most of the stored soil moisture by the time of maturity to the depth the roots penetrate. Irrigation as an offset to drought is partially effective. Where water is a resource that is renewed annually, or that is from a supply seemingly undiminished after long usage, irrigation generally is worth the extra cost. Its use brings new competitive factors into play. The water, if limited, may have more value for uses other than feed production. Other crops often yield more than wheat. There is no simple answer to the questions these alternatives pose, but generally agriculture comes off second to industrial and domestic uses when competing for water.

Research on cloud modification and rain-making have given positive results (2). However, when increases in rain have occurred they have been on the order of 10 to 20% above what might normally have occurred, but results are inconsistent.

We envision a day when there will be more adequate, timely information on still other factors upon which to base wiser decisions. Predictions of probable weather for longer periods of time and the assessment of crop, soil moisture, disease, and insect situations for large regions are active research areas. Reference has already been made to weather modification (2). NASA, USDA, and numerous other research institutions are cooperating in studies of these types. A series of reports from Purdue University are helpful in grasping some of the opportunities and obstacles to the application of such knowledge gained from air- and spacecraft (20). Prediction of outbreaks of rust and insects can be improved by these approaches and the accompanying ground truth.

Breeding for High Yield and Stability

At any point in time it has been short-sighted to say that wheat yields cannot be increased. The 100-bushel per acre yield level is frequently exceeded in our Western states and this barrier was finally broken east of the Rocky Mountains in 1967 by 'Blueboy' in North Carolina, and in 1969 by 'Sturdy' in the High Plains of Texas. A yield of 209 bushels per acre was established in 1965 by 'Gaines' in Washington. These yields, in themselves, are not very important except to show the potentials within present resources. The goal is not simply to match or exceed these high yields occasionally but to stablize production at a level much above the average. We know that this can be done only by breeding efficient, responsive varieties that remain healthy and free from pests all season, and developing soil moisture and fertility management to approach as closely as possible the optimum conditions that are required. Our national average wheat yield has doubled during this century. The yields per acre in California and Arizona have been increased 28 and 37%, respectively, in the last three years above the average for the preceding six years. I would like to see, and believe it realistic to expect, a 50% increase over present national acre yields before the century ends.

What makes varieties responsive and high yielding? Can wheat be made more productive through breeding? Both productivity and stability of yield are modified through the breeding of adapted varieties with necessary resistence to insects and diseases. In an historical sense, basic adaptation of suitable types for each area of the country had to occur before wheat growing could be considered a success. This was represented in the early days by the discovery and wide use of 'Fultz', 'Fulcaster', 'Purplestraw' and a few other varieties in the Eastern states. 'Marquis' spring and 'Kubanka' durum established the crop in Northcentral States.

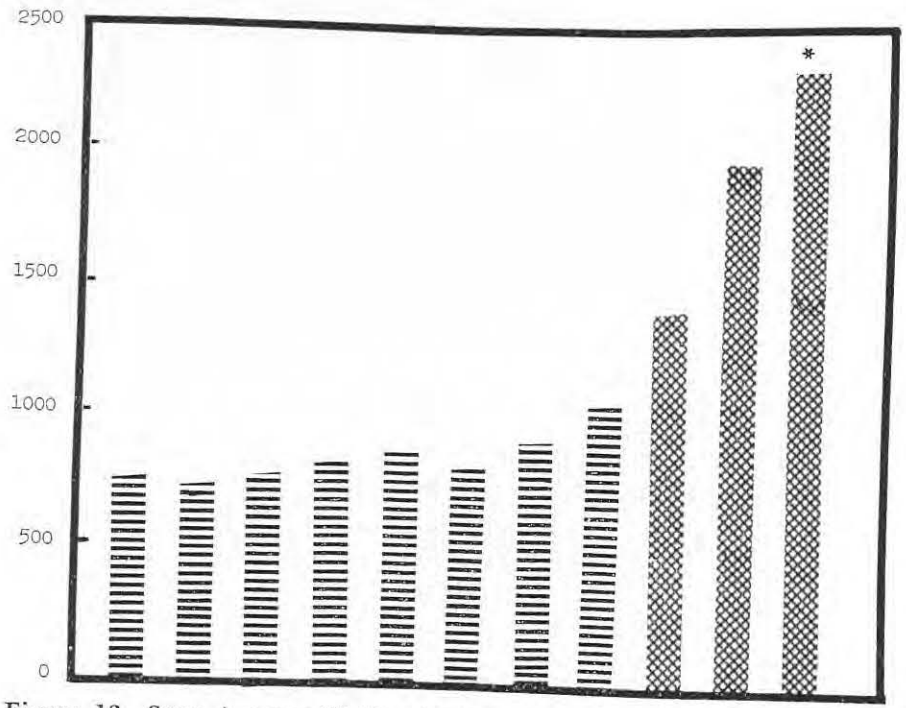


Figure 13. State Average Yields of Wheat in Indiana by Decades, 1870-1966. *1966 Only. Decade 9 Begins the Knox-Monon Era. (Kg. per Hectare)
(From Briggle and Vogel).

'Turkey' was the turning point in the decision for the Central and Southern Plains. Spanish and Australian varieties contributed heavily to the varieties of early-day culture in the Western states. These early-day varieties have all been replaced. In most areas, several replacement cycles have occurred, each representing a better variety form, yet basically embodying the early-day types. Simultaneously, there was resistance to disease and insects bred into many varieties. Yield increments were relatively small. Then, several dramatic events hit all regions—not all at once and not all of one kind. The following illustrate my point: early maturity exhibited by 'Triumph', 'Wichita', 'Scout', and 'Pawnee' in Southern Plains wheats; earliness and short straw found in 'Knox' and 'Monon' in the Ohio Valley; short and early 'Wells' and 'Lakota' durums in North Dakota; semidwarfs with phenomenal yield such as 'Gaines' in the Pacific Northwest and in other varieties in Western states. We do not know exactly why these types were so dramatic. One breeder of considerable experience told me it was "responsiveness to improved management practices." In other words, when these varieties were grown under management conducive to high yield, they produced. Yield ceilings imposed by weak straw, late maturity, low tillering capacity, small numbers of fertile florets per head, and deficient seed plumpness and size, were broken. At least some were. Either more seeds, or larger seeds, or both, give higher yield. It really does not matter, except that breeding could be more orderly if we knew.

A clear illustration of responsiveness appears in Figure 13 which shows the average wheat yield for Indiana by decades beginning in 1870 (4). Through eight decades only slight improvement occurred. After that, there was a marked rise. This coincides with the release of Knox and several other superior yielding varieties, but heavier rates of fertilizer and better management practices were also introduced about this time. Was the greater realizable yield due to fertilizer or variety? It is a moot question.

I am convinced that breeding for yield is rewarding but not from a concept of a genetic unit character. There are two ways for yield expression to be viewed: 1) vigor and eventual translocation of metabolites to the seed; and 2) protection against interference with these metabolic processes. The latter is concerned with hardiness, disease and insect resistance, and tolerance to air and soil "pollutants." The former involves rates of DNA and RNA synthesis and cell division, enzyme activities, photosynthetic rates, and efficiency of translocation.

Genetic evidence shows that one or more genes are found on each arm of every chromosome for such yield influencing effects as those enumerated in the above paragraph. The number of possible genotypes is very great and may be calculated for an F_2 population by raising 3 to the power of the gene number. For example, an F_2 derived from crossing two parents differing by 12 independent genes would provide over a half million different genotypes (3^{12}) of which about 4,000 would be different homozygous types. The breeder not only must generate such populations by cross-breeding the right diverse parents, but he must grow a large enough population and find the more productive selections. When desired and unwanted genes are linked, the numbers game gets worse. Because the yield of a single plant is a poor prediction of yield in close-sown plots, and F_2's are single-plant units, the breeder makes little or no progress by selecting for yield in this generation. I think lack of diversity among parents, failure to grow and evaluate large numbers of progeny, and inadequate methods to measure yield potential are the chief obstacles to empirical breeding for yield in wheat. Time (i.e., number of years) compensates for small populations and generally over time the diversity of crosses a breeder studies is relatively great.

Breeding for single gene, specific effects, as in the case of greenbug resistance or rust resistance, is much simpler but becomes less so as the

Table 6. **United States Wheat Production Potential as Reduced by Six Kinds of Hazards.**

HAZARD	PERCENTAGE REDUCTION
Diseases	14
Weeds	12
Insects	6
Harvest	5
Storage & Processing	4
Violent Weather	5

Based in large part on USDA Handbook 291, "Losses in Agriculture", 1965, 120 pp.

number of specific races or biotypes is increased from which protection is sought. The backcross has been used successfully for adding single traits to varieties but the typical application of the method always narrows diversity. Induced mutations is another method which also suffers from the same limitation.

The evidence to support protective breeding is overwhelming and cannot for a moment be minimized or forgotten. Without resistance to soilborne mosaic, wheat would probably disappear from half of the acreage east of Oklahoma City. The risk from severe stem rust damage is about 1 year in 3 for North Dakota and adjacent areas, yet no appreciable loss has been suffered there in the last 15 years because of the diligent work by responsible breeders who transferred effective genes into varieties to be grown on farms. The Pacific Northwest battled common bunt of wheat for 60 years before enough genes for resistance could be bred into commercial varieties to protect them from infection.

Nor are these jobs finished. The losses from disease (Table 6) show clearly that we lose annually 14% (32), and probably more, from recognizable disease damage and 6% to insects. Violent weather adds at least 5% to these losses. It is perhaps overoptimistic to think all of such loss can be prevented but there is a wide gap to close.

Breeding may fail. For some maladies we have no resistance for exploitation. Three avenues are open: 1) generate new resistance; 2) use chemicals; or 3) grow the crop out of phase to avoid the malady. Germ plasm building is an important sideline of every breeder and a main job of many geneticists. 'Agent', 'Agrus', 'Transfer', and 'Compair' are not very familiar variety names yet all are of tremendous importance as newly generated resistance to the leaf rusts of wheat utilizing resistance from *Agropyron* and *Aegilops*. 'Transec' and 'WRT-235', denote rye-derived rust resisting wheats. In the development of these, both natural and irradiation-induced recombinations are involved. The USDA maintains a collection of common wheats obtained from 75 countries of the world, durum wheats from 60 countries, and other species of wheat from 40. The total now exceeds 22,000 separate accessions. Even so, we believe that many "old land" varieties should be added to our collection. Improved varieties are replacing them, hence, the natural variation which has evolved in diverse forms grown by farmers all over the world and in wild forms, may quickly be lost unless more collections are preserved. However, no one knows how many collections represent a reasonable number. The use and status of small grain germ plasm were discussed rather fully in a recent review (21).

Mutation-breeding has been mentioned. Irradiation to induce chromosomal breaks from which desired translocations might be obtained is a useful technique. However, useful stocks directly derived from the use of chemical mutagens or rays of various origins are few in number; most of them need clearer documentation. Changes have been induced, so, in time, this source of diversity may be significant in the improvement of wheat for yield or to impart protection.

Agricultural Chemicals

The use of chemicals of all kinds to control pests has come under criticism during the last year or two. Only the uninformed believe that concern about safety of use of chemicals is something new. Federal legislation of 1947 regulating use of pesticides in agriculture and the Miller Bill of 1954 were giant steps in safeguarding our food production and food products. The people's stake in pesticides has received a lot of costly attention. Some long-range effects are showing up and must not be ignored. Hopefully, we learn something annually by which to make use of chemicals even safer.

Efficient, highly productive agriculture without chemicals cannot be predicted with any assurance. Protective chemicals for the control of seedborne diseases and for insect control have been used safely and with profit on wheat for many years. We are beginning to use systemic materials, some effective as seed treatments, which will protect the plant from cereal leaf beetles and aphids for 6 weeks, from powdery mildew for 4 weeks, and eliminate loose smut completely. A chemical to control rust appears feasible and, again, a seed treatment would be ideal. We suffer loss from a number of omnivorous fungi which attack several hosts and exist in innumerable pathogenic culture types. These are very difficult to breed against and perhaps chemicals can be found to help in reducing damage from them.

Some estimates indicate food production might be cut 30% if all chemicals were discontinued. This seems high in the case of current wheat practices, but it is conceivable that a 30% benefit in total production might be achieved through an all-out effort in which chemicals were fully exploited.

Other Opportunities

Growing the crop out of phase to get higher yields by avoiding the malady has very little practical significance now. Seeding and ripening dates for highest yield have largely been determined and adopted. Rotations offer some additional assistance, and supplemented with improved fertilizer and agricultural chemicals, great advances. Large-scale machinery has been the main benefactor to the wheat farmer to provide him with the capability to do the right job in the right way at the right time. Some people have said to me that the farmer would raise better wheat crops if he spent more time in the field, but this is not necessarily true. The use of only 3 man-hours per acre of wheat compared to 15 hours used 50 years ago is related to the high yields of recent times because the work is done so much better. Early maturing varieties escape some hazards and diseases and this illustrates a way breeders have phased the crop to a safer period. A shift from winter wheat to spring wheat in the Pacific Northwest would avoid dwarf bunt but since winter wheat yields more than spring wheat where bunt is not encountered, this becomes an unattractive solution.

Physiological efficiency of wheat and altered plant morphology to increase photosynthesis are being emphasized (3, 28). Wheat ranks relatively low in efficiency of photosynthesis among crops. Through photorespiration wheat apparently is wasteful of metabolites or of its opportunity to fix CO_2, in contrast to corn, sorghum and sugarcane. Physiologists refer to the phenomena as high- and low-compensating responses in terms of the CO_2 equilibrium value each group will establish in a closed, illuminated chamber (28). When corn and wheat are grown together in such a chamber, corn thrives at a CO_2 equilibrium far below wheat, and the latter dies (28). Furthermore, the arrangement and location of chloroplasts in these two groups of plants differ markedly. In corn, the fixation of CO_2 was primarily in plastids surrounding the vascular bundles, and was dispersed in sugarbeet leaves (a high CO_2-compensator species like wheat) (Figure 14). Several investigators are searching for germ plasm in wheat to permit some practical use of these findings and to elucidate the riddles these discoveries pose.

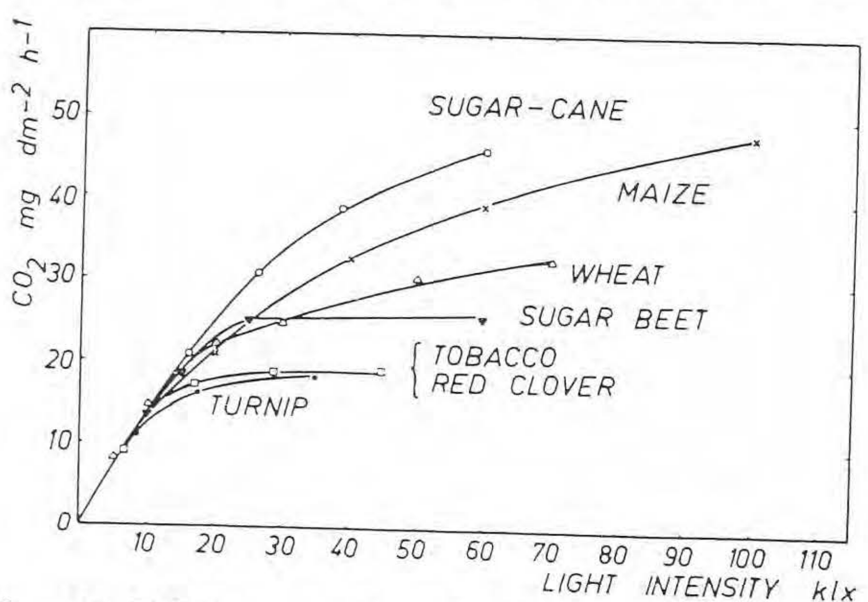


Figure 14. **Light Response Curves of Photosynthesis for Different Crop Plants. Attached Leaves, CO_2 Concentration = 0.03 vol. %, Temperature = 20C (28).**

Used by permission of American Society of Agronomy.

The problems and opportunities for germ plasm manipulation to obtain higher yields have been reviewed by Sprague (25). Differences in inherent yielding ability in crops may arise, he says, from any one of several deficiencies: 1) energy transfer mechanisms; 2) net assimilation rate; 3) translocation and utilization of photosynthate; 4) nutrient uptake and use; 5) plant growth substances; 6) response under stress conditions; and 7) efficiency of water use. To make progress along these lines requires a capability to identify the desired responses, germ plasm that might be utilized, and a coordinated effort by the breeder and physiologist to create functionally balanced varieties. An empirical approach has largely brought us to the point where we are today, and further progress undoubtedly will come. However, Sprague rightly calls for a major expansion of research in physiological genetics aimed at orderly, scientifically based breeding for yield increases.

Summary

The margin of supply between total wheat production and the amount used for food can be considered available for feed. This is on the order of one-half to one billion bushels in the United States. Competing uses for this wheat are exports to dollar and concessionary markets, relief, and strategic reserves. Supplies for uses other than food could, in most years, exceed one billion bushels without expanding our present base acreage. Freedom for wheat to move in competition with feed grains is governed by price either in the open market or under the influence of government policy.

Recent price changes have tended to establish a base price for wheat about equal to feed grains if protein content is taken into account. This is causing farmers to make decisions on a new basis.

The acre yield of wheat is a major determinant of net returns; hence, ways to increase the yield are of vital importance. Consistent production likewise is important if a feeding program is to be sustained. Productivity is the sum total of soil management, moisture, fertility, timely farm operations, weather, pest control, and responsive varieties. Ways to improve the position of wheat farmers through the alleviation of all of these obstacles without increasing unit costs, is what research is all about in this area.

The average yield per harvested acre has doubled in this century. Another rise of 50% is a reasonable goal to attain by the year 2000. A substantial increase in yield and prices competitive with other grains appear to be the road that must be followed to bring wheat into the feed market on a regular basis.

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Nutritional Values of Wheat and Wheat By-Products as Affected by Modern Production and Milling Techniques

J. A. SHELLENBERGER

Modern civilization ranks wheat among the cereal grains consumed mainly as a food commodity rather than as animal feed. In antiquity, neither man nor animal likely had much selectivity concerning types of wild grasses available to be eaten. However, there is evidence that when man learned selectivity among the grains that could be grown, for a period he regarded barley more highly than wheat as human food. Wheat, apparently for a time, was not regarded especially as human food and was, therefore, used mainly as animal feed. Use of wheat for feed is at present on the upswing of popular interest, so it now has gone the full cycle of utility.

The situation today does not differ in principle from what has prevailed in the past, namely, when wheat is available and comparable in cost to other sources of nutrition for domesticated animals, it is used for feed. However, because in the processing of wheat for human use as food, portions of the wheat supply are utilized as feed, the consideration of wheat as feed becomes complicated.

Since the earliest times, efforts have been made to devise ways in which grain could be ground conveniently and portions of the endosperm separated from the germ and branny outer parts of the kernel. Wheat, for example, in the early development of processing procedures, was ground between stones by a rubbing motion, and the outer portions of the kernel partially separated by means of sieves made from hairs of animals (12). The branny parts were not used for food but became either feed for animals or were used as fuel.

Wheat obtained its prominence as human food when man discovered that flour mixed with water developed a dough, and that this dough retained gas as fermentation set in. The baking industry resulted from knowledge gained that the fermented doughs could be baked to produce an acceptable food. This entire procedure depends on the unique properties of wheat proteins to form gluten—a phenomenon duplicated nowhere else by either plants or animals. For this reason, throughout the world, wheat has been for centuries the cereal grain for which there was no substitute insofar as the production of white bread was concerned. To fulfill the demand for wheat flour relatively free from bran, complicated procedures for processing wheat were developed, although it has long been recognized that the methods used discarded portions of the kernel richest in proteins, vitamins, lipids, and minerals for human nutritional needs. Cobb (4), in 1905, produced a diagram of the cross section of a wheat kernel showing the increased protein content of five arbitrary zones, ranging from the starchy endosperm to the outer layer of bran. The distribution of the nutrients of the wheat kernel and how the milling process redistributes these constituents between flour and co-products, depending on extraction rate, has been discussed in books by Bailey (2) (3), Hlynka (6), Storck and Teague (12), and Swanson (14).

The processing of wheat in the United States came about rather slowly. Wheat is not indigenous to the American continent and was first introduced into Mexico by the Spanish about 1529; however, it was first grown in what is now continental United States on Roanoke Island off the coast of South Carolina in 1585. It was the mid 1600's before sufficient wheat was produced in the North American colonies to warrant concern about flour mills and flour milling. Centers for processing wheat developed in New York City, Rochester, Buffalo, St. Louis, Minneapolis, and Kansas City, Missouri, as settlers moved west and land was planted to wheat. At all milling centers, finding markets for the by-products of wheat processing, namely, screenings, shorts, and bran, became a problem as milling enterprises increased in size and capacity. In fact, legal measures had to be taken in Buffalo in the mid 1800's to restrict milling companies from dumping bran and shorts into the canals and obstructing navigation. These products of wheat milling traditionally have been subject to considerable price fluctuation and discriminatory reactions to their feed value. With the development of the formula feed industry, coproducts of milling industry began to establish a definite place as the base of feed formulations.

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The flour miller is the victim of circumstances insofar as feed manufacturing is concerned. Roughly, about 72% of the total material comprising the wheat kernel during processing becomes wheat flour for human consumption. Thus, the miller has approximately 28% of the processed wheat to sell as feed, mainly as bran, shorts, red dog and germ. Because the miller must fractionate the wheat kernel in a manner that will produce a flour of specific analytical limits and use-properties, feed co-products must absorb the quality and quantity fluctuations. The miller has no other choice.

There have been many improvements and changes in equipment and milling procedures, but none alters the basic concept that milling merely separates the various parts of the wheat kernel. The products will be characterized by the quality of the processed wheat, and the processing will neither add nor subtract from the original nutritive value. The important consideration is the knowledge that in milling wheat, the more nutritious parts of the wheat kernel become feed.

Millfeeds are defined by the Association of Feed Control Officials, Inc. (1970) as follows:

Wheat Bran is the coarse outer covering of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling.

Wheat Germ Meal consists chiefly of wheat germ together with some bran and middlings or shorts. It must contain not less than 25% crude protein and 7% crude fat.

Wheat Middlings consists of the fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and some of the offal from the "tail of the mill." This product must be obtained in the usual process of commerical milling and must contain not more than 9.5% crude fiber.

Wheat Shorts consists of fine particles of wheat bran, wheat germ, wheat flour, and the offal from the "tail of the mill." This product must be obtained in the usual process of commercial milling and must contain not more than 7% crude fiber.

Wheat Red Dog consists of the offal from the "tail of the mill" together with some fine particles of wheat bran, wheat germ, and wheat flour. This product must be obtained in the usual process of commercial milling and must contain not more than 4% crude fiber.

Efforts are now in progress to enact a Uniform State Feed Bill, and both the Association of American Feed Control Officials and the American Feed Manufacturers Association have passed resolutions favoring such an act. However, at present, State regulations determine the limitations on chemical or ingredient composition and these vary among States. It is obvious from the definitions of the kinds of millfeeds that there is, in commercial milling operations, a wide range of overlap in the consigning of feed constituents into definite categories. For example, there is often no difference between Wheat Middlings and Wheat Shorts as manufactured during a particular milling operation. For this reason the term wheat middling will not be used, and the term "shorts" will include considerations that could otherwise be included under wheat middlings.

Table 1. Average composition of cereal grains[1]

Name of Analysis[2]	Wheat (Hard)	Rye	Corn (Dent)	Barley	Oats	Rice	Sorghum
Moisture, %	10.0	10.5	15.0	10.6	9.8	11.4	10.6
Protein, % (Nx6.25)	14.3	13.4	10.2	13.0	12.0	9.2	12.5
Fat, %	1.9	1.8	4.3	2.1	5.1	1.3	3.4
Fiber	3.4	2.2	2.3	5.6	12.4	2.2	2.2
Ash, %	1.8	1.9	1.2	2.7	3.6	1.6	2.0
Thiamine, mg./kg.	5.5	4.4	4.6	5.7	7.0	3.2	4.6
Niacin, mg./kg.	63.6	1.3	26.6	64.5	17.8	40.0	48.4
Riboflavin, mg./kg.	1.3	1.8	1.3	2.2	1.8	0.7	1.5
Pantothenic acid, mg./kg.	13.6	7.7	5.9	7.3	14.5	7.0	12.5

[1] Source: Feed Composition—Joint United States—Canadian Tables, Publication 1232, National Academy of Sciences—National Research Council, 1964.

[2] All values reported on moisture-free basis.

Although the protein value of wheat in any marketing year in the United States varies from seven to twenty-two percent, depending on variety and growing location, the average protein content of wheat is higher than that of other cereal grains, and its essential amino acid distribution compares favorably with that of other grains as shown in Figure 1 (11). A number of very important papers on this subject were presented at the annual meeting of the Animal Nutrition Research Council in Washington, D. C., October 15, 1958. Average compositions of the more important cereal grains are compared in Table 1.

The milling industry has long known that it manufactured an important nutritive constituent for the feed industry. However, millfeed represents no more than 10% of the total ingredients used by the formula feed industry and probably comprises no more than 5% of the total volume of feed consumed. The production, distribution, and selling price of millfeed depend on many interacting variables such as feed-grain price, livestock population, competition from noncereal concentrates, and the fact that millfeed results from flour demand, and thus is manufactured often when prices and demand for millfeed are depressed. In addition, millfeed stocks do not store conveniently and, therefore, must be disposed of soon after manufacture.

In an effort to analyze and improve its competitive position, the milling industry, through the Millers' National Federation, held a panel discussion during the annual convention in Chicago, Illinois, May 14, 1963, on "Millfeed: By-Product, Co-Product, or Product?" (8). The result was clearly that millfeed should not be considered or regarded as a by-product of the processing of wheat. Also equally clear was that the industry had been laggard compared with other industries in researching, developing, promoting and selling, on a sound business basis, the total products resulting from its processing operations. The question was, what to do to improve millfeed and the feed industry's concept of millfeed?

The milling industry formed a Millfeed Research Committee headed by Dr. W. R. Johnston, Vice President for Research and Development, International Milling Company, Inc., to guide the industry in making millfeed better understood and a more marketable commodity.

Dr. Johnston discussed some of the functions of the Millfeed Research Committee in a paper presented at the Association of Operative Millers Technical Conference at Minneapolis, Minnesota, in May 1965 (7). It has been recognized that a major difficulty in the use of millfeeds by the feed industry has been lack of knowledge of the nutritional and economic worth and nomenclature misunderstanding of such products as bran, shorts, red dog, and durum. Convenient formulations by large feed manufacturers using computerized systems do not lend themselves readily to the use of ingredients that lack standardization and vary widely in chemical analysis and nutritive values. Differences result in the analysis and feed value of millfeeds when made from hard or soft, red or white, winter or spring wheat. Also, two geographical origins of the same kind of wheat will result in different values of the same feed ingredient from one variety.

To clarify the situation, research was sponsored by the Millers' National Federation to completely analyze flours and millfeed made from different wheat types when milled by the same procedure. The results, reported by Farrell *et al.* (5), and Waggle *et al.* (16), show the range of difference in the proximate analysis of the wheat, flour, and millfeed, and of the amino acid, minerals, vitamins, and gross energy values. The nutritional values of these millfeeds were investigated by Moran *et al.* (9) (10), and Summers *et al.* (13), and results were reported for metabolizable energy, metabolizable dry matter, protein quality, nitrogen digestibility, and growth and feed conversions of chicks when diets contained the various fractions, namely, bran, shorts, red dog, and germ. The wheat protein range of the various samples varied from 13.8% for hard red spring to 9.2% for soft white, and other constituents of the wheat kernels varied similarly. However, protein qualities of the millfeeds from these wheats (as measured by net protein utilization, protein efficiency ratio, and nitrogen retention) all agreed well. As would be expected, because of its lower digestibility, the nitrogen in bran in all cases was used less than nitrogen of the other feed products.

In Table 2 are summarized for comparison a few of the data from Summers, Slinger, Pepper, and Moran (13). They show the variability of the metabolizable energy and net protein utilization values for millfeeds manufactured from five hard red winter wheats and a soft white wheat. Variability is as great within a single wheat class as between classes even when the protein content range is from 13.3% to 9.2%. Such differences show the need for accurate nutritive information concerning a millfeed for it to be used efficiently and to maximum extent in the formulation of a feed.

Table 2. Selected data showing metabolizable energy and net protein utilization of millfeeds from five hard winter wheats and one soft white (13).

Wheat Class	Metabolizable Energy Kcal./gm.				Net Protein Utilization			
	Bran	Red Dog	Germ	Shorts	Bran	Red Dog	Germ	Shorts
Hard Red Winter								
13.3% protein H	1.22	2.96	2.65	1.95	44.1	55.9	56.5	53.7
11.9% protein R-3	1.27	2.81	2.38	2.03	40.6	57.0	57.3	60.9
11.5% protein R-1	1.42	3.35	2.46	2.49	40.5	55.8	53.8	55.7
11.2% protein R-2	1.26	3.22	2.71	2.14	38.6	54.4	65.3	57.7
10.7% protein	1.10	3.17	2.47	2.13	42.7	57.9	58.8	59.0
Soft White Winter								
9.2% protein	1.38	2.75	2.56	1.98	41.1	59.9	59.4	60.3

Summers *et al.* (13) also determined the sequence of limiting amino acids for each of the mill fractions for the various wheat types and found in all cases, small but statistically significant differences; however, the differences were attributed to an accumulation of procedure errors rather than to inherent alterations in the samples themselves. The limiting amino acids are not the same for all millfeed products, and this fact is distracting in formulating a feed ration because of the overlap in the production of the milling fractions.

Wheat yields flour, bran, shorts, and red dog in the milling process, the amounts depending on the physical properties of the wheat, the milling operation, and the products desired. All products produced cannot, at the same time, be accurately manufactured to analytical standards. There is no practical way for the usual milling operation to produce flour to the buyer's specification and also to produce standardized millfeed. The problem is difficult and complicated, but the industry is aware of the urgent need to promote more extensive use of millfeed by the formula feed industry, and of the need to standardize both products and product definitions. A start has been made to bring about improvement; progress now can be expected in the following areas:

1. Establish for the milling industry definitely defined chemical and physical property limits for bran, shorts, red dog, and germ, and thus market to the feed industry a more uniform product.
2. Provide to the feed industry protein, amino acid, and metabolizable energy values for all millfeed products.
3. The feed industry should be supplied with reliable information from the milling industry on the nutritive value of millfeeds for various purposes compared with other competitive feed ingredients.

4. Research will continue to supply information on the full potentialities and nutritive values of millfeeds for all types of animals and this knowledge, combined with improvement in product uniformity and better marketing systems will establish millfeed as a reliable feed ingredient.

The nutritional value of millfeed for livestock and poultry is well established; however, the problem to be overcome by the flour milling industry is to develop ways in which millfeeds can be supplied to the feed market as a more uniform and standardized product. The future will undoubtedly bring about many improvements in the procedures for the manufacturing and marketing of millfeeds for livestock and poultry feed formulations.

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A Reappraisal of Wheat in Swine Rations

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These comments are couched in terms of "reappraisal" since wheat is no newcomer to the swine feeding scene. It has been fed to hogs, to varying extents, for many years and has been subjected to some appraisal as a result of this experience. During this time, however, many changes have occurred: new varieties of wheat have been introduced, cultural practices have varied and, perhaps most significantly, economic conditions have altered, so a reappraisal is due.

As one reviews the literature on wheat feeding, a number of inconsistencies are apparent. These apparently stem, to some extent at least, from lack of definition of the specific wheat used in the feeding comparisons. *Wheat* is far from being a discrete entity—it may be many different things to different people and in different places. Generally speaking, five distinct classes of wheat are grown in the United States: hard red spring, soft red winter, hard red winter, durum and white. Within each of these classes there are a number of species, so that there is a very considerable diversity of base material. Some nutrient values for these different classes of wheat are listed in Table 1, which has been assembled from comprehensive data originating in the U.S. and Canada, by Crampton and Harris (1969).

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Table 1: Nutrient Comparisons* for Major Classes of Wheat

Wheat Class	DM	Ash	CF	E.Ex	NFE	DP**	DE**	Ca	P	B_1	Niacin
	%	%	%	%	%	%	kcal/kg	%	%	mg/kg	mg/kg
Durum	89.5	1.8	2.2	2.0	70.1	12.4	3630	.15	.40	6.3	?
Hard Red Spring	86.5	1.7	3.0	1.9	66.0	12.8	3470	.05	.41	5.2	57.8
Hard Red Winter	89.1	1.8	2.7	1.6	70.0	11.9	3575	.05	.40	6.2	50.9
Soft Red Winter	89.1	1.8	2.2	1.6	72.5	10.1	3614	.09	.29	5.3	57.4
Soft, White	90.1	1.8	2.3	1.7	73.4	9.9	3650	.09	.30	4.8	59.2

*Items listed are, respectively, Dry Matter, Ash, Crude Fiber, Ether Extract, N-Free Extract, Digestible Protein, Digestible Energy, Calcium, Phosphorus, Thiamine and Niacin.
**Determined specifically for swine.

These data (Table 1) are averages of large numbers of samples and within-class variation is obscured. Nevertheless, there are variations of 29% in digestible protein, 5% in digestible energy, 200% in *Ca*, 38% in *P* and 31% in thiamine content between extremes. It would certainly seem possible that feeding comparisons of these different classes of wheat, even against a common standard, such as corn, might yield quite different results.

Much of the original appraisal of wheat as a swine feed was made on economic, rather than nutritional grounds. The feeling was held, particularly during the last century, that wheat was a food for humans and not for hogs. This concept was only partly dispelled by Coburn in 1894 when he exhorted Kansas farmers that, with wheat and corn approximately the same price per bushel, it was "neither unprofitable nor wicked" to feed the wheat to hogs (see Heinemann, W. W., 1957). Through most of the first half of this century demand for wheat for milling kept its price pegged above that of comparable feed grains. One should not dismiss the implications of the human vs. hog food question lightly today, in the shadow of the much-publicized World Food Crisis, even though on this continent, at present, the problem is one of distribution rather than production.

Wheat as a Major Ration Component

It has become conventional, in swine feeding, to use cereal grains as the major ration component, balancing them where necessary with supplementary protein, minerals and vitamins to meet the animals' nutritional requirements. Any evaluation of wheat, then, must compare its effectiveness in supplying the nutritional requirements of swine with that of other cereals, and perhaps other ration components. Along with its nutritional value, of course, the palatability of wheat to hogs must be considered. On this point the literature suggest general agreement. Cunha (1957) states that wheat (type unspecified) is "more palatable than corn for pigs," while Morrison, (1956) after summarizing a great deal of data, concluded that "wheat of good quality is well-liked by swine." In a few instances where swine have "gone off feed" on predominately wheat rations, the method of preparation or type of feeding practice may have been involved. Numerous authors suggest that fine grinding causes wheat to form a sticky mass of fine, floury particles in the pig's mouth, thereby contributing to unpalatability, (see Carroll and Krider, 1950). Others have suggested that hand-feeding of unground wheat to swine is unsatisfactory because the pigs eat too rapidly and either go off feed or convert the grain inefficiently. This situation can be corrected by either coarse-grinding, rolling or pelleting the wheat, or by introducing a self-feeding system.

It would be convenient indeed, if wheat could be assigned an index value in comparison to corn or other cereal grains, as a major ration component for swine. No single such value is possible, thanks to the diversities already mentioned, and varying figures must be used in the context of the specific situations in which they were obtained. For example, Kentucky workers assigned wheat a value of 95% of corn, when it replaced half the corn in swine grown-finisher rations (Cromwell, Overfield and Hays, 1969) while North Carolina studies gave soft, red winter wheat (Blue Boy) a value of 90% of corn in complete pelleted rations (Clawson and Alsmeyer, 1970). Hollis and Palmer (1970) have provided data suggesting efficiencies of 89% and 87% respectively for Florida-grown wheat and barley as compared with corn in supporting weight gains in swine. It should be noted, however, that use of both wheat and barley permitted lower levels of soybean meal supplementation than did corn in bringing the Florida rations to the desired protein content. Oklahoma studies evaluate local wheat and milo equally in supporting swine gains when each diet had the same protein supplementation (Luce *et al.*, 1969).

North Dakota workers have focused attention on the differences in performance of swine on similar rations formulated with either durum or hard red spring wheats (Dinusson, 1970). While the hard red wheat proved generally satisfactory, the durum required special care in grinding and benefited from mixture with other grains. One may conclude on the basis of available data, that wheat feeding of swine is not seriously limited by consideration of palatability, but the methods of processing some wheats may be critical.

Wheat as an Energy Source

Since the organic matter of wheat, in common with the other cereal grains, is largely carbohydrate, wheat serves as a major source of dietary energy. There are various ways of evaluating energy, including estimation of total digestible nutrients (TDN) and digestible energy (DE). The relatively straightforward means of determining digestible energy makes it an appropriate criterion of describing energy values of swine ration constituents. Moreover, it has been established (Swift, 1957) that a direct relationship exists between DE and TDN.

Table 2: Comparison of Wheat and Other Cereals as Energy Sources for Swine.*

Cereal and Type	TDN	DE
	%	kcal/kg
Ground wheat	76.7	3322
Ground corn	76.2	3456
Ground barley	69.0	2900
Ground milo	76.8	3313

*Data from Robinson, Prescott and Lewis, (1965).

It is obvious that wheat is a much better source of available energy, measured by both criteria in Table 2 than a fibrous grain, like barley, and a similar comparison might be expected for oats. A more intriguing question is how wheat compares with the other non-fibrous grains commonly fed to swine, like corn and milo. Here the variations among individual lots of wheat become significant, and again the failure to define the specific nature of wheat used in studies such as that shown in Table 2 is regrettable.

There have been a number of studies in which wheat has been compared with other grains as the major energy source in swine rations. Generally, these follow two patterns: either equivalent substitution of the grains, pound for pound, or adjustment to an isonitrogenous basis. Lawrence (1967), in England, fed wheat in comparison with corn, milo and barley in high-level cereal diets (85% in starter, 90% in finisher diets) to pigs from weaning to slaughter at 200 lb. live weight. Contrary to the data in Table 2, he found that digestible energy was highest (and approximately equal) for the wheat and milo diets, and lower for those based on corn and barley. Lawrence attributed the poorer performance on the corn diet to the fact that all diets were fed as wet mashes and apparently this adversely affected palatability of the corn. Digestible energy values were 3557, 3594 and 3378 kcal/kg for the wheat, milo and corn diets, respectively. Nevertheless, weight gains on the corn diet were good, averaging 1.55 lb/day overall, as compared with 1.48 lb. on the wheat and 1.41 lb. on the milo diet. Gill, Oldfield and England (1966) reported somewhat similar comparisons in terms of liveweight gains in pigs when they substituted equal weights of Utah hulless barley, Hannchen barley, Oregon H-355 corn and Gaines (a soft white) wheat. Gains were best on the corn diet, next, and approximately equal on the wheat and hulless barley diets and poorest on the regular barley mix. The levels of gains used in these diets were 80% at the start and 85% during the finishing phase.

Bowland (1967) compared wheat (hard red) with hulless barley, barley and rye at 61% levels in starter rations for pigs, when the need for highly available energy is especially critical. The wheat diet was approximately equivalent to the hulless barley and barley diets in terms of feed intake, rate of gain and efficiency of feed conversion and all three were superior to the rye diet. Oregon studies, using soft white wheat or corn as the only grains in creep rations for suckling pigs, with equivalent supplementation in each case, suggested that the wheat-based ration was superior in terms of average 56-day weaning weights (England, 1966). Bowland later investigated the use of wheat in high and low-energy swine rations, where the variation in available energy was accomplished by dilution with oats. Again, the effectiveness of wheat as an energy source was demonstrated. The low-energy diet was apparently less palatable, and the amounts of the two diets eaten were approximately equal, so that growth was significantly better on the high wheat diet.

All of these experiences, (and many more could be cited) suggest that wheat is a very satisfactory energy source for swine. Its somewhat lower energy content than corn, which consequently supports somewhat lower animal gains, may most probably be attributed to corn's higher fat content. This is not an unmixed blessing on the corn side of the ledger. Corn oil is unsaturated and tends to soften the depot fat in the hog carcass somewhat, while wheat feeding has long been known to produce a hard carcass fat (see, for example, Loeffel, 1931).

The data presented have provided some evidence that processing methods may significantly affect animal performance on rations based on wheat or other cereal grains. Several experiments have suggested that pelleting produces greater benefits when applied to relatively high-fiber rations, containing considerable quantities of barley or oats, than when applied to low-fiber grains like wheat, corn or milo (Lehrer and Keith, 1953; Thomas and Flower, 1956). There is evidence, however, that wheat-based rations may also be improved by pelleting. In two separate trials, Hines (1970) has shown that wheat is equal or superior to milo in swine ations, and that both wheat and milo rations may be improved by pelleting. Bowland (1964) has shown with rations in which wheat was com- ined with some fibrous grains (barley, oats), it could be used success- ully under conventional or limited feeding, liquid or dry, or floor versus onventional self-feeder practices. It would appear that wheat is a ver- tile energy source, without major problems restricting its availability.

Wheat as a Protein Source

Although cereal grains are commonly, and appropriately, considered primarily as contributors of energy, the high levels at which they are used means that they incidentally supply a considerable proportion of the ration protein. Consequently, the suitability of their protein for supporting growth of animals becomes an additional point of importance, for non-ruminant species, along with their values as sources of energy. It is possible that part of the differences in performance of wheat in comparison with other cereals, reported herein, may have been due to the adequacy with which they met protein requirements, particularly in cases where total crude protein in the rations tended to be minimal.

Adequacy of a protein for supporting growth in non-ruminants is generally acknowledged to be a reflection of its amino acid composition, and particularly of the relative proportions of the essential amino acids. It has been known for many years that grains as a class tend to be deficient in lysine and tryptophan and, in some cases, methionine (Osborne and Mendel, 1914). The relative amino acid concentrations in wheat and some other common feed ingredients have been calculated by Altschul (1965) and are listed in Table 3.

Table 3: Amino Acid Patterns of Some Common Proteins.

Protein Source: Amino Acid	Cows Milk	Meat (Beef)	Soybean	Milo	Corn	Wheat
			mg Amino Acid/g N			
Isoleucine	341	323	319	338	225	253
Leucine	620	488	483	594	717	409
Lysine	475	537	429	197	169	174
Methionine & Cystine	214	253	197	354	200	265
Phenylalanine & Tyrosine	599	428	557	525	496	457
Threonine	280	278	269	241	225	192
Tryptophan	81	63	80	88	33	67
Valine	409	321	336	416	263	272

It would appear from Table 3 that the most limiting amino acid in wheat protein is lysine, and Becker (1958) has offered similar data, suggesting that the lysine in wheat represents only 49% of the requirements of this amino acid by the young pig. The decreasing price of commercially-available lysine has encouraged experiments involving its supplementation. Bowland (1960) found that a basal diet for baby pigs consisting of wheat and sugar, minerals, antibiotics and vitamins, could be greatly improved, in terms of growth rate produced, by supplementation with 0.2% L-lysine. Increasing the lysine supplementation to 0.6% improved performance of the animals still further, but not to the same extent as 8% fish meal (added at the expense of wheat). It is noteworthy that supplementation of the basal ration with 0.1% DL — methionine and 0.07% L-tryptophan, in addition to the lysine, did not improve performance over that attained with 0.6% L-lysine alone. Dinusson (1970) has provided evidence that supplementation of a ration containing 97.7% durum wheat (plus vitamin-mineral supplement) with 0.7% L-lysine increased gains of growing pigs from 0.72 to 1.34 pounds per day.

Further studies at Alberta (Bowland and Grimson, 1968) compared growth performance of pigs from 3 to 9 weeks of age fed diets containing 22% crude protein, or 14% crude protein with and without supplementation with lysine and methionine. All of the test diets contained approximately 60% wheat, which therefore contributed significantly to the dietary protein; however the increased protein in the high-protein diets was achieved largely through addition of herring meal. The lysine and total sulphur-bearing amino acid contents of the high and low-protein diets were 1.16%, 0.69% and 0.70%, 0.48% respectively. These experiments demonstrated that when L-lysine and DL-methionine were added to the low-protein diets, to equal the amounts of these amino acids in the high-protein diet, the growth performance was improved to equal that on the high-protein diet. At currently-prevailing prices, this amino acid supplementation did not produce as economical gains as feeding the higher protein level, however the authors recommended inclusion of cost data for amino acid supplements in future linear-programming of swine rations.

The area of protein quality appears to be one of promise for improvement of wheat rations, particularly those devised for feeding fast-growing young pigs. It is also assuredly one where even minor variations in amino acid patterns may significantly alter the level of growth supported, due to the high levels of wheat commonly fed. Availability of amino acid analyzers in many nutrition laboratories should facilitate accumulation of amino acid data on various types of wheat so that they may be used with increased efficiency as suppliers of dietary protein. For the future, the possibility of breeding wheat types with improved amino acid balances should be pursued. Alexander (1966), among others, has drawn attention to the implications of the development of "opaque-2" corn for the producers of other cereals, including wheat.

Wheat By-Products

Wheat's long acceptance as a human diet staple has made a number of milling by-products available for swine feeding. Thomas and associates (1955, 1956, 1959) have investigated the use of wheat millrun ("wheat mixed feed") under varying conditions of supplementation. They reported some lessening of growth rate and reduction of feed-conversion efficiency as high levels of wheat millrun (50% or more) replaced whole grain, usually barley, in swine grower rations. The fact that the millrun compared unfavorably with a fibrous grain suggested that the difficulty did not lie in the energy-availability area, while equivalent protein supplementation of the various test rations made a protein deficiency imposed by the millrun on the entire ration unlikely. One may speculate that the problem with rations high in wheat millrun is attributable to palatability or acceptability characteristics rather than to nutrient availability, *per se*. Bell (1960) after extensive studies with laboratory animals, is inclined to doubt flavor difficulties in diets containing wheat bran, but points out the effect of this bulky feed upon stomach volume, rate of passage of food and fecal volume.

There have been some indications of growth inhibition in mink and in poultry when fairly high levels of wheat germ meal have been included in their diets. For example, Creek *et al.* (1961) showed, in tests with chicks, that growth was significantly lessened when wheat germ meal was used as either the major energy source or the major protein source. The inhibitory effect was largely eliminated by autoclaving the wheat germ meal, suggesting the presence of a thermolabile inhibitor. It is highly doubtful that economic considerations would allow the use of such high levels (25% or more) of wheat germ meal in swine rations; nevertheless the demonstration of inhibition by this wheat fraction suggests that processing methods might be devised to improve performance on the whole grain.

Summary

Available evidence suggests that wheat is generally satisfactory as a major source of both energy and protein in rations for swine. Where less-than-optimum performance has been obtained on wheat rations, the reason may be in incidental factors such as method of processing or of feeding rather than in deficiency of specific nutrients or direct difficulties with nutrient availability. It has been shown, however, that lysine supplementation enhances growth of young pigs on wheat rations and this supplementation may be provided by appropirate, intact protein, or by L-lysine itself. Although evidence has been provided for existence of a thermolabile growth inhibitor in wheat germ, it is doubtful that this would occur in high enough quantities in whole-wheat rations for swine to cause significant growth depression. Analytical data on wheat show considerable variation among different types, grown under varying cultural conditions. It is strongly recommended that such differences be more extensively and accurately documented and that resulting data be used in computer formulation of swine rations in future.

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Wheat in Swine Finishing Rations

WILLIAM G. LUCE

In recent years in many areas of the United States, wheat has been competitively priced with other cereal grains. Thus, interest has increased tremendously in its use as a feedstuff for growing-finishing swine. Unfortunately since World War II, published research on the use of wheat for growing-finishing swine has been rather limited until recently.

Evaluating Wheat in Feeding Trials

In the last two or three years several research reports have been published on the value of wheat for growing-finishing swine. Luce *et al.* (1969) reported on a trial involving 320 crossbred pigs in which hard red winter (Triumph variety) was compared to milo. Experimental rations used in this study are shown in Table 1. Results are shown in Table 2.

The results published indicate that wheat tended to support similar gains as milo especially when equal amounts of supplemental protein were used (rations 1 and 5). The slight reduction of average daily gains for the pigs on the 15% crude protein diet (ration 3) may have been the result of a lysine deficiency during the earlier growth stages. Based on the analyzed content of the wheat and calculated content of the soybean meal, the lysine content of ration 3 was 0.51%. This is considerably lower than the 0.70% requirement listed by NRC (1968) for growing pigs weighing 20 to 35 kg.

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Table 1. Comparison of Experimental Rations.

	Ration Number				
Ingredients, %	1	2	3	4	5
Ground milo	75.00	40.05	---	37.60	---
Ground wheat	---	40.05	85.90	37.60	75.40
Soybean meal (44%)	20.10	15.15	9.50	20.10	20.10
Molasses	1.50	1.50	1.50	1.50	1.50
Dicalcium phosphate	1.40	1.10	0.70	1.05	0.65
Ground limestone	0.90	1.05	1.30	1.05	1.25
Trace mineralized salt	0.50	0.50	0.50	0.50	0.50
Vitamin-Antibiotic mix[1]	0.60	0.60	0.60	0.60	0.60
Total	100.00	100.00	100.00	100.00	100.00
% Composition					
Protein, calculated	15.00	15.00	15.00	16.67	18.35
Protein, chemical	15.42	15.42	14.95	16.87	18.00
Calcium, calculated	0.70	0.70	0.70	0.70	0.70
Calcium, chemical	0.67	0.68	0.72	0.67	0.73
Phosphorus, calculated	0.60	0.60	0.60	0.60	0.60
Phosphorus, chemical	0.60	0.56	0.55	0.60	0.57

[1] Vitamin-antibiotic mix furnished 1500 IU, Vitamin A; 500 IU, Vitamin D; 1.1 mg., riboflavin; 6 8 mg., niacin; 2.1 mg., pantothenic acid; 114 mg., choline; 8.2 mcg., Vitamin B_{12} and 20 mg., tylosin per pound of complete feed.

Table 2. Comparative Values of Wheat Vs. Milo for Growing-Finishing Swine[1]

	Ration Designation				
	1	2	3	4	5
	100% milo	50% milo 50% wheat	100% wheat	50% milo 50% wheat	100% wheat
Treatment	(basal)	equal crude protein	equal crude protein	equal supp. protein	equal supp. protein
Pens per treatment, no.	4	4	4	4	4
Pigs per pen, no.	16	16	16	16	16
Av. initial wt., lbs.	49.30	49.00	49.20	49.70	49.80
Av. final wt., lbs.	203.30	204.90	201.80	205.30	205.40
Av. daily gain, lbs.	1.68	1.68	1.61	1.76[1]	1.69
Av. daily feed intake, lbs.	5.28	5.28	5.22	5.51[2]	5.48[2]
Feed per lb. gain, lbs.	3.15[3]	3.17[3]	3.28	3.16[3]	3.28
Av. adjusted backfat, in.	1.36	1.39	1.43	1.37	1.40

[1] Treatment 4 is significantly higher ($P < .05$) than treatment 3.

[2] Treatments 4 and 5 are significantly higher ($P < .05$) than treatment 3.

[3] Treatments 1, 2 and 4 are significantly lower ($P < .05$) than treatments 3 and 5.

Significantly more feed per pound of gain was required using the 100% wheat rations (rations 3 and 5) as compared to the 100% milo ration (ration 1). However, when wheat replaced only 50% of the milo, feed utilization was not appreciably affected. The type grain used had little apparent effect on average daily feed intake or backfat thickness.

Gill *et al.* (1966) reported that pigs fed Gaines wheat tended to gain slower and require more feed per unit of gain than pigs fed corn with equal amounts of protein supplement. Cromwell *et al.* (1969) also reported that growing-finishing swine fed a 16% crude protein corn-soybean diet gained faster and required less feed per unit of gain than pigs fed diets substituted with either ½ or all the corn with wheat. These research workers reported wheat to have only 95% the value of corn.

Danielson and Grobouski (1970) reported that growing-finishing pigs fed diets composed of wheat tended to gain slower than pigs fed corn or milo diets. However, feed conversion was not appreciably affected. They also reported that a substitution of ⅓ or ⅔ of the milo portion of the diet with wheat did not apparently affect rate of gain.

Jensen *et al.* (1967) and (1969)) reported that wheat rations when appropriately supplemented with protein and/or lysine will produce gain and feed conversion ratios similar to that of a 12% protein corn-soybean meal diet. Jensen *et al.* (1967) demonstrated that a 13.7% crude protein, 15.3% crude protein or 12.4% crude protein + 0.15% lysine wheat rations tended to produce similar rate of gain and feed-gain ratios as a 12% corn-soybean diet for growing-finishing swine. However, a 12.4% wheat-soybean diet did not produce gains or feed-gain ratios comparable to a 12% corn-soybean meal diet.

Processing of Wheat

Since wheat occasionally fails to produce equal gains or feed-gain ratios as corn or milo, a few research workers have explored methods of processing as an avenue to improve utilization of wheat.

Luce *et al.* (1970) reported on a trial in which growing-finishing pigs were fed either a fine, medium or coarse grind or a close dry rolled wheat ration. Methods of preparation had little apparent effect on rate of gain, feed conversion or probed backfat thickness.

England *et al.* (1965), Jensen *et al.* (1967), Jensen *et al.* (1969) and Clawson and Alsmeyer (1970) have shown pelleting of wheat diets to be an effective method to improve feed utilization and rate of gain in growing-finishing swine. Results of the research conducted by Clawson and Alsmeyer (1970) using the soft red winter wheat (Blue Boy variety) are shown in Table 3. A standard corn-soybean meal or wheat-soybean meal ration fortified with vitamins and minerals was used. The crude protein level was 15.5% from the start of the experiment until the pigs weighed approximately 45 kg. At this point the protein level was reduced to approximately 13.6% crude protein.

Summary

Available literature indicates that wheat can be used successfully in swine rations. While there is some disagreement between reports from different experiment stations, a perusal of the literature would suggest that it is probably largely due to the different varieties of wheat being fed and differences in nutrient composition. The nutrient composition, especially amino acid content, must be taken into consideration when formulating optimum wheat rations for growing-finishing swine.

Methods of processing that may improve utilization of wheat for growing-finishing swine need to be explored further. At the present time, it would appear that pelleting will give about the same beneficial results as would be expected for corn or grain sorghum.

With the present knowledge concerning the use of wheat in growing-finishing swine rations, it would appear that price will largely determine its use. When wheat is as cheap or cheaper than other cereal grains such as corn or grain sorghum, nutritionists should seriously consider the use of wheat in swine rations.

Table 3. Comparison of Wheat and Corn Base Diets When Fed Ground or Pelleted[1]

	Ground Corn	Pelleted Corn	Ground Wheat	Pelleted Wheat
No. pigs	47	46	47	47
Av. initial wt., kg.	24	24	24.5	24
Av. final wt., kg.	90.4	92.3	91.8	91.8
Av. pig days	90	86	91	91
Av. daily gain, kg.	0.73	0.79	0.74	0.75
Av. daily feed, kg.	2.21	2.26	2.27	2.20
Feed/gain	3.02	2.86	3.06	2.93

[1] Clawson and Alsmeyer (1970)

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Utilization of Wheat In Turkey Feeding Programs

THOMAS W. SULLIVAN

Introduction

Wheat and wheat by-products have been used for centuries as a food for both animals and humans. Although generally considered as an energy source, wheat must also be recognized and evaluated as a major source of protein and amino acids. The price of wheat relative to other cereal grains restricted its use in animal feeds from the early 1940's until recently.

During the past few years, a steady decline in price has allowed an increasing use of wheat in turkey feeds. In some instances there has probably been too much reluctance or caution in replacing traditional feed grains with wheat. Some caution in this usage of wheat may have been justified, however, because turkeys, turkey feeding programs and varieties of wheat have all changed greatly during the past 25 years.

Data concerning the nutrient composition of wheat has been obtained and reported at a much faster pace in recent years. Also, a number of feeding trials have been conducted with turkeys. McGinnis (1964), Sanford (1966), Harper (1966) and Biely (1969) have reviewed the value of wheat in poultry rations.

This paper will review the pertinent and significant literature relative to the utilization of wheat in turkey feeding programs.

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Table 1. Metabolizable energy values for wheat and other cereal grains.*

Ingredients[1]	Form	Metabolizable energy[2] Kcal./lb. of dry matter	
		range	mean
Corn, yellow all analyses		1580-1800	1740
Corn, yellow	whole	1720-1760	1740
Corn, yellow	ground	1580-1790	1720
Corn, yellow	pelleted	1730-1800	1770
Wheat, all analyses		1340-1800	1540
Wheat, western, feed	whole	1370-1610	1540
Wheat, western, feed	ground	1340-1800	1550
Wheat, western, feed	pelleted	1480-1700	1580
Wheat, Ontario	ground		1530
Wheat, Ontario, sprouted	ground		1520
Wheat, Ontario, sprouted and moldy	ground		1530
Barley, Western, all analyses		1210-1670	1420
Barley, Western	whole	1320-1520	1420
Barley, Western	ground	1210-1470	1380
Barley, Western	pelleted	1450-1670	1520
Oats, Western, all analyses		1050-1720	1360
Oats, Western	whole	1210-1210	1210
Oats, Western	ground	1230-1610	1430
Oats, Western	pelleted	1050-1720	1390

*Sibbald, I. R., and S. J. Slinger. 1962. Poultry Sci. 41: 1612-1613.

[1] Names of ingredients conform to the definitions presented in the Canadian Feeding Stuffs Oct; the term "western" indicates that the ingredient was grown in Western Canada.

[2] The range and mean M.E. values are based on sample values and not on individual determinations.

Nutrient Composition of Wheat

Particular attention has been given recently to the metabolizable energy (M.E.), protein and amino acid contents of various wheats.

Energy. Sibbald and Slinger (1962) reported M. E. values for wheat and other cereal grains commonly used in poultry rations. These values, presented in Table 1, indicate that wheat has a lower energy value (about 90%) than yellow corn. However, the metabolizable energy value of wheat was greater than barley and oats. Hubbell (1968) has reported feedstuff analysis data which are frequently used in formulating turkey feeds. Metabolizable energy values listed by Hubbell are presented in Table 2. These data indicate that the M. E. value of both hard and soft wheats is about 89 percent of the value for yellow corn. It should be emphasized that Hubbell's feed ingredient analysis data were given on an "as fed" and not on a "moisture free" basis.

Certain treatments or processing methods have increased the feeding value and probably the M.E. value of wheat. These treatments will be discussed later in this paper.

Table 2. Metabolizable energy values for wheat and other cerea grains.*

Feedstuff	Metabolizable energy Kcal./lb.	% of corn
Yellow corn	1530	100.0
Milo maize	1480	96.7
Oats	1140	74.5
Rice (rough)	1215	79.4
Barley	1190	77.8
Wheat, hard red	1360	88.9
Wheat, soft Western	1360	88.9

*Hubbell, C. H. 1968. Feedstuffs Analysis Table, The Miller Publishing Co., P. O. Box 67 Minneapolis, Minn. 55440.

Table 3. Protein and amino acid composition of experimental whea samples used in milling studies.*

Component	Hard red winter	Hard red spring	White wheat (Gaines)	Soft red winter
	%	%	%	%
Moisture	12.49	12.60	13.00	14.75
Protein[1]	11.73	12.40	9.20	11.75
Amino acids[2]				
Lysine	0.33	0.31	0.32	0.35
Histidine	0.28	0.26	0.26	0.31
Arginine	0.57	0.52	0.55	0.63
Aspartic acid	0.62	0.62	0.57	0.65
Threonine	0.36	0.36	0.32	0.38
Serine	0.61	0.61	0.52	0.63
Glutamic acid	4.01	4.27	3.45	4.27
Proline	1.31	1.35	1.06	1.36
Glycine	0.51	0.52	0.47	0.53
Alanine	0.44	0.45	0.40	0.48
Cystine	0.33	0.32	0.29	0.35
Valine	0.52	0.53	0.48	0.56
Methionine	0.21	0.20	0.16	0.21
Isoleucine	0.43	0.44	0.38	0.44
Leucine	0.84	0.86	0.74	0.88
Tyrosine	0.38	0.38	0.32	0.38
Phenylalanine	0.59	0.59	0.49	0.62

*Deyoe, C. W., D. H. Waggle and E. P. Farrell. 1967. Feedstuffs 39:No. 17, 26-30, 42 & 43.

[1] Percent NX5.7; if the reader wishes to place the value on a factor of 6.25, he should multipl the above protein value by 1.096.

[2] All amino acid values are reported on a 14% moisture basis.

Protein and amino acids. Protein and amino acid composition of whea varies widely and is influenced or determined by genetic and environ mental factors. Wheat breeders today are interested not only in tota yield of protein, but in the amino acid content of the protein. Develop ment of hybrid wheats with high protein and higher lysine contents i now in progress. These high protein wheats should have a definite impac on the formulation of turkey rations in the near future.

Deyoe *et al.* (1967) have reported the protein and amino acid composition of blended samples of four wheats from different areas of the United States. Hard red winter wheats came from north central Oklahoma, southwest Kansas, northeast Kansas 1964, northeast Kansas 1965 and a composite from several Kansas locations. Hard red spring wheats came from northwestern Montana and from southeastern North Dakota; the white wheat sample was Gaines from Pullman, Washington; the soft red winter wheat came from east central Indiana. Protein and amino acid analyses of these four composite samples are presented in Table 3. The authors have presented these analytical data as a reference from which to ascertain the nutritional or feeding value of various wheats; hence, all amino acid values are reported on a 14 percent moisture basis.

Kohler and Palter (1967) studied methods for amino acid analysis of wheat products. These workers have compared their data on the amino acid composition of hard red winter wheat with previously reported values (Table 4). Kohler and Palter (1967) concluded that essentially all of the previously published results on cystine and methionine are too low, undoubtedly because of oxidative losses during hydrolysis. Also, their values for valine and isoleucine tend to be higher than most previously reported results; it was concluded that vigorous hydrolysis conditions (125°C. for 24 hours) were needed to liberate these two resistant amino acids, valine and isoleucine.

Table 4. **Amino Acid composition (gm/amino acid/16 gm. N) of hard red wheats.***

Component	Whole wheat		
	WRRL[1]	Lyman et al.[2]	Simmonds et al.[3]
Nitrogen (dry basis), %	2.42	2.64	2.56
Recovery of N as amino acids or ammonia, %	96	----	----
Lysine	2.61	2.67	2.71
Histidine	2.29	2.12	2.55
Ammonia	3.92	----	----
Arginine	4.74	4.71	5.06
Aspartic acid	5.06	4.85	----
Threonine	2.98	2.76	3.03
Serine	4.90	5.22	----
Glutamic acid	30.80	29.30	----
Proline	9.46	9.94	----
Glycine	4.03	3.94	----
Alanine	3.49	3.37	----
Cystine	2.31	1.80	----
Valine	4.79	4.69	4.46
Methionine	1.70	1.74	1.32
Isoleucine	3.89	3.78	4.50
Leucine	6.79	6.52	6.48
Tyrosine	3.10	3.19	3.24
Phenylalanine	4.64	4.43	4.92
Tryptophan	----	1.13	1.53

*Kohler, G. O., and R. Palter, 1967. Cereal Chem. 45:512-520.
[1] Western Regional Research Laboratory composite sample of hard red winter wheat (12% protein).
[2] Blend of hard red spring and hard red winter wheats.
[3] Average of five values for red wheat.

Table 5. **Amino acid composition of a selected high-protein line and parental varieties of wheat grown in 1966.***

Component	Wheat variety or line			
	Atlas 66	Wichita	Comanche	2500
	gm. of amino acid per 100 gm. protein[1]			
Lysine	3.3	3.2	3.2	3.2
Histidine	2.9	2.7	2.8	2.9
Ammonia	4.6	4.1	4.5	4.3
Arginine	5.6	5.5	5.5	5.4
Aspartic acid	5.7	5.6	6.3	5.5
Threonine	3.4	3.4	3.5	3.2
Serine	5.6	5.0	5.7	5.0
Glutamic acid	36.8	34.2	36.1	36.2
Proline	12.7	12.1	12.6	12.2
Glycine	4.7	4.4	4.6	4.4
Alanine	3.9	3.7	3.7	3.6
½ Cystine	1.8	2.0	1.9	2.0
Valine	4.6	4.3	4.6	4.5
Methionine	1.1	1.6	1.7	1.7
Isoleucine	3.8	3.9	3.9	3.8
Leucine	7.6	7.8	7.5	7.4
Tyrosine	3.8	3.7	3.9	3.8
Phenylalanine	5.3	5.5	5.6	5.4
Protein, % dry wt.	18.0	14.1	15.0	18.3

*Mattern, P. J., Ali Salem, V. A. Johnson and J. W. Schmidt, 1968. Cereal Chme. 45:437-444.
[1] Nitrogen was determined by the Gunning Kjeldahl method. Total N x 5.7 was used to convert nitrogen to protein values.

Mattern *et al.* (1968) at the Nebraska Agricultural Experiment Station have reported the amino acid composition of selected high protein wheats. Their amino acid composition data for parental varieties, Atlas 66, Wichita and Comanche, and one selected high-protein line are presented in Table 5. Johnson, Mattern and Schmidt (1969) have recently reported essential amino acid values for 16 high-protein wheats. These average values, presented in Table 6, are very reliable and representative for high-protein wheats, recently produced on an experimental basis.

The protein of wheat, like that of other cereals, is deficient in some of the essential amino acids, such as lysine, methionine and perhaps threonine. Also, wheat contains an excess of other amino acids such as proline and glutamic acid. Wheat breeding research currently in progress is aimed at increasing the protein and amino acid (especially lysine) content of wheat.

Vitamins and minerals. Perhaps the most recent comprehensive data on

Table 6. Average essential amino acid and protein composition of 16 high-protein wheats.*

Component	Gm. of amino acid per 100 gm. protein
Lysine	2.9
Isoleucine	3.7
Leucine	7.1
Methionine	1.6
Phenylalanine	5.2
Threonine	3.0
Valine	4.5
Tryptophan	1.1
Protein, % dry wt.	17.2

*Johnson, V. A., P. J. Mattern, and J. W. Schmit. 1969. Symposium on Plant Breeding, Cambridge, England, June 26-27, 1969.

Table 7. Mineral composition of experimental wheat samples used in milling studies.*

Minerals[1]	Hard red winter	Hard red spring	White wheat (Gaines)	Soft red winter
Ca, %	0.038	0.024	0.024	0.024
P, %	0.38	0.35	0.28	0.41
K, %	0.39	0.32	0.37	0.41
Na, %	0.01	0.005	0.005	0.01
Mg, %	0.11	0.11	0.09	0.10
Zn, ppm.	46.7	37.0	21.0	41.0
Fe, ppm.	27	20.0	30.0	22.0
Mn, ppm.	27.4	36.0	24.0	28.0
Cu, ppm.	7.1	5.2	4.2	4.2
Se, ppm.	0.28	0.50	0.04	0.04
B, ppm.	1.1	1.6	1.8	2.2
Sr, ppm.	0.72	0.69	0.48	0.48
Al, ppm.	5.0	5.0	5.0	5.0
Ba, ppm.	6.7	3.0	3.5	6.2
Co, ppm.	0.13	0.12	0.13	0.10

*Deyoe, C. W., D. H. Waggle and E. P. Farrell. 1967. Feedstuffs 39:No. 17, 26-30, 42 & 43.
[1] All mineral values are reported on a 14% moisture basis.

Table 8. Vitamin composition of experimental wheat samples used in milling studies.*

Vitamins,[1] mcg./gram	Hard red winter	Hard red spring	White wheat (Gaines)	Soft red winter
Niacin	53.1	56.1	46.6	48.4
Pantothenic acid	9.8	9.2	8.4	8.6
Folic acid	0.35	0.43	0.37	0.41
Thiamine	3.70	4.26	4.11	4.11
Riboflavin	1.65	1.50	1.32	1.54
Pyridoxine	2.21	2.66	2.02	1.69
Alpha tocopherol	14.1	13.9	14.5	15.2
Betaine	587.8	1008.4	1026.5	1442.1
Choline	1080.2	1205.6	1139.6	981.2

*Deyoe, C. W., D. H. Waggle and E. P. Farrell. 1967. Feedstuffs 39:No. 17, 26-30, 42 & 43.
[1] All vitamin values are reported on a 14% moisture basis.

the vitamin and mineral content of wheat was reported by Deyoe *et al.* (1967). These data for combined samples of four wheats, previously described, are presented in Tables 7 and 8. The wheat samples analyzed contained from 1.20 percent ash in white wheat to 1.61 percent ash in soft red winter. Considerable variation was evident in the trace mineral contents of different wheats; this was probably due to variations in soil and climatic conditions. Wheat is a fairly good source of certain water soluble vitamins and alpha tocopherol.

Evaluation of Wheat in Turkey Feeding Trials

Poley and Wilson (1939) studied and compared the utilization of corn, wheat, oats and barley by growing and finishing turkeys of the Standard Bronze strain. When judged by the amount of feed required to produce a unit of body weight gain, wheat was practically equal to corn. The feeding value of wheat was 99.0, barley 98.0, and oats 89.3 percent as compared to yellow corn in growing rations. In the finishing rations wheat had a value of 101, barley 87.7 and oats 96.2 as compared to yellow corn.

Slinger *et al.* (1958) concluded that Canadian number 5 wheat was equal in energy value to United States No. 2 yellow corn. These workers suggested that energy values for wheat in the published literature were too low for the Canadian grade of wheat used extensively for feed in that country. Summers *et al.* (1959) reported significantly increased growth rate in poults to four weeks of age, when either an all-wheat diet or a one-half wheat and one-half corn diet was fed as compared to an all-corn diet. Data from this study are presented in Table 9. Dried whey and fish solubles gave a somewhat greater response with diets containing corn than with the "all-wheat" diet. Since the wheat diets contained more

Table 9. Effect of unidentified factor sources on the performance of B. B. Bronze poults fed diets varying in wheat and corn.*

	4-week data[1]		
Dietary treatments	Body wt.	Survival	Feed/gain
	grams		
Corn basal	461	85/88	1.94
Corn basal + 2.5% dried whey + 2.5% fish sol.	515	85/88	1.94
Wheat & corn basal	496	82/88	1.88
Wheat & corn basal + 2.5% dried whey + 2.5% fish sol.	547	86/88	1.87
Wheat basal	525	86/88	1.84
Wheat basal + 2.5% dried whey + 2.5% fish sol.	546	86/88	1.82

*Summers, J. D., W. F. Pepper and S. J. Slinger. 1959. Poultry Sci. 38:922-928.
[1] Duplicate groups of 22 males and 22 females were assigned to each treatment.

Table 10. Influence of grain source on the performance of B. B. Bronze poults.*

Dietary treatment	Average 8-week data[1]	
	Body wt.	Feed conv.
	lbs.	
Corn diet	3.92	2.00
Spelt diet[2]	3.84	2.29
Barley diet	3.78	2.11
Barley diet + 2.5% Dawenzyme	3.75	2.08
Wheat diet L.S.D. ($P<0.05$)	4.12	2.02
Wheat diet L.S.D. ($P<0.05$)	.28	.21

*Arscott, G. H., and J. A. Harper, 1962. World's Poultry Sci. J. 18:278-284.

[1] Duplicate lots of 30 poults per treatment; dietary protein level was held constant at 29.0%.

[2] Spelt, *Triticum spelta*, is a relative of wheat, which resembles barley in appearance.

animal fat, the wheat response may have been due to the higher level of added fat and/or energy.

Sibbald and Slinger (1963) studied the nutritive value of ten samples of Western Canadian grains. These workers suggested that within the ranges studied, bushel weights were of little value in estimating the nutritive worth (M. E. and protein levels) of either wheat or barley. The bushel weights of oats, however, served as a useful guide to M. E. content.

Arscott and Harper (1962) at the Oregon Station have studied and compared the effect of grain sources on poult growth. Data from one experiment are presented in Table 10. These results show that wheat and corn were comparable relative to growth rate and feed efficiency of poults to 8 weeks of age. Harper (1966) has also conducted studies in which Gaines variety wheat replaced one third, two thirds and all of the corn in turkey diets. Data from this study are presented in Tables 11 and 12. Growth rates to eight weeks of age were comparable for poults on all treatments; however, feed conversion was better for the all-corn or partial corn diets. Body weights of both males and females at 20 and 24 weeks decreased as the amount of dietary wheat increased. Also, feed conversion data show a linear increase with increasing level of wheat. The all-wheat diet was 91.0 to 92.6% as efficient as the all-corn ration at 20 and 24 weeks, respectively. This difference in feed efficiency was close to the M. E. value of wheat (89-90%) relative to yellow corn.

Waldroup *et al.* (1967) conducted two trials to determine the comparative feeding value of wheat, corn and milo in turkey diets. When substituted on a pound-for-pound basis in mash diets, wheat and milo supported significantly greater gains in turkeys 11 to 21 weeks of age than did corn. Pelleted diets containing wheat produced significantly greater gains than pelleted corn diets, but there was no difference between pelleted milo and corn feeds. Data from this experiment are presented in Table 13. Waldroup *et al.* (1967) conducted a second trial in which corn, wheat and milo were compared in linear programmed diets fed to turkeys day-old to 23 weeks of age. All diets fed in this trial were pelleted. There were no significant differences in body weight gain or feed efficiency, which could be attributed to the feed grains used. The 23-week data from this experiment are presented in Table 14. These results would indicate that corn, wheat or milo may be used effectively in turkey feeds, when fed on the basis of their nutrient composition in properly balanced diets.

Table 11. Effect of replacing corn with varying levels of wheat in turkey starting diets.*

Dietary treatments[1,2]			4-week data		8-week data	
Corn	Wheat	Sex	Body wt.	Feed conv.	Body wt.	Feed conv.
%	%		lbs.		lbs.	
100.0	0.0	M	1.22	1.73	3.8	2.05
		F	1.09		3.1	
66.7	33.3	M	1.24	1.60	3.7	2.05
		F	1.13		3.2	
33.3	66.7	M	1.25	1.62	3.8	2.27
		F	1.06		3.0	
0.0	100.0	M	1.30	1.77	3.9	2.19
		F	1.10		3.1	

*Harper, J. A. 1966. Feedstuffs, 38: No. 9; 66-67.

[1] Three lots of 30 Medium White poults per treatment.

[2] Diets contained 29.0 to 30.0 percent protein.

Table 12. Effect of replacing corn with varying levels of wheat in turkey growing diets.*

Dietary treatment[1,2]			20-week data		24-week data	
Corn	Wheat	Sex	Body wt.	Feed conv.	Body wt.	Feed conv.
%	%		lbs.		lbs.	
100.0	0.0	M	15.2	3.71	19.2	4.02
		F	10.2		11.4	
66.7	33.3	M	15.4	3.76	19.4	4.06
		F	10.1		11.0	
33.3	66.7	M	15.3	3.85	18.9	4.22
		F	9.7		10.7	
0.0	100.0	M	15.3	4.08	18.5	4.34
		F	9.6		10.7	

*Harper, J. A. 1966. Feedstuffs, 38: No. 9; 66-67.

[1] Three lots of 30 Medium White poults per treatment.

[2] Dietary protein levels were approximately 21.5, 17.5 and 15.0% for 9-12, 13-17 and 18-24 weeks, respectively.

Table 13. Effect of grain source and pelleting on the body weight gain and feed efficiency of Large White turkeys.[1]

Grain source	Form	11-21 week data	
		Weight gain[2]	Feed/gain
		kg.	
Corn	mash	3.83c	4.35
	pellet	3.99bc	4.10*
	Average	3.91x	4.22
Wheat	mash	4.20ab	4.43
	pellet	4.29a	4.17*
	Average	4.24y	4.30
Milo	mash	4.14ab	4.42
	pellet	4.15ab	3.93*
	Average	4.14y	4.17
	Mash	4.06	4.40
	Pellets	4.14	4.07

[1] Waldroup, P. W., D. E. Greene, R. H. Harris, J. F. Maxey and E. L. Stephenson. 1967. Poultry Sci. 46:1581-1585

[2] Within treatment means or composite averages, values followed by the same letter do not differ significantly ($P < 0.05$).

*Differs significantly from value for mash diet.

Table 14. Final body weight and feed efficiency data for Large White turkeys fed corn, wheat and milo diets in pelleted form[1,2].

Grain source	23-week body wt.	0-23 week feed/gain	Feed consumption
	kg.		kg./bird
Corn	8.38	3.21	27.4
Wheat	8.44	3.23	27.3
Milo	8.49	3.38	28.2

[1] Waldroup, P. W., D. E. Greene, R. H. Harris, J. F. Maxey, and E. L. Stephenson. 1967. Poultry Sci. 46:1581-1585.

[2] Thirty-six male and 36 female poults were assigned to each treatment.

Table 15. Influence of lysine supplementation of wheat-soybean meal rations on body weight gain and feed efficiency of male, B. B. Bronze turkeys[1].

Dietary treatments[2]		24-week wt. gain	0-24 weeks feed/gain
M.E. level	added lysine		
	%	lbs.	
Medium	0.0	23.7	3.54
Medium	0.10	23.5	3.50
Medium	0.20	22.9	3.68
High	0.0	23.6	3.02
High	0.10	24.6	3.03
High	0.20	24.3	3.08

[1] Sell, J. L. 1964. Dept. of Animal Sci., Univ. of Manitoba, Winnipeg. Research report, Project 702:02.

[2] Two groups of 20 male poults were assigned to each treatment. Medium and high energy levels differed by approximately 100-115 Kcal. of M.E./lb.

Amino acid supplementation of wheat diets. Slinger *et al.* (1953) fed poults a diet containing 21.5 percent ground wheat, 15.0 percent ground corn and 5.0 percent oat groats as grain components. Supplemental methionine levels of 0.025 and 0.05 percent did not increase body weight gain, but did result in small and consistent improvements in feed efficiency.

Sell (1964) investigated the value of supplemental lysine in wheat-soybean meal rations for turkeys 0-24 weeks of age. The final or 24-week data from this trial are presented in Table 15. Addition of lysine to "medium" energy rations failed to increase weight gain or improve feed efficiency. The 0.20 percent level of added lysine reduced weight gain and decreased feed efficiency during the 12-24 week period. These data indicate that lysine was apparently not limiting in the "medium" energy ration, and also illustrate that an excess of this amino acid can adversely affect turkey performance. In contrast, turkeys fed the "high" energy ration responded favorably to lysine supplementation; the 0.10 percent level of added lysine was apparently adequate.

Fat suplementation of wheat diets. Joshi and Sell (1964) studied the effects of including soybean oil, sunflower oil, rapeseed oil or animal tallow in wheat-soybean meal rations for starting poults. Male B. B. Bronze poults were used and the fat sources were tested at 5.0 and 10.0 percent of the ration. Inclusion of soybean oil, sunflower oil or animal tallow stimulated weight gain from day-old to six weeks and improved feed efficiency. However, the addition of rapeseed oil depressed weight gain as compared to the low-fat, basal ration. The magnitude of growth depression was directly related to the rapeseed oil content of the ration.

Factors Which Influence Nutritional Value of Wheat

Origin. The type or variety of wheat, climatic conditions and soil fertility greatly influence the protein and amino acid composition of wheat. The M. E. value and trace mineral contents of wheat are also influenced by variety, climate and soil fertility. Variations in nutrient composition of wheat relative to these factors have been discussed earlier in this paper.

Water treatment and enzyme supplementation. The feeding value of wheat is often improved by water treatment or the addition of enzyme supplements to the diet. Fry *et al.* (1958) reported data from two experiments with starting poults; these data are presented in Table 16. These results show that water treating both barley and wheat gave significantly greater body weight gain.

Adams and Naber (1969a) have reported that water soaking grains improved their nutritive value for growing chicks. This was consistently

Table 16. Effect of water treating and enzyme supplements on nutritional value of grains for starting turkeys[1].

Grain	Water treatment	21-day data Wt.	21-day data Feed/gain	Enzyme suppl.	27-day data Wt.	27-day data Feed/gain
		gm.			gm.	
Corn	No	419	1.36	No	646	1.47
Corn	---	---	---	Yes	687	1.49
Barley	No	292	1.64	No	433	1.78
Barley	Yes	408	1.52	Yes	566	1.64
Wheat	No	398	1.42	No	612	1.54
Wheat	Yes	437	1.40	Yes	632	1.50

[1] Fry, R. E., J. B. Allred, L. S. Jensen and J. McGinnis, 1958. Poultry Sci. 37:372-375.

true for wheat and barley and occasionally true for corn. These workers also observed significant improvements in growth when chicks were fed diets containing wheat or barley soaked in 0.1 or 0.2 normal hydrochloric acid. However, in most cases the improved growth response obtained from the acid treatment of grains was no greater than from water treatment alone. Adams and Naber (1969a) also reported that steam expansion of corn or wheat was not effective in improving their nutritive value in chick diets. Supplementation of grain diets with commercial enzyme preparations was not effective in improving the nutritive value of corn, wheat or barley. Adams and Naber (1969a) evaluated partially germinated grains in chick diets; this treatment significantly improved the nutritive value of corn. The response from wheat treated in this manner approached significance, and little or no response was obtained from germinated barley.

Adams and Naber (1969b) reported that water or acid treatment of wheat flour or wheat gluten significantly improved growth rate of chicks, while untreated wheat flour depressed growth due to beak impaction which limited consumption. These workers have indicated that soft wheat did not respond to the water soaking treatment as did hard wheat. According to Naber and Adams (1969b), improved growth response in chicks fed grains subjected to water-soaking and acid treatments may be attributed to increased metabolizable energy values of the experimental diets.

Naber and Touchburn (1969b) have studied the effect of water treatment of components of hard red winter wheat on growth and energy utilization by the chick. They have concluded that water treatment probably increases the susceptibility of wheat starch to enzymatic degradation and thereby promotes increased energy utilization by the chick. An earlier report by Naber and Touchburn (1969a) indicated that water treatment and improved nutritive value of grains probably involve partial hydration and/or gelatinization of starch granules. These changes would apparently contribute to increased energy utilization by the chick.

Fineness of grind and beak impaction. When finely ground wheat or wheat flour is fed in turkey diets, pasting or impaction of the beak and beak necrosis occur. This condition has been observed by the author, by Adams and Naber (1969b) and quite obviously by many other workers. Summers *et al.* (1970) have indicated that this problem is largely overcome by coarse grinding of wheat, and does not occur when the feed is pelleted or crumbled. Therefore, coarse grinding or rolling of wheat is recommended in turkey feeding programs.

Other Considerations

Palatability. Turkeys readily consume wheat when given free-choice access to various cereal grains. Results of several studies have been very consistent and clearly indicate that turkeys prefer and will choose wheat over other grains.

Moldy wheat. Blakely *et al.* (1963) conducted four experiments in which six moldy wheats were incorporated into turkey poult rations for a six-week period. Moldy wheat, used as the sole source of grain in starter diets, significantly depressed body weight gain in only one experiment. Assays of 40 samples of moldy wheat showed that only two (5%) carried *Aspergillus fumigatus,* where as *Candida albicans* was not found in any of them. Mortality was low in all experiments and could not be attributed to the dietary treatments.

Fire and smoke damaged wheat. MacGregor and Blakely (1961) concluded that fire and smoke damaged wheat (21% of kernels charred) was entirely satisfactory for growing turkeys.

Carcass quality. Several studies have indicated that wheat-fed turkeys yield highly acceptable carcasses (Poley and Wilson, 1939; Marsden *et al.,* 1957; Goertz *et al.,* 1961a; Goertz *et al.,* 1961b). Fleshing qualities, meat tenderness, flavor and juiciness of wheat-fed turkeys have been quite satisfactory. The color of dressed carcasses from turkeys fed wheat rations is uniformly light, due to lack of xanthophyll pigment deposition in the skin. This lack of yellow skin pigmentation does not affect the grade or acceptability of turkey carcasses; on the contrary, such carcasses appear more uniform and will generally grade higher than carcasses showing variable yellow pigmentation.

Summary and Conclusions

Extensive studies have demonstrated that wheat performs very well in turkey feeding programs. Turkeys have readily accepted free-choice wheat and will generally select wheat over other cereal grains. Feed formulators and nutritionists should consider the following relative to the inclusion of wheat in turkey feeding programs:

1. Wheat has a metabolizable energy value of 88-92% of that for yellow corn.
2. Water-soaking and partial germination of wheat have improved the nutritive value of wheat for turkeys on an experimental basis. However, neither of these treatments appears commercially and economically feasible at present.
3. The protein content of wheat may vary from a low of about 9.5 percent to a high of 18.5 percent. Variety, climatic conditions and soil fertility largely determine the protein and amino acid composition of wheat. Lysine is apparently the first limiting amino acid in high-protein wheats, while methionine is apparently the first limiting amino acid in low-protein wheats. A high-protein, hybrid wheat with a higher lysine content is the goal of intensive wheat breeding research currently in progress. The achievement of this goal will significantly influence the role of wheat in turkey feeding programs.
4. Wheat should be coarsely ground or rolled for turkey rations; the inclusion of finely ground wheat or wheat flour in turkey rations will cause beak impaction and depressed body weight gains.
5. The carcass quality characteristics of wheat-fed turkeys have been highly acceptable.

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The Use of Wheat In Modern Feeding Programs For Broilers or Replacement Pullets

TALMADGE S. NELSON

The importance of the cereal grains in the formulation of poultry feeds was emphasized by the introduction of high energy rations about 20 years ago. Prior to that time ingredients used in diets were without specific classification. The complex nature of todays' computer formulated feeds balanced in energy, amino acids, minerals and vitamins depends on the cereal grains as the primary source of energy. In this capacity they also serve in a secondary role as sources of amino acids. Thus, both the energy and amino acid content of specific cereal grains must be considered when formulating poultry rations.

Corn is the primary cereal grain used in poultry rations in most of the United States. In the Pacific Northwest and in Canada wheat is the predominant cereal grain. Wheat is also the primary cereal grain used in poultry rations in Australia (McDonald, 1962; Cumming, 1969). Pino (1962) reported that corn, rice and wheat in that order were the energy sources used in the Pacific area.

Whether or not to use wheat in poultry rations is basically a question of availability and/or economics. Where competition with other cereal grains exists, the use of wheat may vary from year to year depending on the availability and price of other grains. Wheat has been fed to poultry since the industry has been in existence (Ewing, 1963). It is usually fed to animals when its price is low compared to corn. However,

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in the United States the use of wheat as a food for human consumption has largely priced wheat out of the feed market. This food-feed competition has existed for many decades. Wright (1899) stated "wheat was formerly too dear to be employed unless damaged; and if the damage be great, it had better not be meddled with. . ." More recently, Nichols (1970) also commented on the economics of feeding wheat. Thus, if the price of wheat becomes competitive with other cereal grains, it is possible that it may be used in feeds in geographic areas where it was not used before.

Digestibility

The digestibility of most of the components of wheat is similar to that of other cereal grains. There appears to be little or no difference in the digestion of different types of wheat. Halnan (1926) reported that the digestibility of all nutrients in two varieties of wheat were similar. Halnan (1928) also found that strong wheat, weak wheat and durum wheat and corn were all equal as sources of nutrients for poultry based on digestion trials. Morimoto and Yoshida (1954) reported that the nitrogen-free extract of both wheat and corn were completely digested. Bolton (1955) obtained complete digestion of the sugar and starch portion of wheat whereas cellulose and lignin were not digested. Eighty percent of the protein in wheat and 86% of the protein in corn was digested. Butterworth (1962) used three different methods to test protein utilization from cereal grains by chicks. Wheat, barley and corn were equal in value based on gross protein value and protein retention measured by a balance study and body composition. Vohra (1966) summarized energy sources used in poultry rations. The digestion coefficients of protein and nitrogen-free extract for corn, barley, milo and wheat did not vary greatly. The coefficient of digestion for the ether extract portion of wheat was lower than that of the other cereal grains. This is probably of little importance because of the low amount of fat in wheat.

Energy

Much of the nutritional research on feeding wheat to young chicks during the past 20 years has been studied to determine its metabolizable energy content. Hill (1952) reported that the calculated energy content of wheat was 1,423 calories per pound. The values for wheat and several other cereal grains were similar to determined values. Several investigators have reported the metabolizable energy content of unspecified types of wheat (Table 1). The values reported by Sibbald *et al.* (1960) were 26% lower than those found by Hill and Renner (1957). The metabolizable energy content of the wheats tested by Potter and Matterson (1960) Sibbald and Slinger (1962) and Sibbald and Slinger (1963) were similar. Butterworth (1962) reported that the metabolizable energy content of wheat was 1140 kilocalories per pound, which is almost 50% less than that reported by Hill and Renner (1957). Matterson *et al.* (1965) found that the metabolizable energy content of wheat was 1470 kilocalories per pound. The metabolizable energy content of three samples of Australian wheat, apparently on an air dry basis, was 1,490, 1,320 and 1,480 kilocalories per pound (McDonald, 1964).

Several investigators have reported the metabolizable energy content of specific varieties or types of wheat (Table 2). Anderson (1955) and Hill *et al.* (1960) tested different types of wheat ranging in protein content from 19.5% to 17.2% on a dry matter basis. The metabolizable energy content of these samples was similar in spite of variation in protein content. The average energy content of these samples was 1,660 kilo-

Table 1. Metabolizable energy content of wheat.

	Metabolizable energy
	Kilocalories per pound[1]
Hill and Renner (1957)	1,690
Potter and Matterson, (1960)	1,470
Sibbald, *et al* (1960)	1,340
Sibbald and Slinger, (1962)	1,540[2]
Sibbald and Slinger, (1963)	1,490[3]
Matterson *et al.* (1965)	1,470
	1,570

[1] Dry matter basis.
[2] Average of 25 samples.
[3] Average of 3 samples.

Table 2. Metabolizable energy content of wheat.

	Type or Variety	Protein	Metabolizable energy
		%[1]	Kilocalories per pound[1]
Hill, *et al.* (1960)	Hard red	17.2	1,610
	Hard yellow	13.3	1,690
	Soft red	14.0	1,650
	Soft white	10.5	1,710
	Canadian frosted	16.3	1,630
Sibbald, *et al.* (1962a)	Avon	14.1	1,530
Sibbald, *et al.* (1962b)	Northern	17.4	1,400
Sibbald and Slinger, (1962)	Western feed		1,550
	Ontario		1,530
Schumaier and McGinnis (1967)	Burt	13.1	1,380
	Marfed	13.1	1,460
	Omar	12.8	1,440
	Gaines	11.5	1,410
	Itama	14.3	1,310
Lockhart, *et al*, (1967)	Durum		1,590
Falen and Petersen	Gaines		1,280

[1] Dry matter basis.

calories of metabolizable energy per pound of dry matter. The energy content of Canadian frosted wheat was no different than that of the other samples of wheat tested. Sibbald *et al.* (1962a, 1962b) found the metabolizable energy content of Avon wheat was higher than that of Northern wheat. The energy content of wheat was not affected when it was sprouted, sprouted and frozen, or sprouted and allowed to mold. Falen and Petersen (1969) also reported no difference in the metabolizable energy content of normal and sprouted wheat. Sibbald and Slinger (1962) summarized the energy values they had obtained for various samples of wheat. The average metabolizable energy content of all samples tested was 1,540 kilocalories per pound of dry matter. The energy content of the whole grain and ground grain, or pelleted grain were similar. Schumaier and McGinnis (1967) tested five varieties of wheat grown in the Pacific Northwest. The metabolizable energy content ranged from 1,310 to 1,460 kilocalories per pound of dry matter. Lockhart *et al.* (1967) found the energy content of durum wheat was 1,590 kilocalories per pound.

The metabolizable energy content of the various samples of wheat shown in Tables 1 and 2 were not consistent. The difference between the lowest and highest was about 25%. Hill *et al,* (1960) observed that the metabolizable energy content of wheat was consistent in spite of a wide range in protein content. Schumaier and McGinnis (1967) found that the proximate analysis of wheat did not indicate metabolizable values. They also observed that the energy content was not related to pentosan content or to the location where the wheat was grown. Sibbald and Slinger (1963) tested wheat with bushel weights of 57, 61 and 65 pounds and found no difference in their metabolizable content. The condition of the wheat apparently has little or no effect on its energy content. The metabolizable energy value for Canadian frosted wheat was similar to other samples tested, Hill *et al.,* (1960). Sibbald *et al.* (1962a) found no difference in the metabolizable energy content of normal wheat and laboratory preparations of sprouted wheat or sprouted wheat that had been frozen or allowed to mold prior to feeding.

The physical form in which wheat is fed and the effect of pelleting on its metabolizable energy has been studied with inconsistent results. McIntosh *et al.* (1962a) fed wheat as the whole grain and coarse, medium and fine ground grain. No consistent effect of grinding was obtained although in two of the three tests higher values were obtained for whole wheat. McIntosh *et al.* (1962a, 1962b) and Sibbald and Slinger (1962) showed that pelleting wheat did not improve its energy content. However, indirect evidence has been reported suggesting that pelleting will improve the energy content of wheat. Cave *et al.* (1965) improved the metabolizable energy of wheat by-products 15 to 30% by pelleting. Bayley *et al.* (1968) also increased the energy utilized from wheat bran and wheat germ by pelleting but also found that this treatment decreased the energy content of middlings and shorts. Summers *et al.* (1968) reported that pelleting increased the energy content of wheat bran. If the energy content of these by-products can be increased by pelleting then it is possible that the energy utilized in whole wheat can also be improved by pelleting. The degree of improvement would be in proportion to the amount of the by-product present in the intact wheat.

Protein-amino acids

The protein content of the various types of wheat ranges from approximately 10% to 16% on an air dry basis (Crampton and Harris (1969). There is apparently little or no difference in the quality of the protein in wheat as its content varies. Hepburn and Bradley (1965) found different proportions of amino acids in varieties of hard wheat high and low in nitrogen. However, these differences were small compared to the magnitude of difference in total nitrogen. They concluded that the differences in amino acid composition were too small to be of importance in nutrition and that typical analysis tables could be used for the amino acid contribution of wheat to diets.

The protein of wheat is apparently well utilized by the chick although it is deficient in lysine and perhaps the sulfur containing amino acids. Davidson *et al.* (1962) demonstrated amino acid imbalances in oats, barley, corn and wheat when these grains were fed as the only protein source. Jeppesen and Grau (1948) fed chicks a diet containing a wheat protein concentrate supplemented with lysine, methionine, arginine, tryptophan and leucine. Growth depression occurred only when lysine was omitted from the diet. March *et al,* (1950) also showed that wheat protein is deficient in lysine. They reported that the addition of lysine to a diet containing wheat as the sole source of protein stimulated growth, whereas methionine and tryptophan depressed growth. They also showed that the combination of fish meal with low protein wheat was more effective than when combined with high protein wheat. Carpenter (1951) indicated that barley, oats, and wheat were deficient in lysine and the sulfur containing amino acids.

Slinger *et al.* (1953) conducted two experiments with chicks in which high levels of wheat were fed in the starting and finishing rations. The addition of methionine had no effect on final body weights but appeared to improve feed efficiency. McDonald (1957, 1958) reported that the sulfur amino acids were deficient in diets composed largely of wheatmeal and that a growth response by chicks was obtained by adding methionine to these diets.

Table 3. Amino acid content of wheat and the biological availability to growing chicks.[1]

Amino Acid	Content of grain %	Biological availability[2] %
Lysine	0.362	94.3c
Histidine	0.287	95.5c
Arginine	0.604	92.0bc
Aspartic acid	0.687	91.9bc
Threonine	0.391	92.7bc
Serine	0.609	94.5c
Glutamic acid	5.241	97.5c
Proline	1.394	96.6c
Glycine	0.627	70.8a
Alanine	0.394	89.9bc
Cystine	0.136	96.1c
Valine	0.543	92.2bc
Methionine	0.180	81.8b
Isoleucine	0.436	94.2c
Leucine	0.894	95.2c
Tyrosine	0.384	94.3c
Phenylalanine	0.645	95.8c
Protein (N x 6.25)	14.91	
Means		**93.6 ± 4.66**[3]

[1] Sharby, 1969

[2] Means of six individual chicks. Means not having the same superscript are significantly different ($P<0.01$).

[3] Means of 17 amino acids with standard deviation.

While much of the work on wheat protein has been defining its amino acid adequacy, the final determination of its quality is the availability of these amino acids. Sharby (1969) studied the amino acid content of wheat and their biological availability to growing chicks (Table 3). The sample studied contained 0.362% lysine and 94.3% of this was absorbed by the chick. It also contained 0.316% of the sulfur amino acids. However, the absorption of cystine was 96.1% whereas only 81.8% of the methionine was absorbed. This low availability of methionine may explain why McDonald (1957, 1958) obtained a growth response from supplemental methionine when chicks were fed diets containing wheatmeal. The average availability of the amino acids in wheat reported by Sharby (1969) was 93.6%. The average biological availability of the amino acids in soybean meal and grain sorghum was 89.7 and 97.6 (Bragg *et al.* (1967, 1969).

A portion of the amino acids in wheat is in the aleurone cells which comprise about 7% of the wheat kernel. Kohler *et al.* (1970) observed that many of these cells pass through the alimentary tract intact, reducing the amount of nutrients digested. These cells are ruptured by pelleting, which released the nutrients for utilization by the chick. Thus undigested aleurone cells could explain some of the beneficial effects of pelleting on the energy content of wheat by-products. This may also explain why Sharby (1969) found that the amino acids were not completely available to the chick.

Feeding trials

The feeding of wheat as a portion or as all of the cereal grain in the diets of growing chicks has produced variable results. Crampton (1936) reported that barley, corn and wheat were essentially equal in balanced rations. Poley (1938a) fed chicks diets containing 75% wheat. When the wheat was finely ground feed accumulated on the beaks of the chicks whereas it did not when the wheat was coarse ground. Biely *et al.*, (1951) found that wheat could replace corn pound for pound in the Connecticut broiler ration. However, when the levels were adjusted for protein content growth depression occurred which, they stated, may have been the result of amino acid or mineral imbalances. A reduced energy content of the diets may have also contributed to the growth depression. Slinger *et al.* (1953) grew chicks to 10 weeks on diets containing wheat as the primary cereal grain and concluded that growth was satisfactory. Summers *et al.* (1959) fed diets containing various combinations of wheat and corn and including the complete replacement of corn by wheat. They reported that diets containing wheat were equal to or superior to diets containing corn based on the rate of growth and efficiency of feed conversion. Sibbald *et al.* (1960) also reported that chicks fed wheat gained better than those fed corn. Davidson *et al.* (1961) concluded that when protein and energy were controlled in rations containing individual and mixed cereal grains there was no difference in the energy utilization.

Yoshida (1962) fed chicks various cereal grains in isocaloric and isonitrogenous diets. Compared to corn, the index of weight gain for oats, wheat, and barley was 93, 90, and 83.

McIntosh *et al.* (1962b) fed growing pullets diets containing wheat and corn alone and in combination. Weight gains and feed efficiencies were superior when the diets contained both grains compared to wheat alone. The form in which the grain was fed influenced the rate of gain when the diet contained wheat as the only cereal grain but not when the diet contained wheat and corn. Ground wheat was approximately equal to corn plus wheat. Pelleted and whole wheat were not as efficiently utilized in the all wheat diets. Older chicks appeared to utilize whole wheat better than young chicks. They suggested that wheat may be included in the starting ration at a level of 30% without affecting weight gain and feed efficiency. After 5 weeks of age wheat can be fed as the sole cereal grain without adverse effects.

McDonald (1964) concluded that corn and wheat were equal on direct comparison in high energy diets. However, if diets are adjusted for protein content, wheat-fed chicks grew less. Milner and Woodford (1965) dried high moisture wheat and fed it as the sole cereal grain and protein source. No difference was obtained for wheat dried at various temperatures. Lambert *et al.* (1968) compared pre-ripe and ripe wheat when it replaced a portion or all of the grain. No difference occurred in body weight of chicks although feed efficiency was better when chicks were fed control diets. Chicks fed sprouted wheat perform as well as those fed normal wheat (Sibbald *et al.*, 1962a; Falen and Petersen, 1969).

Adams and Naber (1969a) compared the performance of chicks fed diets containing equal amounts of corn, wheat or barley. When these grains were untreated, chicks fed the diet containing corn gained slightly more weight in five of six experiments and had better feed efficiency in four of these tests. Soaking wheat in dilute hydrochloric acid improved chick growth but steam expansion did not. Adams and Naber (1969b) obtained better growth and feed efficiency of chicks fed soft wheat than those fed hard wheat. Soaking these wheats in water improved the performance of chicks fed hard wheat but not those fed soft wheat. Naber and Touchburn (1969) compared the performance of chicks fed diets containing either corn, wheat or barley. When these grains were untreated, chicks fed corn grew faster and had better feed conversion rates at four weeks of age followed by those fed wheat then barley. Water treatment of the grains resulted in a statistically significant improvement in growth rate of chicks fed both wheat and barley which the authors attributed to increased starch utilization in these grains.

Petersen (1969) fed chicks diets containing 50% cereal grains. Their ability to promote growth was evidenced in descending order by corn, oats, sorghum low in tannin, wheat, sorghum high in tannin, and barley. Average feed consumption was similar for the corn, sorghum and wheat diets but was higher when the chicks were fed diets containing either barley or oats.

Diets containing high levels of wheat will be deficient in two and perhaps three vitamins and in pigments. Poley (1938a) reported a vitamin A deficiency in chicks fed a diet containing wheat. This deficiency was prevented by alfalfa meal. Wagstaff *et al.* (1961) obtained a growth response by adding biotin to diets containing 75% of each of several cereal grains. Dermatitis occurred when the diets contained wheat or barley but not when they contained either corn, milo, or oats. When the diets contained supplemental biotin, the growth of chicks fed wheat and corn was similar and was better than that of chicks fed the other grains. McDonald (1957) showed that wheat diets were marginal in folic acid.

Wheat contains neither leutin nor zeaxanthin, the pigments responsible for the yellow color in the shanks and skin of chickens. In some areas of the world where wheat is the primary cereal grain fed, light skinned breeds have been developed. However, if pigmentation is desired, it must be supplied by some ingredient other than wheat.

Body Composition

The effect of the different cereal grains on body composition has created sporadic interest among investigators. Maw (1935-36), Maw and Maw (1938-1939) and Maw *et al.* (1938-39) fed cockerels and broilers diets containing either corn, barley, oats or wheat. The corn diet produced more fat in the edible portions of the flesh. Wheat, barley and oats produced more fat in the abdominal area and skin. Poley *et al.* (1940a, 1940b) fed diets containing corn, barley and wheat to fryers and roasters. The corn fed chickens had more fat in the edible portions than those fed wheat or barley. However, the different treatments had no effect on the dressing and cooking percentage. The aroma, juiciness and tenderness of the meat of the chicks fed the various grains were the same. Lewis *et al.* (1956) reported the ether extract content of chicken carcass when different grains were fed. The highest mean percentage of ether extract in the dark and light meat occurred when the chicks were fed diets containing barley followed by wheat, oats and corn. When the whole carcass was examined, the distribution of fat in the abdominal, neck and subcutaneous regions was greatest for corn followed by wheat, oats and barley. Petersen (1969) studied the effect of various grains on body composition and taste of meat. None of the grains caused differences in the protein and ash content of the carcass. The variation was greater for fat, moisture and dry matter. Fat composition was highest when the diet contained sorghum, lowest when it contained barley, and intermediate when the diets contained wheat, oats, and corn. This investigator suggested that the grain fed may influence fat synthesis in the body. No differences were found in the appearance, consistency, or taste of the meat from the chicks fed the various grains.

Phytase

One aspect of wheat in the nutrition of the chick which appears to have been overlooked is its phytase content. This enzyme hydrolyzes phytate to inositol and inorganic phosphate. Phytate phosphorus is not available to the chick (Gillis *et al.* 1957) but after hydrolysis by phytase can be utilized as well as a supplemental inorganic phosphate (Nelson *et al,* (1968a). Mellanby (1944) and McCance and Widdowson (1944) reported that certain cereal grains including wheat contain phytase. Peers (1953) found that phytase was concentrated in the endosperm. Acker and Beutler (1963) observed that the breakdown of wheat phytate increased when the relative humidity increased from 45 to 80%. They found this hydrolysis to be enzymatic and bacterial. Evidence suggesting that wheat phytase increased the utilization of phytate phosphorus in the diet of chicks has been reported.

The total and phytate phosphorus content of wheat apparently varies according to variety. Lee and Underwood (1948) and Nelson *et al.* (1968b) reported that approximately two-thirds of the total phosphorus in wheat occurred as phytate. Hay (1942) noted that white wheat may contain less phytate phosphorus than red wheats. Young and Greaves (1940) found that phytate did not vary directly with total phosphorus and that both total and phytate varied with both variety of wheat and the treatment during the growing season. The contribution of wheat phytase to phytate hydrolysis has not been investigated sufficiently to conclude that it actually occurs when wheat is a dietary ingredient.

Summary

Wheat can be fed as the sole cereal grain in rations for growing chickens. This is confirmed by the fact that it is being fed in geographic areas where it is the predominant cereal grain available. The performance of chicks has been variable when comparisons were made of diets containing wheat as the sole cereal grain, diets containing other cereal grains, or combinations of wheat and other grains. The primary reason for this variation in chick response appears to be the energy content of the diet.

The energy level is the primary problem encountered when using wheat as the only cereal grain in diets for growing chickens. This is particularly true when a high energy diet is required. However, this is an economic rather than a nutrition problem. The cause of this problem is the higher protein content of wheat combined with its energy level. When diets contain adequate levels of amino acids, less wheat or other ingredients are required to supply these amino acids. This results in lower energy in the diet unless it is added as fat. The cost of the supplemental fat must be considered in terms of improved chick performance and the price of competitive grains.

The energy content of wheat is variable. However, as much variation in its energy content occurs among investigators as among types and varieties of wheat tested. The variation in the energy content of wheat is probably no greater than that reported for other cereal grains.

In addition to energy, the cereal grains supply from one-fourth to one-third of the amino acids in broiler diets and from one-third to one-half of the amino acids in diets for replacement pullets. None of the cereal grains has a distinct advantage in amino acid pattern. The average biological availability of the amino acids in wheat is in the range of 90 to 95%. The average biological availability of the amino acids in grain sorghum exceeds 95%. No information is available concerning the availability of the amino acids in other cereal grains. Until such information is available, the cereal grains must be compared on the basis of total protein or total amino acid content when this is the consideration. This is especially true for wheat because of the difference in the protein content of the types and varieties available for feed use.

The physical form in which wheat is fed can be important. Finely ground wheat becomes sticky if it gets wet. Diets containing high levels of fine ground wheat may stick to the beaks of chicks, especially if they are young. In order to avoid this the wheat should be coarse ground, or the feed should be pelleted.

Wheat does not contain the pigments responsible for the yellow color in the skin and shanks of chickens. If pigmentation is desired, it must be supplied by other ingredients. The need for diets containing pigments may also contribute to the economic disadvantage of wheat compared to corn.

All of the cereal grains are deficient in some of the vitamins and mineral elements. With the possible exception of the beta-carotene content of corn, none of the cereal grains has a distinct advantage over the others in vitamin or mineral content. The availability of commercially prepared supplements essentially eliminates vitamin and mineral deficiencies as a problem in diet formulation.

Wheat appears to have a greater advantage as an ingredient in diets for growing chickens other than broilers. This is primarily an economic factor since less energy and little or no pigmentation is needed when chickens are grown for replacement purposes. McIntosh *et al.* (1962b) recommended that the wheat content of starter diets fed to growing chickens be limited to 30%. After five weeks of age wheat can be fed as the sole cereal grain. It should be fed as coarse ground grain, or the feed should be pelleted.

The value of wheat in the rations of growing chickens will be based on its nutrient content and the cost of competing nutrient sources. This can be determined easily and rapidly by computer formulation.

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Wheat for Energy and Amino Acids in Layer Diets

C. W. Carlson

Prior to the price support era beginning with the late 30's, there was considerable interest in the use of wheat for layer diets. For many years thereafter it wasn't feasible to use wheat. In recent years, the reduced cost of wheat as a feed grain has caused it to again become attractive for use in animal feeds. However the information at hand for laying hens on nutrient availability and utilization from wheat is either very old or found in just a few limited recent reports. This simplifies surveying the literature for such information, but leaves something to be desired as to obtaining confirmatory data for making reliable recommendations.

An early report from our laboratory by Poley & Wilson (1941) indicated that bushel test weight of wheat, corn or barley had little consistent influence upon their nutritional values for laying hens. The diets used were rather crude or deficient in some nutrients by today's standards—i.e. 79% grain, 10% meat and bone scraps, 5% buttermilk, 5% alfalfa meal, 1% salt and 0.5% fish oil concentrate. The latter was included only from Nov. 1 through April 1 of each year. The best performance of any group of hens was only 55.4% egg production on a hen-day basis with a diet using 60 lbs./ bushel test weight wheat. In 3 of 4 studies, the hens fed higher test weight wheat outperformed those on the lower test

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Table 1. Effects of Leucine Supplements to a High Wheat Diet for Laying Hens.[1]

Exp.	Treatment	Egg Production	Feed/Doz. lbs.
		%	
1	High wheat[2]	60.9	5.0
	High wheat + 0.08% leucine[3]	64.2	4.6
2	High corn	51.5	5.5
	High wheat[2]	50.2	5.8
	High wheat + 0.08% leucine[3]	51.2	5.6
	Wheat and barley	45.9	6.3
	Wheat and barley + 0.08% leucine[3]	51.2	5.6
3	High wheat[2]	71.0	--
	High wheat + 0.3% leucine	74.0	--
4	High wheat[2]	68.8	4.2
	High wheat + 0.03% leucine	72.5	4.1

[1] From Anderson and Draper (1956).

[2] Contains in %, wheat 55.9, y. corn 14.5, barley 5, fish meal 2, meat and bone meal 3, 44% soybean meal 10, alfalfa meal 5, dried whey 2, bonemeal 1.5, limestone 0.5, salt 0.5 and vitamin and minerals supplements.

[3] From 3% corn gluten meal replacing soybean meal.

weight supplies, but for corn or barley there were no real differences. The diets were high in protein, from 18-23%, and when the high test weight wheat was used it lowered the protein levels of the diets because the wheat itself was lower in protein. This was probably a desirable effect and could perhaps explain the results obtained. Performances under these conditions were not greatly affected, whether corn, wheat or barley was used in the diet.

In a war-time report, Heuser (1943) showed that hens receiving diets containing wheat or wheat by-products and corn as the cereal component performed much better than those receiving a diet with only corn as the cereal component. The wheat diet was most palatable, hens on the corn diet did not eat as much feed, which probably influenced their performance. No differences were noted for mortality.

Amino Acids

A report by Anderson & Draper (1956) indicated a basically wheat diet to be slightly deficient in leucine. Data from this paper are given in Table 1. In every instance the leucine supplement elicited a response; the overall differences were statistically significant at the 5% level. The high wheat diet contained by calculations 1.26% leucine, whereas 1.35% had been indicated by Cravens (1948) to be the very minimum needed for maximum egg production. Increased levels of other amino acids in this high wheat diet perhaps may have accentuated the need for leucine. Further work which might substantiate this rather high requirement for leucine has been just recently conducted by Guenthner (1970) in our laboratory, see Table 2. In this work, hard spring wheat, corn, milo and triticale were used as the basic energy source in formulating 12 and 15% protein diets. With the 15% protein levels there were no differences in hens' performances, but, with the 12% protein diets, performances of hens on the triticale and wheat diets were poorer than with corn or milo diets. In these 12% protein diets, all of the protein was derived from wheat or triticale whereas some soybean meal was used with milo and considerably more soybean meal was used with corn. Milo is in itself a good source of leucine, approximately twice that of wheat, and whereas soybean meal is also a good source, corn gluten meal could contain about three times as much or 10% leucine. By calculations, the low protein wheat or triticale diets only contained 0.7% leucine whereas the corn or milo diets contained 1.2% leucine. All diets had been supplemented with methionine, lysine and tryptophane to meet 125% of the requirements suggested by Johnson & Fisher (1958).

Table 2. Egg Production of Laying Hens as Affected by Dietary Cereal Component and Protein Level[1]

Grain[2]	Protein Level	
	12%[3]	15%[3]
Triticale	62	71
Wheat	65	79
Milo	68	79
Corn	79	80

[1] From Guenthner, Unpublished data, S.D.S.U., 1970.

[2] Diets were formulated to be adequate in all nutrients by N.R.C. standards except protein (see text). Essentially they were cereal-soybean meal diets supplemented with minerals and vitamins.

[3] Hen-day production of 3 hens in each of 16 cages and 4 hens in each of 12 cages per treatment over a 9-week period.

Wheat has long been the basic feed grain in northern North Dakota and the Canadian prairie provinces. March and Biely (1963) showed that the addition of lysine and methionine to a 14% protein diet containing 69% wheat elicited a marked increase in egg size. Glycine addition (0.255%) caused a sharp drop in egg sige that was not corrected by methionine (.25%) and lysine (0.25%) additions. The study was of such short duration that the egg numbers data were of limited value. However, they interpreted the glycine to have caused an amino acid imbalance, whereas the 14% protein wheat-soybean diet might have been slightly limiting, first in lysine and then in methionine.

Another report from Canadian workers showed that a 13.5% protein wheat-soybean ration was first limiting in lysine, see Table 3 (Sell and Hodgson, 1966). In two experiments, addition of methionine alone to a 13.5% protein diet was detrimental to the performance of laying hens, markedly reducing egg numbers. On the other hand, addition of lysine alone increased egg numbers in both studies and markedly increased egg size in the first study, which was of 308 days duration. In the second

Table 3. Lysine and Methionine Supplementation of a 13% Protein Wheat-Soybean Diet for Laying Hens.[1]

Treatment	H.-D. Egg Prod.	Feed/ Doz.	Egg Wt.	Consumption Protein	Consumption Meth.	Consumption Lys.
	%	Kg.	gm.	gm.	gm.	gm.
Exp. 1 (308 days)						
16.8% Protein[2]	78.2ab*	1.85	58.9a	20.2	.31	.76
13.5% Protein[3]	72.2bc	1.90	54.3b	15.4	.24	.52
13.5% Protein + Meth. (0.1%)	66.7c	1.93	55.5b	14.5	.34	.49
13.5% Protein + Lysine (0.1%)	77.4ab	1.85	57.7a	16.1	.25	.66
13.5% Protein + Meth. + Lys.	81.6a	1.80	59.2a	16.4	.38	.67
Exp. 2 (112 days—the study ran 196 days longer, but with higher protein wheat)						
Control (17.2% Protein)[4]	87.1a	1.48	55.7a	18.4	.28	.71
16.2% Protein[5]	83.4ab	1.50	55.6a	17.0	.28	.72
13.4% Protein[6]	80.2b	1.62	53.7ab	14.5	.24	.51
13.4% Protein + Meth. (0.1%)	73.7c	1.56	49.8d	12.9	.31	.45
13.4% Protein + Lysine (0.1%)	83.2ab	1.58	53.1bc	14.7	.24	.62
13.4% Protein + Meth. + Lys.	79.8b	1.55	51.5cd	13.8	.33	.59
Exp. 2 (cont.—196 days)						
Control (17.6% Protein)[4]	74.1a	1.75	58.6a	19.1	.29	.72
18.3% Protein[5]	72.6a	1.73	58.8a	19.1	.31	.78
16.4% Protein[6]	73.4a	1.80	56.8a	18.1	.29	.61
16.4% Protein + Meth.	63.9b	1.83	54.0b	16.0	.35	.53
16.4% Protein + Lysine	73.8a	1.79	56.5a	18.1	.29	.72
16.4% Protein + Meth. + Lys.	69.3ab	1.76	54.0b	16.6	.37	.66

[1] From Sell and Hodgson, 1966.
[2] Major ingredients included wheat 75.5%, 45% soybean meal 7%, meat meal 4%, alfalfa meal 2% and distiller solids 2% with mineral and vitamin supplements.
[3] Wheat 86.5% and soybean meal 4%.
[4] Wheat 71.5%, soybean meal 8%, meat meal 4%, alfalfa meal 2%, and distiller solids 2%.
[5] Wheat 70.5% and soybean meal 15.0%.
[6] Wheat 84.0% and soybean meal 4.5%.
*Numbrs not followed by the same superscript letter are significantly different at $P \leq 0.05$.

phase of the second experiment, lysine gave no response either in egg numbers or egg size, however methionine was again detrimental. This brings up a problem that we don't have the complete answer for at this time—i.e. should the higher protein content of certain supplies of wheat be considered and utilized? In the latter part of this second experiment, the "low protein" diet contained, by analysis, 16.4% protein, whereas the "low protein" diet contained 13.4% protein initially. This means that the wheat itself contained approximately 17 and 13.5% protein, respectively, for the two periods. In this study, the greater protein content supplied adequate lysine to meet the requirement. However, for younger birds one cannot depend on the greater amount of protein from a higher protein sample of grain to be well balanced in amino acids. To make a 20% protein diet using barley of 10.4 vs 15.9% protein or oats of 12.6 and 19.2% protein, we (Carlson, et al 1953) had to use widely differing amounts of soybean meal. The chicks grew fastest on the diets containing the low protein cereals; these diets contained the greatest quantities of soybean meal and by calulations supplied .94-.98% lysine. However, the diets with the high protein samples supplied only 0.71-0.76% lysine. This, we concluded, accounted for the rather poor performance of chicks on these diets.

Table 4. Fish meal Supplementation of an all Wheat and Wheat-oats Diets for Layers.[1]

Grain	Fish meal	Egg Prod.	Egg Wt.	Body Gain	KCal/ Bird/ Day	Protein/ Bird/ Day	Mortality
	%	%	gm.	gm.		gm.	%
Wheat[2]	0[3]	58.5	57.8	54	404	20.3	18
Wheat	2	66.8	59.5	134	383	20.7	6
Wheat	5	70.5	60.6	173	372	22.5	8
Wheat-oats[4]	0	61.2	59.0	132	366	17.5	14
Wheat-oats	2	70.5	60.8	151	362	19.0	10
Wheat-oats	5	70.7	61.2	158	351	20.5	3

[1] From Table 4, Smith and Chancey, 1967.
[2] Containing, in percent, wheat 88, alfalfa meal 3, tallow 1.5, minerals 7 and vitamin supplements 0.5.
[3] Replacing a like amount of grain.
[4] As 2 above except oats replaced ½ of the wheat.

In the last part of the second layer study by Sell and Hodgson (1966), the lysine intake data show that the hens on the 16.4% protein diet were just barely receiving the lysine requirement. The hens were older too, so quite likely their lysine needs were met since Novacek and Carlson (1969) have shown that the need for lysine decreases with the age of the bird. Methionine supplementation of the 16.4% diet so upset the amino acid balance of the diet that the hens reduced feed intake and consequently were deficient in lysine, and probably leucine as well.

Smith and Chancey (1967) reported data to show that a largely wheat diet was not adequate for laying hens, see Table 4. Slightly better performance was noted when a wheat-oats diet was used, but both diets required supplements of fish meal to promote maximum egg size and egg numbers. Note that even though total protein intake was more than the theoretical requirement — i.e. 17.5 to 20 grams per hen per day — performance of the hens was subnormal. This is further substantial evidence that wheat protein alone is not completely balanced in amino acids, according to the needs of the laying hens, at least. Calculations indicate that lysine and leucine supplements should have been highly beneficial in this experiment. Calculations of the amino acid composition of the wheat vs. wheat-oats diets for lysine content, using the data in Table 5, shows that the diets contained 0.40 and 0.42% lysine, respectively. The 2% fish meal supplement would supply about 0.1% lysine which would have brought the lysine content up to the 0.5% level that Johnson and Fisher (1958) indicate is required. Similarly, the leucine content would have been about 0.6% in the all wheat and 0.7% in the wheat-oats diets. The 2% fish meal also would have supplied about 0.1% leucine which should have given a response. Note further from the data in Table 4 that

Table 5. Amino Acid Composition and Energy Content of Cereal Grains.[1]

	Midwest Barley %	No. 2 Corn %	Milo %	Midwest Oats %	Hard Wheat Spring %	Hard Wheat Winter %
Protein	11.5	8.7	11.0	12.0	14.0	13.0
Amino Acids						
Arginine	.53	.50	.36	.80	.70	.60
Cystine	.18	.18	.15	.22	.25	.22
Glycine	.36	.50	.40	.50	.70	.60
Histidine	.27	.20	.19	.20	.30	.26
Isoleucine	.53	.40	.46	.53	.70	.60
Leucine	.80	1.10	1.40	.90	.90	.80
Lysine	.53	.20	.20	.50	.45	.40
Methionine	.18	.18	.13	.18	.20	.17
Phenylalanine	.62	.50	.47	.60	.70	.60
Threonine	.36	.40	.36	.40	.42	.36
Tryptophane	.18	.10	.12	.16	.18	.10
Tryosine	.36	---	.70	.53	.60	.50
Valine	.62	.40	.53	.70	.60	.50
Metabolizable Energy						
kcal/lb.	1290	1560	1480	1190	1480	1480
kcal/kg.	2840	3430	3250	2620	3250	3250

[1] From Tables 9.6 and 9.7 Scott, *et al* 1969.

Table 6. Effect of Grain and Protein Level on Laying Hens.

Grain	Proportion of diet %	Protein Level[2] %	Egg Prod. %	Body Wt. Gain gm.	Feed Cons./ Hen/Day gm.	Protein/ Cons./ Hen/Day gm.	Other Dietary Ingredients Lard %	Other Dietary Ingredients Cellulose %
Barley	70.0	10	40.5	41	106	10.6	2.0	12.5
	64.0	12.5	61.5	333	115	14.4	5.5	6.0
	58.0	15	63.3	525	108	16.2	9.0	.9
Oats	66.4	10	60.9	262	124	12.4	3.0	12.5
	62.9	12.5	67.7	459	116	14.5	6.3	6.3
	59.3	15	67.1	592	108	16.2	9.6	.0
Wheat	59.4	10	43.4	30	116	11.6	0.1	22.1
	65.5	12.5	65.3	379	121	15.1	0.8	11.5
	71.6	15	68.3	506	115	17.3	1.5	0.8
Corn	50.1	10	51.9	122	119	11.9	0.1	24.2
	57.2	12.5	66.3	310	118	14.7	0.1	12.8
	64.3	15	69.8	512	112	16.7	0.2	1.4

[1] From Lillie and Denton, 1968.

[2] Protein level attained by variations in the amount of soybean meal supplied. Cellulose and lard were used as indicated in the last columns to equilibrate the energy levels to 1388, 1618 and 1848 KCal of M. E./Kg. for the 10, 12.5 and 15% protein diets respectively, so the energy: protein rations were held somewhat in line.

wheat ranks above the other grains as a source of methionine, cystine, tryptophane and glycine. However, wheat would not supply the sulfur amino acid requirements of even the laying hen.

In a study repeated over a two-year period, Lillie and Denton (1968) reported that wheat and barley were inferior to corn and oats when used to formulate a 10% protein diet for laying hens, see Table 6. However, with 12.5% or 15% protein diets, oats, wheat and corn were quite comparable, with barley being somewhat inferior. In this work, 15.1 gm. of protein/hen/day largely supplied by wheat was adequate for near maximum egg production. A level of about 16-17 gm. of protein from the oats, wheat or corn diets supported maximum performance. Regardless of protein level, the authors reported that for egg production the cereals ranked as follows: oats>corn>wheat>barley. However, on the 12.5 and 15.0% protein diets there were no real differences between the corn, oats and wheat diets. The large amount of lard used with the barley and oats diets probably accounted for their excellent performance with respect to feed requirements. Unfortunately no egg weight data were reported.

Table 7. Effect of Wheat, Corn or Wheat and Corn in Layer Rations.[1]

Treatment	Average of ten 28-day Periods Egg Prod. %	Body Wt. Gain gm.	Egg Wt. gm.	Feed Doz. Egg Kg.
All Wheat	70.3	254	56.7	1.98
½ Corn, ½ Wheat	72.0	241	56.9	1.87
All Corn	70.9	259	57.8	1.87

[1] From Arscott, 1965.

Arscott (1965) reported that white Western No. 2 wheat could be used to replace all or half of the corn in a laying ration without adversely affecting egg production, see Table 7. No significant differences in numbers of eggs produced over ten—28 day periods were observed. Feed efficiency was reduced with the wheat diets, and from the data obtained he made the statement that wheat has 95% of the feeding value of corn for laying hens. The somewhat reduced egg size could have been due to the lower levels of linoleic acid supplied by the wheat, this will be discussed. Unfortunately data on protein or amino acid intakes were not included in this report. The diets were supplemented with protein from soybean and fish meals—in this case 13.75 and 3% respectively, irrespective of the grain source. The extra protein supplied by wheat was therefore disregarded.

Another report from our laboratory indicates that wheat contains a good balance of amino acids needed to supplement a 9.4% protein corn-soy-glucose diet for laying hens (Novacek, 1970). The data shown in Table 8 illustrate a marked response from 3% protein from wheat even though the lysine, tryptophane and sulfur amino acid requirements had been supplied. Corn, barley, soybean meal and milo supplied a similar improved balance of amino acids, but to a slightly lesser extent, perhaps. Note that a rate of nearly 70% production was obtained with 12.6 gm. of protein per day over a 10-month period. This calculates to be a protein

Table 8. Effect of 3% Protein from Various Sources in Supplementing a 9.4% Protein Layer Diet.[1]

Treatment	Egg Prod.	Body Wt.	Egg Wt.	Death Loss	Cons./Hen-Day Feed	Cons./Hen-Day Protein	Cons./Hen-Day Lys.	Cons./Hen-Day Meth. & Cys.
	%	kg.	gm.	%	gm.	gm.	mg.	mg.
Basal[2]	58.1	1.7	59.1	10	107	10.0	667	534
Yellow Corn[3]	65.0**	1.8	59.6	13	103	12.8	647	517
Milo[3]	62.9*	1.9	58.3	11	104	13.0	652	522
Hard Spring Wheat[3]	67.8**	1.9	58.6	8	102	12.6	636	508
Barley[3]	65.5**	1.8	58.3	13	100*	12.3	622	496
Oats[3]	59.2	1.8	59.6	9	92**	11.3	573	458
Soybean Meal[3]	65.1**	1.9	59.5	9	104	12.9	651	520

[1] From Novacek, 1970. (Ph.D. Thesis).

[2] Basal diet contained in percent yellow corn 41.8, 50% soybean meal 11.2, glucose 34, yellow grease 5 and mineral and vitamin supplements with added methionine to supply 0.30%, tryptophane to supply 0.15% and lysine to supply 0.63%, respectively.

[3] Used to supply 3% protein equivalents, replacing glucose.

*, ** denotes significance at the 0.05 and 0.01 level, respectively.

Table 9. Fatty acid composition of cereal grains.[1]

	Barley %	Corn %	Milo %	Oats %	Wheat %
Total Lipids (L)	1.9	3.9	2.9	4.6	2.2
Fatty Acids, % of L.					
14:0	0.5	0.1	0.1	0.1	0.1
16:0	27.6	16.3	20.0	18.9	25.2
16:1	---	---	5.2	1.3	0.3
18:0	1.5	2.7	1.0	1.1	1.7
18:1	20.5	30.9	31.7	39.5	24.7
18:2	43.3	47.9	40.2	34.1	39.2
18:3	4.3	2.3	2.0	1.9	5.9
L x 18:2	0.78	1.77	1.11	1.49	0.82

[1] From Table 4, Edwards, 1967.

efficiency in excess of 40% whereas on conventional diets 25% efficiency is the typical figure for protein utilization. Further work is under way to elucidate which of the amino acids were essential to obtain these responses.

Energy

A factor in the Smith and Chancey (1967) study and in the Arscott (1965) study that may have accounted in part for the egg size deficiency is the smaller amount of linoleic acid supplied by wheat vs. oats or corn. According to the data of Edwards (1964) for fatty acid composition of cereal grains, see Table 9, wheat doesn't look too poor, except that total lipid content is only 2.2% compared to 4.6 or 3.9% for oats and corn, respectively. On this basis, the wheat-oats diet used by Smith and Chancey (1967) supplied 1.02% linoleic acid, whereas the all-wheat diet contained 0.72% linoleic acid. Similarly, the wheat vs. corn diets of Arscott would have contained about 0.7% and 1.4% linoleic acid, respectively. Edwards (1966) has further indicated that the linoleic acid requirement for maximum egg size is over 1.25%, so that this could well account for the smaller egg sizes noted for all-wheat diets. We have noted similar effects of smaller egg sizes with largely milo diets, and this also could be due to a linoleic acid deficiency.

Replacing one-half the wheat with oats would also have decreased the energy content of the diets used by Smith and Chauncey (1967) by about 10% or 277 Kcal/Kg. of diet. They noted no differences in food intake, however total food consumption for all groups was quite high. The 351 Kcal per day was excessive, perhaps even for the cool conditions of Newfoundland. With regards to total energy content, wheat ranks fairly high — equal to milo and about 200 Kcal below good No. 2 corn — see Table 5. Arscott's data (1965) for feed efficiency corresponded closely to the differences in energy content of wheat and corn.

Table 10. Composition of Samples of Western Canadian Grains.[1]

Grain	Bu. Wt. lbs.	Energy KCal ME/Kg	Protein %	Crude Fiber %	Ether Ext. %	Ash %
Wheat	57	3390	17.8	3.8	2.6	1.8
Wheat	61	3190	17.7	3.2	2.5	1.7
Wheat	65	3260	16.8	3.1	2.6	1.6
Barley	46	2530	15.1	6.6	2.6	2.4
Barley	50	2360	12.7	6.7	2.5	2.5
Barley	55	2710	14.0	4.8	2.4	2.2
Oats	39	2820	12.0	10.7	6.9	3.0
Oats	42	3120	12.9	12.3	5.5	3.4
Oats	46	3300	12.7	12.2	5.6	3.4
Rye	--	2550	11.8	2.9	2.0	1.6

[1] Taken from Table 1, Sibbald & Slinger, 1963.

Examination of the data in Table 10 for several Canadian samples of grain shows that the variation in energy content is not correlated with bushel weight or protein content, whereas there may be a positive relationship for the other grains, at least oats. Nonetheless, wheat is a good energy source and fits in very well with our modern concern for higher energy feeds. Note also, however, the relatively low lipid content of wheat, barley and rye samples compared to that of oats. When wheat is used as the major source of energy in the laying hen diet, it would be desirable to include some good source of linoleic acid. Tallows that contain only 1-2% linoleic acid would not be very valuable for this purpose, but yellow grease which contains 12-15% linoleic acid could be quite useful. About 3-4% stabilized yellow grease would be recommended with a largely wheat diet to supply the additional linoleic acid requirements, at least for the early part of the hen's laying cycle. Sometime after large egg size had been attained, it would seem possible that the linoleic acid content could be lowered. However, further work should be conducted on this point, i.e. would egg numbers be cut down with a reduced intake of linoleic acid? Jensen and Shutze (1963) showed that egg numbers were not adversely affected by a linoleic acid deficiency, only egg size was reduced. However they were working with hens that only averaged 45% production in either case. Conceivably a low linoleic acid diet as obtained with wheat could be desirable in reducing excessive egg size in later stages of the production cycle.

Summary

There is no doubt but that considerable improvement in protein utilization for production of meat, milk and eggs are going to be essential if we are to see animal protein continue to be produced for human consumption. Wheat can make a great contribution towards meeting the energy and amino acid needs of laying hens when properly used. On the caution side however are the data which have been discussed to show that wheat protein in itself is deficient in the sulfur amino acids, methionine and cystine and in lysine and leucine, and the data indicating wheat to be inadequate in linoleic acid for laying hens. These shortcomings can be overcome with the proper use of supplements or mixtures of feed grains or by feeding excess protein. Wheat ranks high as a source of glycine, tryptophane and metabolizable energy. For energy purposes, *per se,* wheat has about 95% of the feeding value of corn and is equal to the energy value of milo for laying hens. Wheat can be satisfactorily used in layer diets in place of corn or other grains to supply the major energy requirements, however the extra protein should be largely disregarded, and a good source of linoleic acid should be included in the diet.

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The Use of Wheat In Modern Feeding Programs for Other Poultry and Game Birds

ROLLIN H. THAYER

Introduction

Comprehensive reviews on the utilization of wheat in the feeding of turkeys, broilers and replacement pullets, and layer hens have been presented in this Proceedings by Sullivan, Nelson, and Carlson, respectively. Very little research has been reported in the literature in which wheat and wheat by-products were compared to other cereal grains in the feeding of game birds, ducks and geese. This means that in those cases where data are lacking, research findings obtained in studies with turkeys and chickens will need to be adapted to meet the needs of other classes of poultry, and used to supplement available data in the formulation of practical feeding recommendations. This is the approach which has been followed in compiling this summary paper.

Replace Corn and Milo on an Equivalent Nutrient Basis

It is standard practice to use wheat and in some instances wheat by-products to replace corn or milo in rations for all classes of poultry. This has been the procedure to a more limited degree insofar as oats and barley are concerned. The nutritionist doing the formulating must make it a point to utilize the wheat or wheat by-products on an equivalent nutrient basis rather than on a pound for pound basis. This involves not only protein, but amino acids, energy, minerals and vitamins. Nutrient analysis tables must be representative of the wheat sample being used or actual analysis values must be obtained if major errors are to be avoided.

The use of grain sorghums in poultry feeds is a prime example of the difficulties which can be encountered unless the nutrient composition values which are used in formulation are typical of the specific lot of grain which is being used. Experience has shown that the crude protein level of grain sorghums can vary from a low of 4% or 5% to a high of 12% or 14%. Systematic sampling coupled with routine chemical analyses by a number of feed manufacturers during the past three or four years has established this fact. Instances can be cited with turkeys where poor growth and inefficient feed utilization were observed. Grain sorghums were used in these rations on the assumption that the actual protein values approximated average figures, when actually they were significantly below these figures. Considerable economic loss was suffered and could have been avoided if actual nutrient composition could have been established prior to use.

A parallel situation has been reported by Summers *et. al.,* (1959) in some feeding trials in which growing pullets were used. In one feeding trial a comparison was made of corn and wheat with the corn included at a ration level of 51% and wheat included at a ration level of 55.5%. In the formulation procedure, protein was replaced on a equivalent basis, but no attention was given to the final energy content of the two experimental rations. In addition, no attempt was made to standardized insofar as mineral and vitamin content were concerned. Four-week body weights and units of feed per unit of gain were the same for the growing pullets fed the corn and the wheat (Table 1). In a second trial in which

Table 1. Comparison Wheat vs. Corn on an Equivalent Protein Basis.

Grain in Diet	Four week mean wt. (gm.)	Feed/Gain
All Corn	444	1.71
All Wheat	449	1.72

Summers *et al.,* (1959).

Table 2. Comparison Wheat vs. Corn on an Equivalent Nutrient Basis.

Diet	Four week mean wt. (gm.)	Feed/Gain
Basal, all corn (U.S. No. 2)	382	1.88
Basal + 5% wheat	399	1.93
Basal + 10% wheat	396	1.85
Basal + 25% wheat	417	1.78

Summers *et al.,* (1959).

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the corn was progressively replaced by 5%, 10%, and 25% of wheat (Table 2), there was an improvement in growth which was statistically significant at the 1% level of probability. However, there was no improvement in efficiency of feed utilization. This improvement in growth response was due in part to a difference in energy intake. The authors indicated that the wheat samples which were fed provided a higher energy intake than was anticipated from average analysis tables.

Regardless of the nutrient or nutrients responsible for the progressive improvement in growth, this example illustrates the critical need to make use of actual nutrient content figures when wheat and wheat by-products are to be included on an equivalent nutrient basis in feed formulation.

Formulate Based Upon Anticipated Feed Intake

Ration formulation must involve the use of a feed intake figure which it is anticipated will be obtained under the environmental conditions in which the ration is to be fed. Daily nutrient intake requirements should be established, and all nutrients should be included in the anticipated daily feed intake at levels which will meet these requirements. If ration formulation is done with a realistic daily feed intake in mind, requirements for growth and egg production can be met without any difficulty.

Factors Other Than Nutritive Value

Specific characteristics other than nutritive value must be taken into consideration when wheat or wheat by-products are used. The fineness of grind of the wheat or wheat by-products, and the crude fiber content of the entire ration must meet acceptable standards especially when whole ground wheat is fed. The gluten content of the wheat protein tends to make the final ration sticky and gummy, particularly when moisture is encountered. When the physical characteristics of the ration are not favorable, feed particles accumulate in the tips of the mandibles of the poultry eating the feed and cause necrosis. By grinding the wheat rather coarsely and by including fiber from oats or barley, this adverse condition can be largely counteracted. When wheat does replace corn, a combination of ground wheat and pulversized oats in a ratio of five to one should be employed.

Wheat and Wheat By-Products Used Routinely

Recommended rations which are being used extensively for ducks, pheasants, and quail contain wheat or wheat by-products in varying amounts. (Baldini *et. al.*, 1953; Ewing, 1963; Heuser and Scott, 1951; Heuser *et. al.*, 1951; Nestler *et. al.*, 1942; Nestler *et. al.*, 1944; Norris *et. al.*, 1936; Roberts, 1934; Schaible, 1970; and Skoglund, 1940). No actual research data are available in which these feed ingredients have been compared to other cereal grains and cereal grain by-products, but favorable results under a wide range of feeding conditions dictate their continued use. Rations for growing ducks contain wheat middlings at levels of from 10% to 15%. Up to 10% of whole ground wheat has been included. In those rations where wheat middlings were replaced by whole ground wheat, pulverized oats was included at the level indicated in the preceeding paragraph.

Rations for pheasants of all ages contain from 12.5% to 25% wheat middlings and from 5% to 15% of wheat bran. As will be pointed out later, the amount of fiber and the type of fiber are factors to be considered insofar as rations for pheasants are concerned. The level of wheat middlings in rations for bobwhite quail range up to 10%.

Why Grains are Included

There are a number of reasons why grains should be included in rations for game birds. A variety of seeds are normally available in the wild environment, and substitutes for these seeds must be used in rations where game birds are raised in confinement. Grains are an excellent source of carbohydrates and are fed primarily as a source of energy. However, grains contain substantial quantities of protein. Amino acid levels and amino acid ratios in this protein are such that a significant amount of protein of a very high quality is added to the ration when grains are included. The crude fiber which is present in cereal grains contributes bulkiness to the ration, and in so doing aids in the digestion and absorption of food nutrients. The cereal grains are also high in B complex vitamins and Vitamin E. Although it is now a standard practice to add mineral supplements to mixed rations, considerable quantities of certain trace minerals are contributed through the cereal grains.

Need for Vitamin A Supplements

When wheat or wheat by-products are used in rations to replace corn, an adequate intake level of Vitamin A should be provided by supplementation. This is equally true in the case of grain sorghums which are lower in Vitamin A than corn, but the problem may be more acute when wheat is used. Studies with game birds indicate that a Vitamin A deficiency can reach major proportions in a rather short period of time. This is most frequently observed with bobwhite quail. In the wild environment it is difficult to accurately evaluate the true situation since

Table 3. Palatability for Game Birds in Wild Environment.

Grain	Amt. eaten %
Corn	100
Wheat and scratch feed	50
Buckwheat	45
White corn, popcorn and barley	40
Sweet corn and sudan grass seed	35
Sorghum seed	25
Soybeans, oats and rye	15

Hawkins *et. al.* (1937).

quail which are suffering from a Vitamin A deficiency are weakened to such a degree that they easily fall prey to predators. However, enough evidence has been accumulated to indicate that Vitamin A supplementation is important, and this is particularly true when cereal grains are fed which are low in Vitamin A.

Palatability

Ration palatability is a factor which must be given consideration in selecting feed ingredients. Some idea as to the relative palatability of different grains was obtained in a study conducted by Hawkins *et. al.*, 1937. The grains as listed in Table 3 were made available in the wild environment in equal quantities. When the corn had been consumed completely, the amounts of the other grains which had been consumed were measured. The values listed in Table 3 represent the amount of each grain which was consumed in relation to corn at 100%. From these data it is obvious that wheat rates second to corn from a palatability standpoint. It can be concluded from these results that wheat is palatable and compares favorable with corn in this respect.

Feather Picking With Pheasants

The problem of feather picking is encountered frequently when pheasants are grown in confinement. This is particularly true when they are grown in batteries, and management or nutritional measures must be taken to control this vice. Research studies in which wheat and wheat by-products were used, and nutritional measures taken to reduce the incidence of feather picking are reported by Scott *et. al.,* (1954), and Scott and Reynolds (1949).

Scott *et. al.,* (1954) raised pheasants in batteries. During the first three weeks of the growing period the ration contained 28% of protein. Starting when the pheasants were three weeks of age, a 24% protein ration was fed and observations made until the pheasants were five weeks of age. The basal ration which was fed contained 30% of corn, 18% of standard middlings, and 10% of oats. Modifications were made in this basal (Table 4) so that the levels of oat groats and ground oats were varied as indicated.

Table 4. Effect of Ground Oats in a 24% Growing Ration Upon Growth and Feather Picking in Pheasant Chicks.

Treatment after 3 wks. of age	Average weight at 5 wks. (gms)	Week Picking started	Incidence of picking %
No oats (corn)	242	3½	100
23% oat groats	227	3½	100
22% ground oats	222	5	50 (slight)
10% oat groats	240	3½	100
11% ground oats	233	5	75 (slight)

Scott *et. al.* (1954).

Table 5. Effect of Wheat on the Incidence of Feather Picking with Pheasant Chicks.

Combination		Percent fiber	Week feather picking started	Severity of feather picking	Average Weight 5 weeks (gm.)
A.	Whole wheat Rolled oats	2.8	2	5	256
B.	Whole wheat Pulverized oats	3.6	2	3	250
C.	Wheat middlings Pulverized oats	4.2	4	1	292
D.	Whole wheat Rolled oats Alfalfa meal	3.6	2	4	246
E.	Whole wheat Pulverized oats	4.4	4	2	247
F.	Wheat middlings Pulverized oats Alfalfa meal	4.8	2	3	244

Scott and Reynolds (1949).

There was no difference in average body weight at five weeks of age. The levels of ground oats as fed were tolerated very well, and apparently has no adverse effect on growth response. It is obvious however, that the incidence of feather picking was not reduced through the use of oat groats as compared to corn.

The pheasant chicks which were fed the ground oats did not feather pick until the last two days of the feeding trial. At this time hot weather was encountered, and this was thought to be a contributing factor. Nevertheless, the incidence of feather picking was slight, although it reached an incidence of 50% to 75% for the two treatments involved. This would seem to indicate that the addition of ground oats was a desirable ration modification, and significantly reduce the incidence of feather picking.

Scott and Reynolds (1949) utilized whole oats and wheat middlings, in combination with rolled oats, pulverized oats, and alfalfa meal in an attempt to eliminate feather picking with pheasant chicks. The pheasant chicks used in this feeding trial were housed in batteries under well lighted conditions. The respective experimental rations contained 18% of corn, either 14% or 9% of wheat, 14% of wheat middlings, 10% of rolled oats, 10% of pulverized oats, and 5% of alfalfa meal in the combinations as listed in Table 5.

The results which were obtained indicate that growth was not decreased and that energy intake was entirely adequate. The incidence of perosis was zero. Feather picking was not prevented entirely, although results were significantly different among the different treatments tested.

Apparently a combination of wheat middlings and pulverized oats was most effective in eliminating the feather picking vise. Whole wheat in combination with pulverized oats was nearly as effective. It was concluded that level of fiber as well as source of fiber were important considerations. The data would indicate that a crude fiber level of approximately 4% was somewhere near optimum. Crude fiber provided by pulverized oats was more effective in preventing feather picking than was crude fiber from alfalfa meal. These results are in line with previous experience in which crude fiber from pulverized oats has been very effective in preventing cannabilism and feather picking in all classes of poultry.

Availability of Niacin

An adequate level of niacin must be provided in rations which contain wheat middlings. Feeding trials have indicated that the niacin which is found in wheat middlings is not readily available to either laying hens or growing ducks. Vitamin supplementation is a standard practice in ration formulation and substantial quantities of niacin are included in these vitamin supplements. However, care must be exercised to be sure that the total niacin intake is adequate without having to depend upon the niacin from the wheat middlings as a major contributor.

Recent findings by Manoukas *et. al.,* (1968) with laying hens indicate that wheat middlings are a very poor source of niacin. These workers employed a quantitative bioassay in which hatchability was the independent variable. The laying hens in this feeding trial were fed a niacin deficient ration which contained 0.134% of tryptophan.

The results obtained in this study are summarized in Table 6. It is obvious that the niacin from both yellow corn and wheat middlings is poorly utilized by White Leghorn layers. On the other hand, dehulled soybean meal provides a readily available source.

Table 6. Niacin Availability for White Leghorn Hens.

Feed Ingredient	Availability %
Yellow corn	30
Wheat middlings	36
Dehulled soybean oil meal	100

Manoukas *et. al.* (1968).

Table 7. Niacin Availability for Ducklings.

Supplement	Incidence Bowed Legs %
None	100
Niacin, 5 mg/lb	45
Niacin, 10 mg/lb	0
Niacin, 10 mg/lb + antibiotics and sulfa	5
Dried brewers' yeast, 3.8%	25
Dried brewers' yeast, 7.5%	0
Wheat standard middlings, 28%	100
Vitamin mix	0
Vitamin mix (except niacin)	100
Vitamin mix (except niacin) + antibiotics	100

Heuser and Scott (1953).

Research studies have established the fact that bowed legs in ducklings is caused by a deficiency of niacin. Studies conducted by Heuser and Scott (1953) evaluated wheat standard middlings as a source of this important vitamin. Pekin ducks were used and were maintained on wire floors. The rations which were fed contained 40% of corn, 15% of wheat flour middlings, 15% of wheat standard middlings, and 10% of pulverized oats, in addition to other ingredients. The basal ration was supplemented as indicated in Table 7. The incidence of bowed legs on a percentage basis was used as a measure of the availability and the adequacy of niacin intake from the various supplements.

The 100% incidence of bowed legs observed in the ducklings fed wheat standard middlings indicates that the availability of niacin from this feed ingredient is very poor. A supplemental level of 10 milligrams of niacin per pound was required to eliminate the bowed legs entirely. These data would indicate that niacin intake is a critical factor insofar as growing ducklings are concerned, and that wheat standard middlings should not be dependent upon to provide substantial quantities.

Physical Form

The physical form in which feeds are fed have some bearing upon their nutritive value as reflected in weight gain and efficiency of feed conversion. It has become standard procedure to pellet feeds for growing

Table 8. **Effect of Physical Form and Levels of Wheat on Weight Gain and Feed Efficiencies.**

	15 Wks. of Age	
Wheat	**Wt. Gain (Lbs.)**	**Feed/Gain**
Whole	2.54	3.89
Ground	2.68	3.78
Pelleted	2.41	3.91
Mean	2.54	3.86
Wheat + Corn		
Whole	2.74	3.68
Ground	2.73	3.80
Pelleted	2.71	3.79
Mean	2.73	3.76

McIntosh *et. al.* (1962).

ducks and, for this reason, whole or ground wheat in mash form probably does not warrant consideration. For game birds, on the other hand, these three physical forms might be of importance on a comparative basis since game birds in the wild eat whole grain and pelleting would constitute the most desirable form for rations to be fed under confinement conditions. Since no data are available in which wheat in these three forms was fed to game birds, data obtained with growing pullets would seem to have an application.

McIntosh *et. al.,* (1962) grew pullets in floor pens. Wheat was used as the sole cereal, and in a 50-50 combination with corn. The data summarized in Table 8 indicate that there were no differences in energy due to the form in which the ration was fed. However, it would appear that the wheat-corn combination was superior to the wheat alone.

Conclusions and Recommendations

Based upon the data available for game birds, ducks, and geese, and upon inferences which can be drawn from available data on turkeys and chickens, the following recommendations would seem to apply:

1. Use wheat and wheat by-products in the feeding of game birds, ducks, and geese based upon their nutrient content in rations designed to meet nutrient intake requirements.

2. The nutritionist should be aware of the limitations of wheat and wheat by-products from the standpoint of nutrient availability, and their effect on the physical characteristics of the final ration. These two factors must be taken into consideration if adequate rations are to be formulated.

3. Substantial amounts of wheat and/or wheat by-products can be used successfully depending upon their price and availability.

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Rumen Malfunctions – Acidosis Problems with High Grain Rations

ROBERT H. DUNLOP

Introduction

Ruminants differ from other species in that their food is exposed to microbial degradation in the forestomachs prior to biochemical digestion by the secretions of the host. The various microbial species in the rumen fluctuate in numbers with changing dietary conditions. Such changes can become unfavourable to the host when excesses or deficiencies of certain nutrients occur in the diet. An important example of an undesirable excess of a dietary constituent is overfeeding of cereal grains which are rich in starch. By promoting the growth and multiplication of some organisms, an unbalanced population results with accumulation of their metabolic end-products which may be different from those produced by the normal population and may have a detrimental effect upon the host.

The modern feedlot operator is confronted with the dilemma of feeding high-concentrate rations to achieve maximal return which is accompanied by the risk of triggering off an unfavourable fermentation in the rumen that can lead to financial losses from death and the unthriftiness which may affect survivors. Episodes of acid indigestion may occur whenever ruminants ingest an excessive dose of grain or other feed rich in starch or sugar. The problem is frequently associated with faulty management: animals may gain access to the feed supply as a result of defects in fencing, storage containers, pen, stanchions etc.; alternatively, animals may be too rapidly brought on to high levels of concentrate feed or they may be rendered susceptible to excessive intake by missing a feed or two, by letting self-feeders become empty for a period then refilled, by unfavorable climatic conditions, by sudden changes in feed composition, or by having unevenly-sized animals in a lot with a resulting hierarchy that affects feeding behavior.

The general functions of the ruminant digestive tract are illustrated diagrammatically in Figure 1 to provide some orientation for subsequent discussions.

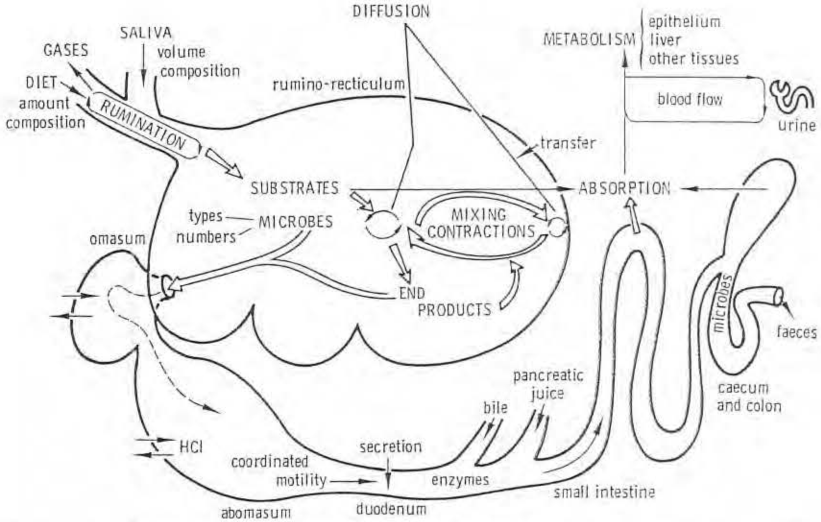

Figure 1. Diagram to illustrate the functions of the gastro-intestinal tract of the healthy ruminant.

Toxic and lethal doses of feeds

The entry of an excessive amount of sugars (e. g. glucose, sucrose, lactose, maltose) or starch into the rumen of cattle or sheep can lead to a major change in the rumen fermentation regardless of the source of such carbohydrates. Any of the common cereal grains, ripe or green ear corn, various root crops such as sugar beet and fodder beet, and various fruits such as apples, grapes and pears, as well as a number of processed foods such as energy-rich concentrate feedstuffs, flour and bakery by-products, molasses, and even certain dairy by-products such as whey have been incriminated. There are differences between feeds that appear to be attributable to several factors, including the proportions of the various carbohydrates that are present, the fineness of divi-

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sion and the presence and proportions of other ingredients or dietary components including water.

It is not clear what the range of doses of the various carbohydrates would be that can trigger the abnormal fermentation. The practical value of knowing the lowest dose that might have this effect is obvious but as yet it has not been studied adequately. It is not even clear whether dose should be referred to body weight or to metabolic size or to some other estimator. In a brief report of incompletely described experiments, Australian workers stated that the dose of crushed wheat that would consistently produce the disease in well-nourished Merino sheep under laboratory conditions was 75-80 g/Kg body weight (49). However voluntary consumption of this amount was not achieved and the dose was added via a rumen fistula. Sheep in poor condition, on the other hand, succumbed after a dose of 50 g/Kg. The only experiment in which voluntary ingestion of a toxic dose occurred was when sheep were gradually brought on to a wheat diet, reaching 80% wheat by the 12th day. The animals were then starved for 24 hours, following which wheat was presented *ad libitum*. Nine out of 25 head died within the following two days. It is of interest to note that, in this case, the animals were group fed and the psychological stimulus of competition between hungry animals that had been starved for a day may have been a key factor in the success of the experiment. Unfortunately, it was not known how much the individual animals consumed, hence no comparisons could be made between those that died and those that survived. The weights of the sheep and the composition of the grain were not given in the report. However the mean wheat consumption was only 36 g/Kg. The experiment was of considerable practical importance, however, because it stressed the significance of controllable factors such as a period of starvation and competition between animals. It also raised questions about the significance of previous exposure to the feed and the possibility of an adaptation process within the rumen. One conclusion is that, although the dose of grain required to produce the engorgement syndrome appears to be very high, under appropriate conditions a proportion of the animals in a group will be sufficiently hungry or greedy to consume the dangerous amount. If animals of mixed sizes are present, e.g. in a feedlot, the larger ones may dominate the feed trough and be the ones affected. Alternatively, when a farmer tries to avoid trouble by feeding hay before filling the feed bunks with grain or concentrate, the larger animals may fill up on the hay and leave the smaller ones to over-indulge on the concentrate. The availability of roughage seems to be a significant factor, if only by reducing the total amount of the concentrated feed ingested. In areas where corn is readily grown, chopped corn ensilage appears to be a valuable diluent of this type.

Recent studies at the Canada Department of Agriculture Research Station at Melfort, Saskatchewan (7) have indicated that chopped hay and cereal straw can be used for a similar purpose of controlling the rumen fermentation in self-fed steers. All the roughage was ground through a one inch screen. The diets were adjusted from 90% roughage plus 10% dry rolled wheat at the start by either 10% or 20% increments in the proportion of wheat every 8 to 10 days until the 70% wheat level was attained. After a longer period at 70%, adjustment was made to 75% and, one week later, to 80% for half the steers (days 71-77 and 77-119 of the trial respectively) while the other half were switched directly to the 80% ration at a later date (for days 107-119 of the trial). In general weight gains and feed conversions were favourable during the trial with the exception of the last two weeks when an unexplained decline in performance was noted in some steers. It was noteworthy that the group that was switched by 20% increments in the proportion of wheat developed digestive disturbances when switched from 50% to 70% wheat. Two steers required treatment and the remainder of the group developed extremely watery diarrhea followed by recovery. These steers had been fed the 70% wheat ration by day 28 of the trial. Since the starting weights averaged 700 lb and daily gains varied from 3.4 lb (days 11-71) to 5.5 lb (days 0-10), the steers would have weighed an average of about 815 lb at the time of the digestive crisis. The average daily feed intake for the critical period was not stated but, for the overall trial, the average was 26.8 lb/day. This would be equivalent to 18.8 lb wheat on the 70% diet or an average intake of only 23 g/Kg. Unless there was a large increase in consumption during this period, this calculation indicates that the hazardous dose of grain in these steers was appreciably lower than that reported for sheep in Australia. Also it indicates that, while there was definite evidence for some type of adaptation in the rumen to high intakes of grain, it would be difficult to predict the safe and hazardous rates of changes of the diet. In this trial it appeared that a sudden change from about 16.4 g/Kg to 23 g/Kg was a critical step in leading to an imbalance in the rumen microbial populations and an abnormal fermentation.

Hironaka (26) reported the results of some interesting experiments on the use of starter rations to bring beef cattle in feed lots on to high intakes of finishing diets rapidly. The principle used was to formulate a starter ration having a digestible energy content at a tolerably low level and feed it for two days then mix it with increasing proportions of finishing ration. Although no definite cases of engorgement or founder occurred, it was observed that a sharp decline in feed intake occurred during the first week if the DE concentration of the feed exceeded 2800 kcal/kg of feed when fed *ad libitum*. It was concluded that the rate of increase of DE concentration of the ration was a critical factor in getting animals on to full feed safely. Animals were taking in an average of 24 g/kg of finishing ration by nine days on feed without controlling feed intake when the proportions of starter to finishing ration were changed by 25% increments at 2 day intervals from 100% starter to 100% finishing ration, in which the major ingredient was barley. The starter rations contained alfalfa and either beet pulp or brewers grains in addition to oats, barley, molasses, minerals, vitamin A and chlortetracycline.

Tremere *et al* (48) reported the results of a study on adaptation to high concentrate feeding in hay fed dairy heifers. This paper is of particular interest since the major ingredient of the diets used was ground wheat. Dosages of grain were expressed as a function of body size. Daily increments in concentrate intake of 7 g per unit of body size ($w_{kg}^{0.75}$) led to accumulation of lactic acid in the ingesta, a fall in rumen pH and the animal going off feed. Frequency of feeding was an important factor, twice a day providing more protection than once a day.

Microbial changes consequent upon overfeeding on grain

The Australian workers noted a virtually complete replacement of the ruminal and intestinal microflora with lactobacilli after excessive intake of wheat by sheep. They also showed that chlortetracycline orally provided protection from an other wise lethal dose of grain (49). Hungate *et al* (30) showed that the numbers of cellulolytic organisms declined while gram-positive species proliferated and protozoa disappeared. They also identified *Streptococcus bovis* and a species of *Lactobacillus* as components of the flora of engorged sheep and suggested that they were responsible for the development and persistence of increased acidity of the rumen ingesta. These results were confirmed and amplified by Krogh (34, 35, 36) who characterized several species of lactobacilli and the responses to a variety of carbohydrate substrates. He gradually increased the daily dose of the substance until an excessively acid fermentation was triggered. The range of dose required varied from 200-600 grams for sucrose and from 600-1200 grams for lactose, which was given as a partial suspension because of its low solubility. He made quantitative measurements of the microbial concentrations of several genera with respect to time. The results indicated that the sequence of events was as follows: a) proliferation followed by decline of *S. bovis* b) reduction of cellulolytic species and protozoa c) proliferation of lactobacilli and d) in some cases only, proliferation of yeasts. Unfortunately, the lactate-utilizing bacteria were not studied. Krogh reported the lactobacilli isolated were sensitive to antibiotics but not to sulfathiazole. Bullen and Scarisbrick (11) also noted that sodium penicillin, given within 6 hours of dosing with an otherwise lethal dose of grain, as one to four doses of 5 x 10^5 Units each into the rumen greatly reduced the degree of accumulation of acid in the rumen. They also showed that rumen acidosis could be distinguished from *Clostridium welchii* type D enterotoxemia which may occur under similar dietary conditions.

Lactate utilization and removal can be accomplished by a variety of species of rumen organisms. Baldwin concluded from isotope labelling patterns that the production of propionate from lactate in rumen contents taken from the cattle fed on high carbohydrate diets occurs mainly via the acrylate pathway (6). This finding points to a role for *Peptostreptococcus elsdenii* in such utilization since it is the only rumen organism known to metabolize lactate via this pathway. However Hobson *et al* (27) reported that this organism occurs in low numbers in the adult rumen. There may be other species capable of utilizing this pathway and the possibility of a role for the protozoa in lactate utilization has not been clearly demonstrated. Certainly the microbiological aspects of lactate removal merit further study since they could be a key to the process of adaptation to high grain diets or to convalesence after an outbreak has occurred.

The phenomenon of adaptation should be studied from the standpoint of the various possible regulatory factors, such as concentrations of substrates (starch or sugar), hydrogen ion concentrations, ammonia concentration, redox potential, osmolality, inhibitory or promoting substances and lactate isomer concentrations in the ingesta.

Chemical changes in the rumen contents

The consistency of the ingesta changes profoundly after the abnormal fermentation of grain overfeeding develops. The contents became milky and a yellowish-green or even grayish color, gas formation is greatly reduced after several hours and the floating or suspended roughage is greatly reduced.

The most dramatic changes in chemical composition are the large increases in hydrogen ion concentration (100-1000 fold) and lactate concentration (21). The lactic acid is a mixture of the two isomers, D-lactic acid and L-lactic acid. The proportion of the two isomers varies considerably with L-lactic acid tending to be predominant initially, following which D-lactic acid increases to equal or exceed the concentration of L-isomer. The pK_a of lactic acid is about 3.7, hence even if the pH falls to 4.0 the majority of the lactic acid that is formed is buffered by alkaline salts in the rumen. However the small proportion of undissociated lactic acid that persists is of great significance because this acid has a corrosive action on the rumen epithelium. Also at pH 4.0 almost all the volatile

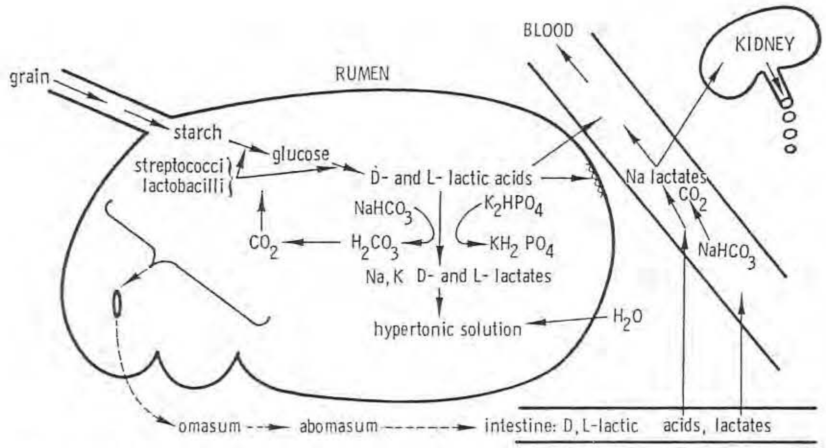

Figure 2. Diagram illustrating some of the significant changes that occur following engorgement on grain if a lactic acid fermentation takes place. The symbol ﹏ indicates damage to the ruminal epithelium.

fatty acids present will exist in the undissociated acid form in which they readily penetrate the mucosa of the rumen. A diagram representing these changes is shown in Figure 2.

Many other changes occur in the composition of the ingesta after a ruminant overeats on grain. There is a major rise in osmolality which can be as much as double the normal value. This causes water to move from blood to lumen (10, 15) and thus could be a significant dehydrating factor (internal dehydration since the fluid is trapped in the forestomachs unless diarrhea occurs). A preliminary report suggests that the degree of hypertonicity of rumen contents is correlated with reductions in feed intake and the rate of cellulose digestion (8).

Other electrolyte concentrations change. Potassium and phosphate levels increase while bicarbonate and volatile fatty acid concentrations decline. Sodium may diminish while ammonium ion increases. Free sugar may become detectable and, later in the course, unusual acids, such as succinic and formic, may appear (42, 43). Chloride may increase in the later stages as well, particularly if gastro-intestinal statis persists.

Macromolecular products from microorganisms appear in the contents in increased amounts. This is probably attributable to the increased rate of destruction of protozoa and bacteria under acidic conditions. Some of these components contain endotoxins that can be demonstrated by studying their pyrogenic activity in rabbits after intravenous injection (21). However, the significance of this finding for the well-being of the affected ruminant has not been determined. Endotoxins are less active via the oral route but the presence of very large amounts in the gastro-intestinal tract might be a contributing factor. The failure of steroids having glucocorticoid activity to have a significant beneficial effect in treatment may indicate that the role of endotoxin is a relatively minor one (37). It is possible that such toxins could account for the non-histamine toxic factor demonstrated to occur in the ingesta of affected animals (16).

Other toxic factors for which a toxic, and possibly lethal, role have been proposed are histamine (12) and alcohol (3, 4). The available data on histamine analysis are very variable and it seems unlikely that histamine consistently plays a major role in the lactic acidosis syndrome (44, 45). Alcohol has not been studied adequately up to the present but the data from Hungary suggest that extremely high blood levels may be attained under some circumstances (31, 46) following ingestion of grain meal (up to 670 mg/100 ml reported) or glucose (up to 1600 mg/100 ml reported blood alcohol concentration). Further studies on the role of ethanol are needed.

Consequences of ruminal changes for the functional status of the animal

The changes in rumen microbes, chemical composition and dynamic processes, such as rates of gas production, can have profound effects on the wellbeing of the animal. The first effect is a local one on the epithelial surface of the rumen and other parts of the gastro-intestinal tract. Lactic acid, hypertonicity and, probably, other factors participate in the damaging effect upon the epithelium which is characterized by microvesicle formation, loss of keratin, vacuolation, invasion by poly-morphonuclear leukocytes, desquamation and death of epithelial cells and small hemorrhages (1, 32, 47). In later stages damage, and even ulceration may occur in the omasum, abomasum and duodenum (18). These effects upon the epithelium probably lead to derangements in the strength and coordination of contractions of these organs (5), partly as a direct action and partly by changes in the function of the receptor component of visceral reflexes. The net effect is rumen stasis which may be accompanied or followed by diarrhea.

While motility is becoming impaired, absorption of lactic acid proceeds and leads to a systemic acidosis of the metabolic type (17, 21, 51). Large increases in lactate concentration of the blood are observed while plasma bicarbonate falls. The effect on these parameters usually reaches a maximum between about 24 and 36 hours after the overfeeding episode and is followed by a return towards normal values, even overshooting to produce a metabolic alkalosis in some cases (18, 20). The blood lactate of normal ruminants is comprised of about 100% of L-isomer but the engorged animals often show D-lactic acidosis with the D-isomer accounting for the majority of the lactate present (21, 22). In animals which deteriorate into a shock-like state L-lactate and pyruvate may rise and this is usually an ominous sign of failure of the circulation to supply adequate amounts of oxygen to the tissues. It is still unresolved whether other toxic factors are absorbed and play a role in producing some of the signs of the disease. It seems unlikely that histamine would be absorbed to a significant extent at the pH of the rumen ingesta of acidotic animals because most of its molecules have two positive charges at pH 4. If histamine is involved it is presumably attributable to absorption from the intestine. The changes in osmotic pressure of the rumen contents lead to dehydration into the rumen from the other body fluids. This causes the hematocrit and the concentration of plasma proteins to rise. The declining blood volume and acidosis lead to circulatory difficulties and inadequacies of regional perfusion with blood. It is thought that these circulatory disturbances may account for some of the other signs of deranged function that are observed. These include reductions in the rates of salivary secretion and urine formation as well as a number of manifestations of disturbed performance of the central nervous system. Signs that may have a partly neurological basis are anorexia, ataxia, reduced muscular tone and strength, lowered rate of respiration, abnormal body temperature (may be high or low, depending upon environmental factors and stage of the disease) increased pulse rate, depressed gastric motility, and reduced behavioral and reflex responses to environmental stimuli. Similarly, depression of function of many organs can be predicted to occur. The liver may be an important site because of its important role in lactate utilization. It should be noted that ruminants have a limited capacity to utilize D-lactate (9, 21, 25, 28). Consequently, the continuing entry of D-lactic acid by absorption in the face of decreased renal function (29) creates a particularly hazardous situation.

The outcome of the detrimental effects may be a progressive deterioration, followed by coma and death. If the animal survives the acute phase of acidosis, it may recover promptly if normal gastrointestinal function is restored or, more frequently, it may be affected by a chronic phase of convalescence and unthriftiness. The acid conditions in the rumen often persist for several days, following which restoration of function occurs very slowly and death may occur during this period from causes that are as yet poorly characterized. This period of unthriftiness can be a major cause of economic loss in outbreaks affecting substantial numbers of cattle as in feedlots.

An example of some of the biochemical changes that may be observed in a case of lactic acidosis as a function of time are shown in Figure 3.

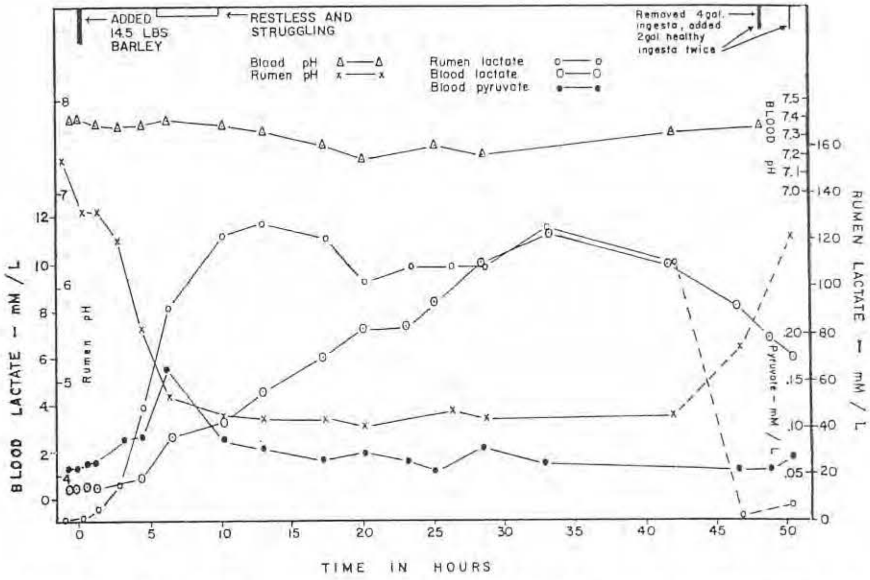

Figure 3. Typical data from an experimental case of lactic acidosis in a Holstein steer weighing about 130 kg.

The dose of barley was approximately 50 g/kg.
The animal was equipped with a rumen fistula and recovered after the ingesta was removed.

Production of similar detrimental changes to the acidosis syndrome by simple chemical solutions

The Australian workers attempted to reproduce the acute disease by adding lactic acid to the rumen to maintain the rumen pH at 4 for a long period but this only led to a mild acidosis with no hemoconcentration. In subsequent experiments they introduced lactic acid solutions at pH 3 or abomasal contents adjusted to pH 3 with lactic acid directly into the duodenum. This procedure produced severe acidosis, lactic acidemia and some reduction of blood volume followed by recovery after termination of the infusion. In neither of the two groups of experiments were the lactate concentrations and isomeric compositions reported. Finally, they incubated ground wheat with ruminal fluid for 24 hours at 37° C *in vitro*. The product had a lactate concentration of 150 mM/1 and pH 4.4. When infused into the duodenum the sheep developed typical signs of wheat engorgement and was moribund within 20 hours. Changing the infusion solution to normal fluid restored the animal to health (49).

In the only other study of this type (17, 21) an attempt was made to study the deterioration in function that resulted when a lactic acid solution of known isomeric composition (57L:43D) was introduced into the emptied washed rumen of otherwise healthy rumen-fistulated cattle. Three experiments were conducted in one of which a lactic acid solution (dose of total lactate 47.1 mM/kg at pH 3.60) was used alone, in another the lactic acid solution was rendered very hypertonic by the addition of mannitol and, in the third, the effect of hypertonic mannitol alone (72.5 mM/kg) was studied. The first animal developed D-lactic acidosis and became depressed but recovered. The second animal developed signs and chemical changes comparable to those of the acutely engorged animal and died within nine hours while the third developed severe hemoconcentration and moderate L-lactic acidosis (21). The latter animal died after the experiment was terminated. It was concluded that dehydration and lactic acidosis may be critical components in the pathogenesis of the disease. In animal No. 2 the total dose of lactic acid and lactate in the form of its salts was 42 mM/kg but the dose of undissociated D-lactic acid was estimated to be only 11.7 mM/kg (pH was 3.60) and the dose of mannitol was 49 mM/kg.

Treatment

There have been few controlled studies of the treatment of lactic acidosis. In one such study prednisolone was found to be ineffective (37). A preliminary report of another study indicated that most medical approaches involving drugs are ineffective, including several for which extravagant claims have been made (19). The best chance of recovery follows complete emptying of the reticulo-rumen either by surgical means or by use of repeated flushing via a large diameter stomach tube. A transplant of ingesta from a healthy animal, if available, seems to promote recovery and restoration of the rumen epithelium (17). Alternatively, a conservative approach to treatment using oral antibiotics and water in repeated doses plus parenterally administered electrolyte solutions and other drugs has been recommended (13, 14, 19). There is only limited documentation of the efficacy of this approach, however.

Complications of acidosis; related problems

Treatment is not the answer to the problem of acidosis because it is expensive and invariably followed by a set-back and an unthrifty period. Some of the pathological sequelae have been reported. These include a variety of lesions of the gastro-intestinal tract including rumenitis with invasion by fungi or Spherophorus organisms, ulceration of omasum, abomasum or duodenum, and also problems in other body organs such as the liver, kidneys, and central nervous system.

Other syndromes have been considered to be attributable to or associated with the acidosis syndrome. Among these is laminitis which has been tentatively attributed to the absorption or release of histamine (40). Although laminitis or some type of soreness of the feet does occur in some cases of acidosis it may also be observed in grain-fed animals in which there is no evidence of acidosis. The term, "founder", applied to the acidosis syndrome appears to be a misnomer since severe laminitis in conjunction with acidosis is rare. In young intensively-fed animals profound changes in the structure of the foot may occur in laminitis but this condition does not appear to be attributable to acidosis (38, 39).

Another related problem is the serious economic problem of liver abcesses. This problem is believed to be secondary to some degree of acidic damage to the ruminal epithelium which may enhance the entry of microorganisms and their passage to the liver via the portal circulation. This problem has been reviewed in an attempt to evaluate the efficacy of antibiotic given with the feed to reduce the incidence of liver abcesses (50). Further studies on the pathogenesis and control of this important problem are indicated.

Feedlot bloat is not directly related to acidosis but has some interesting facets that may bear on the latter syndrome.

Of particular interest was the finding that *Peptostreptococcus elsdenii* increased in numbers in the rumens of bloated animals in one study (24). Since it was noted earlier that this organism is normally present in low concentrations, this finding raises the question that it may serve a protective role against acidosis. *Streptococcus bovis* was also present in increased numbers so it can be assumed that appreciable amounts of lactate were being formed and utilized. However the organism appeared to generate a slime that led to foam formation and increased the risk of bloating. This is but one of a large number of theories on the etiology of bloat and is by no means confirmed.

The control of ruminal fermentations by inoculation of pre-adapted ingesta (23) or by antibiotics (33) afford promising leads for future developments. Unfortunately the available data on the spectra of antimicrobial drugs against rumen organisms is limited (2). New methods of processing animal feeds and the increasing use of additives may create new problems to be characterized and controlled.

As ruminants are pushed harder on concentrated feeds under intensive conditions, a condition that is intermediate between a normal fermentation and lactic acidosis may develop. This state has not yet received adequate study but it may be accompanied by abnormally acidic conditions (pH about 5.0-5.5) and excessively high concentrations of volatile fatty acids rather than lactic acid. Very high levels of VFA have been observed in the rumen contents of some animals that died suddenly on high grain diets (41). Also abnormal accumulation of butyrate has been recorded in cattle on a diet of sugar beet crowns and tops (14). Butyric acid is the most toxic of the VFA, hence this finding may have significance in the pathogenesis of the disease on some diets. It was reported earlier (42) that VFA concentrations decline in the rumen if a lactic acid fermentation develops. The possibility that there may be some forms of abnormally acidic fermentation associated with unusually rapid production of VFA merits investigation.

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Metabolic Aspects of Feeding Wheat to Beef Cattle

R. R. OLTJEN

Until recently, wheat had not been used to any extent as a normal ingredient in ruminant diets primarily because of the economic advantage of its use for human consumption. Because of this relatively little research has been conducted to determine the nutritional value of wheat compared to the other cereal grains in ruminant finishing diets. Other factors which may have contributed to the reluctance of cattle feeders to use wheat are the widespread uncertainty concerning the feeding of wheat to ruminants and also the selection of wheat to demonstrate the acidosis syndrome. It is the purpose of this paper to review the general influence of feeding wheat on certain metabolic aspects of the ruminant.

Rumen microbial patterns: The end products of rumen microbial fermentation supply the ruminant animal with 70-80% of its total energy supply (Warner, 1964). The microbial population also extensively degrades dietary protein to peptides, amino acids, carbon skeletons and ammonia. These protein precursors are then used by the microbes to synthesize their own cellular protein which becomes available to the host animal in the lower gut. It is readily apparent that the performance of the ruminant is *directly* dependent on what occurs in the rumen.

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Ruminants fed high or all-concentrate rations normally have ruminal conditions conducive to rapid growth of the lactic acid-producing bacteria, *Streptococcus bovis* and *Lactobacillus sp.* (Hungate *et al* 1952). Under normal feeding conditions the numbers of these microbes are relatively small compared to the concentration of other microbes.

Slyter *et al* (1970) studied the rumen microbial patterns in steers fed *ad libitum* all-concentrate diets of 90% cracked corn, 90% cracked soft red winter wheat and 60:30 combinations of the two grains and found that steers fed all the diets had similar but elevated bacterial concentrations and very low concentrations of ruminal protozoa. The loss of protozoa (primarily due to the low ruminal pH) may be of major significance because they store polysaccharides and this slows down the rapid degradation of the readily available energy. Steers fed corn had greater concentrations of *Lactobacilli* and other aciduric bacteria but *Streptococcus bovis* was found in greater concentrations in steers fed wheat than corn. There were cellulose hydrolyzing bacteria in the ruminal ingesta of all of the steers but they were not present in sufficient numbers to be detected among any of the 526 strains of bacteria isolated from the higher dilutions of ruminal contents using non-selective roll-tube medium. In a second study the microbial population of twin steers fed *ad libitum* the 90% corn or 90% wheat diets were studied and it was found that the steers fed the 90% wheat diet had the greatest concentrations of *Lactobacilli* and other aciduric bacteria. In a third study, corn, soft wheat, barley and milo were compared in all-concentrate diets with steers. All the grains were coarsely cracked. It was found that the ruminal ingesta of steers fed wheat had the lowest pH, lowest protozoal concentrations and the greatest concentration of *Lactobacillus* and other aciduric bacteria. Each steer in this study was restricted fed an amount of feed equal to 1.5% of body weight daily.

Carbohydrate metabolism: The carbohydrate portion of wheat is readily degraded to the volatile fatty acids (VFA) in the rumen. In studies conducted at Beltsville (Oltjen *et al*, 1966) it was determined that the VFA pattern in the ruminal ingesta of steers fed *ad libitum* all-concentrate diets of 90% cracked corn, 90% cracked wheat or 60:30 combinations of the two grains for 98 days were somewhat different. Steers fed the 90 and 60% wheat diets had lower (5.15 vs. 5.65) pH and greater concentrations (164 vs. 135 mmole/liter) of the ruminal VFA than did steers fed the 90 and 60% corn diets. As the amount of wheat increased in the diet the molar percentage of propionic acid decreased while the molar percentage of butyric acid increased. A follow-up study indicated similar VFA trends. Steers fed all diets gained similarly until 70 days. However, after 70 days steers fed the high wheat diets seemed to go "off feed" and their feed consumption was reduced resulting in a difference ($P<.05$) in daily gains (1.15 vs. 1.35 kg) in favor of the high corn diets for the entire study. It is interesting that the pH was lower and VFA concentration higher in the cattle fed the high wheat diets because their feed consumption was lower than that of cattle fed the high corn diets at ruminal sampling time.

Wheat was compared to corn, milo and barley in metabolism trials in a later study (Oltjen *et al,* 1967). Steer calves were fed (two times daily; 1.5% of body weight) the grains in all-concentrate diets. The VFA concentrations (four hours after feeding) were higher ($P<.05$) in steers fed wheat (150 mmole/liter) and barley (148 mmole/liter) than in steers fed corn (99 mmole/liter) and milo (105 mmole/liter). Ruminal pH was lowest when steers were fed wheat (5.3) followed by barley (5.7) corn (6.0) and milo (6.1). Wheat-fed steers had the highest molar percentage of butyric acid. Ruminal lactic acid was not determined.

Totusek *et al* (1968) fed finishing diets containing 45% wheat, milo or combinations of these grains to beef cattle and reported that the type of grain had very little effect on the pattern or concentration of the VFA. Chou and Walker (1964a,b) fed sheep a limited diet of corn or wheat once daily and reported similar VFA patterns and concentrations for both grains. Allison *et al* (1964) studied the influence of preadaptation of sheep to a wheat diet on ruminal parameters and the overfeeding response and found that unadapted sheep receiving wheat in the rumen had a shift in the VFA pattern shortly after wheat was administered. The most pronounced shift was the lowering of acetic acid and the elevation of butyric, valeric and caporic acids. Rumen pH decreased as lactate increased. The molar percentage of butyric acid seemed higher than normal in sheep not showing acidosis.

Ryan (1964) studied the low molecular weight acids in the rumen following the addition of wheat to the rumen and reported that there was an increase in the ruminal concentration of lactic acid and glucose accompanied with a very marked decrease in the concentration of acetic, propionic, and butyric acids. However, these VFA were in greater accumulation in the first phases and decreased as acidosis became more severe. In many respects it appears that the feeding of large quantities of wheat to ruminants under normal conditions yields a ruminal VFA pattern similar to the feeding of sucrose in a purified diet (Orskov and Oltjen, 1967). The molar percentage of butyric and higher VFA may be indicative of the rate of fermentation.

Overloading the rumen with wheat or other cereal grains results in low pH (5.0) and an accumulation of lactic acid. Particular significance is attached to the accumulation of the D (-) enantiomorph of lactic acid which is more slowly metabolized by animal tissues (Turner and Hodgetts 1949-1959; Ryan, 1964) and may be a bottleneck in ruminal fermentation and utilization of end products. Uhart and Carroll (1967) studied acidosis in steers and reported that steers stopped eating within two or three days after an abrupt shift from alfalfa to a high-grain diet. This was attributed to a high ruminal lactic acid concentration (100 mmole/liter) and acidity (4.8 pH) which developed. The results of Tremere *et al* (1968) indicate that when wheat was fed as the only concentrate to dairy heifers, high lactic acid (14-75 mmole/liter of ruminal fluid) resulted but when the concentrate mixture was only 50% wheat lower (< 4 mmole/liter) levels occurred. High rumen acidity did not appear to be the only factor causing an animal to go off feed, since buffers administered either by intraruminal infusion or feeding did not prevent off feed. Dowden and Jacobson (1960) reported that lactic acid infused intravenously did not depress ruminant appetite, suggesting other factors are involved with the depression.

Haskins *et al* (1969) reported that the lactic acid concentrations in the ruminal fluid of steers fed all concentrate corn based diets *ad libitum* were low and averaged 0.2 mmole/liter of ruminal fluid. Steers receiving hay had higher concentrations. Eadie *et al* (1967) fed high barley diets to steers and reported that under normal feeding conditions the lactic acid concentrations were low and averaged about 0.1 mmole/liter of rumen fluid.

Ethanol concentrations are higher in the ruminal contents of sheep and cattle receiving large quantities of readily fermentable carbohydrate (Allison *et al* 1964; Orskov and Oltjen, 1967). Ethanol accumulation appears to be associated with the synthesis of longer chain acids in the rumen (Orskov *et al* 1967).

Protein metabolism: Gluten forms 80-90% of the total protein in wheat. This component is insoluble in water and neutral salt solutions. The rest of the protein is water soluble and chiefly constitutes the enzyme complex of wheat. Gluten has a high glutamic acid and proline content and a low lysine and arginine content. Metabolism results (Oltjen *et al* 1967) of feeding all-concentrate diets comprised of 91% corn plus 1% urea, 92% wheat, 92% barley or 92% milo to growing steer calves indicated that the protein in wheat was digested to a similar extent (77%) to that in corn (74%) and barley (78%). The protein digestibility for all 3 grains was greater ($P<.1$) than for milo (43%). Adding 1% urea to the milo diet increased digestibility to 57%. Removal of 1% urea from the corn diet resulted in a 59% protein digestibility. Morrison (1956) reported protein digestibilities of 77, 84, 79 and 78% for wheat, corn, barley and milo, respectively. Nitrogen retention (% of intake) was similar for corn with urea (43%), wheat (43%) and barley (38%) but all were greater than milo without urea (24%). Corn without urea and milo with urea resulted in similar retention. Dry matter digestibilities for corn with urea, wheat, barley, milo, corn without urea and milo with urea were 83, 88, 84, 72, 75 and 73%, respectively. These data demonstrate the high nutritional value of the protein and carbohydrate in wheat compared to other grains. Ruminal ammonia concentrations (four hours after feeding) were low (3-6 mg/100 ml fluid) from steers fed the different diets and were not significantly different.

Annison (1956) studied the *in vitro* degradation of casein, zein, wheat gluten and soybean protein and reported that casein and soybean protein were readily degraded while zein and wheat gluten were less extensively and similarly degraded by ruminal microbes. Klosterman *et al* (1956) studied the nutritional value of a hydrolysate of wheat proein in which 80% of the glutamic acid was removed and reported that its over-all feeding value judged by metabolism and feeding trials with cattle and sheep was approximately 95% that of soyeban meal .

Ely *et al* (1970) compared the nitrogen utilization of two varieties of wheat with lambs. One variety (Red Chief) had weak gluten properties while the other variety (Golden 50) had strong gluten properties. Two rations were composed of the two varieties of rolled wheat as the only grain source while cracked corn replaced one-half of each of the wheats in two additional rations. The grains comprised 91% while cottonseed hulls comprised 9% in each of the four diets. Preliminary results indicate that nitrogen digestibility was slightly greater while the percent of digested nitrogen retained was significantly greater with Golden 50. When one-half of the wheat was replaced with corn, nitrogen digestibility was not affected but nitrogen retention was improved in both cases. Brethour and Duitsman (1970) reported that Golden 50 was superior ($P<.05$) to Red Chief in finishing diets with beef cattle. The wheat varieties comprised 38% of the experimental diets. Bris and Dyer (1967) reported that a hard variety of wheat (Burt) was inferior ($P<.05$) to a soft variety (Gaines) when these grains comprised 60% of the diet in feedlot studies with finishing steers.

The blood plasma amino acid patterns of the metabolism steers before feeding (Oltjen *et al* 1967) were similar. Steers fed wheat had the greatest concentrations of plasma glycine, isoleucine and lysine compared to the other grains. Although wheat contained more than twice the amount of glutamic acid as did corn the plasma levels were actually lower in steers fed these grains. The plasma lysine concentration was greater ($P<.01$) in wheat fed steers compared to steers fed the other diets. In general, there seemed to be little relationship between dietary amino acid intake, nitrogen retention and the blood plasma amino acid pattern. This emphasizes the fact that the rumen microbial population degrades the ingested protein to a large extent (Hungate, 1966) and that the resulting plasma amino acid patterns were probably more a reflection of hydrolyzed microbial protein than of dietary ntirogen.

Other observations: Other factors which may be pertinent in determining the nutritional value of wheat are observations that the salivary flow of steers fed wheat (Oltjen *et al* 1967) was greater than that for milo but less than that for corn and barley. Particle size, however, was the smallest for the milo and wheat diets and this may have contributed to the lower flow rates. The weight of ruminal ingesta and dry matter was similar for all grains.

The feeding of the 90% corn or 90% wheat diets on an *ad libitum* basis resulted in similar feeding patterns (Oltjen *et al* 1966). Steers fed wheat spent 86 min/day while steers fed corn spent 96 min/day eating. More than 80% of the time at the feeding occurred from 6 AM to 9 PM.

Ruminal bypass of wheat may occur when steers are fed high levels of grain because of the rapid rate of passage through the rumen. If this does occur, it should be beneficial to the ruminant in terms of carbohydrate utilization because less would be fermented in the rumen (Karr *et al* 1966) but possibly detrimental to protein utilization because of its resistant nature to digestion (Annison, 1956) and its similarity to zein (Little and Mitchell, 1967).

Summary

The feeding of moderate to large quantities of wheat to beef cattle in finishing diets results in a rumen microbial population which has a moderate percentage of *Streptococcus bovis* and *Lactobacillus*. The bacterial patterns of steers fed wheat were, in general, similar to the patterns found in steers fed the other cereal grains. Rumen protozoa are either absent or found in low concentrations under *ad libitum* feeding conditions. Protozoa were found in lower concentrations when steers were fed restricted levels of wheat compared to corn, milo or barley.

The carbohydrate portion of wheat appears to be more rapidly fermented in the rumen than the carbohydrate from other cereal grains and results in lower ruminal pH values and greater VFA concentrations. The molar percentage of butyric and longer chain acids is greatest on wheat diets. Lactic acid concentrations are low under normal feeding conditions.

Metabolism results indicate that the dry matter and protein in soft wheat was utilized similarly to that in corn and barley. Blood plasma amino acid patterns of steers fed wheat were similar to those of steers fed corn and barley. Soft wheat was superior to hard wheat in a feedlot study. Ruminants fed wheat exhibiting weak gluten properties had greater feedlot performance and nitrogen retention than ruminants fed wheat exhibiting strong gluten properties.

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Nutritive Value and Suitable Levels of Wheat for Dairy Cattle

D. E. WALDERN

Introduction

Wheat and its associated products have been staple foods for man and his livestock since ancient times. Wheat provides a livelihood for millions of people as well as comprising an important part of the diet for millions more.

Present-day wheat originated in the highlands of Ethiopia or Iraq (formerly called Mesopotamia). Traces of the wheat plant were found in Stone Age ruins of the Swiss Lake dwellers some 10 to 15 thousand years ago. Excavations of Egyptian pyramids, constructed over five thousand years ago, have provided well preserved samples of wheat. In Biblical times, wheat was called corn.

The Spaniards introduced wheat into North America in 1530 when they occupied Mexico. The French colonists led by Samuel de Champlain first grew wheat in Canada in 1604 (Canada Dept. of Agric. Publ. 1386. 1969).

Today, wheat occupies a major position as an agricultural commodity in the Great Plains areas of the United States, and in the corresponding Prairie provinces of Canada, as well as in the white and soft red wheat growing areas scattered throughout North America.

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During 1968-69 about 55 million acres of wheat were harvested for grain in the United States. The estimate for 1969-70 is below this level. (Oregon Commodity Data Sheet, September 1969). In Canada, wheat was grown on about 25 million acres in 1969, (DBS Field Crop Reporting Series, Nov. 21, 1969) while projected acreage for 1970 is about 74% of the 1969 figure (DBS Field Crop Reporting Series—No. 2 March 18, 1970). Total surplus stocks of Canadian wheat on March 31, 1970 were estimated at a record 1,227 million bushels.

In the Pacific Northwest, (PNW) (Washington, Idaho, Oregon) most of the grain fed in recent years has been barley. About 28% of the grain grown in the area in 1967 was fed to livestock. During the crop year July 1968 to June 1969, total wheat production in the PNW amounted to 139 thousand bushels while white wheat totalled about 129 thousand bushels. However, only 8.7% of the wheat was used in the feed trade (USDA Statistical Reporting Service. PNW Wheat Summary, Second Quarter Crop Year, January 29, 1970). In 1965 and again in 1968 when the price of soft white wheat fell below barley in the Pacific Northwest, the amount of wheat fed to livestock trebled and doubled, respectively, compared to the previous year.

It has been estimated that 100 pounds of Western white soft wheat can replace 100 pounds of barley, corn or milo and 105 pounds of oats on a nutritional basis in dairy cattle rations; thus western white soft wheat will probably be used in dairy rations when the price of it is equivalent to that of corn, barley or sorghum to the feed trade (Task Force, School of Agriculture, O.S.U., Issues and Alternatives in Wheat Production and Marketing, Cooperative Extension Service, January, 1970).

In a recent address to the National Association of Wheat Growers in Oklahoma City, Assistant Secretary of Agriculture Mr. C. D. Palmby pointed out that an estimated 200 million bushels of wheat would be fed to livestock in the U.S. in 1969, which was double the amount fed in the Sixties, but still less than 3% of the total grains being fed to livestock. Mr. Palmby also pointed out that the increase in the amount of feed grains being fed to livestock in the last 15 years was greater than the 1969 wheat crop (Feedstuffs, January 24, 1970).

The marked increase in the consumption of beef and poultry in North America has resulted in a greater demand for domestic use of cereal grains in raising increased numbers of livestock and poultry. On the other hand the numbers of dairy cattle, which also contribute extensively to the meat trade in North America, continue to decline. However, the average milk production per cow per year continues to increase. In 1958 there were just over 18.7 million dairy cows in the United States producing an average of 6,585 pounds of milk and 249 pounds of fat annually. By 1968 the number of cows had declined to just over 13 million with an average annual production of 9,006 pounds of milk and 331 pounds of fat. About 16.4% of U.S. dairy cattle are presently on United States Department of Agriculture DHIA test programs and average close to 12,500 pounds of milk and 473 pounds of fat. Similar trends in dairy cattle numbers and production have occurred in Canada. The cow population declined from 2.8 million in 1965 to 2.5 million in late 1969, with the average production per cow at 9,440 pounds in 1969. The numbers of cows have stabilized somewhat in the past two years. Along with increased annual milk production per cow, the consumption of succulent feeds and dry forages, on a hay equivalent basis, by dairy cattle has increased by almost 16% while concentrate (grain) consumption has increased by an amazing 51% during the past 10 year period. Average yearly grain consumption per cow for DHIA tested herds in the U.S. is approaching 5,000 pounds while that for all dairy cows is about 4,300 pounds. Some 10 years ago the average cow on DHIA received less than 30% of her total dry matter from the concentrate or grain ration while today this figure exceeds 40%. Today's high producing cow requires an adequate level of energy to produce milk. This is being furnished primarily by cereal grains, most of which are *not* wheat. Thus a great potential exists for increased use of wheat in dairy cattle rations. Herd size is increasing. Methods of feeding and management are changing toward greater automation to accompany increased herd size and greater efficiency in labor use. Rations and feeding practices are being geared to feeding greater quantities of grain when the cow requires the additional energy in early lactation.

Price is usually the main factor regulating the use of a given cereal grain in a concentrate ration (grain mixture) of lactating cows. However, many dairymen are unfamiliar with wheat, lack experience in feeding it, and hence are hesitant in using wheat in concentrate rations for their cows. There is also a gap in our knowledge of the relative nutritive value and acceptability of different varieties of wheat for lactating cows and how this might be affected by different methods of processing. Dairymen are concerned about the palatability of concentrates when large amounts of wheat and certain wheat by-products are used in rations for lactating cows. Problems of feed refusal, off-feed, digestive disturbances, cows drying off early, etc., sometimes arise in the minds of dairymen when wheat is considered as an ingredient for their concentrate or grain mix.

In this paper an effort has been made to review the literature on wheat and wheat by-products in dairy cattle rations and to set forth recommendations and practical guidelines for the use of wheat by dairy cattle.

Composition of Wheats

Research on the feeding value of wheat extends well over 75 years. In many experiments the type and variety of wheat used, bushel weight, and other characteristics were not defined. Many varieties grown only 15 years ago are not sown today and have been replaced by new improved varieties. Thus only very limited accurate chemical compositional data are available for wheat fed in lactation and other trials with dairy cattle over the years.

The effect of type and variety of wheat on its feeding value for dairy cattle is little known. The chemical composition of wheat of a given type and variety varies from year to year depending upon area, fertilization rate, moisture conditions, and other agronomic factors. Crude protein content is highly variable. The hard red spring wheats will vary from 12-19% crude protein, the hard red winter wheats from 10-15%, and the soft wheats from 8-12%. The protein content of the concentrate ration for lactating cows is adjusted in relation to the protein content of the forage fed. Thus concentrate rations containing high protein wheats would require lower levels of supplemental protein when a specific forage is fed than when the concentrate contained a low protein wheat. High protein wheats would then be worth somewhat more than low protein wheats. This would be particularly true when low protein forages were fed as the major roughage.

The published information on the gross and digestible energy content of wheat for ruminants is variable (NRC Publ. 1232). Hence it is apparent that more information is required on gross, digestible, and metabolizable energy levels of the various classes of wheat for ruminants particularly lactating dairy cows. Other papers in this Symposium will be covering the topic of the energy content of wheat for cattle.

The chemical composition and nutritive value for monogastrics of wheat by-products from hard red winter, hard red spring, soft white winter, and soft red winter wheats from various locations in the United States has recently been reported from a cooperative study conducted by Kansas State University and the University of Guelph, Ontario, Canada. The wheats were milled at Kansas State University and the relative amounts and proximate analysis of each resultant major fraction determined (Farrell *et al*, 1967). Amino acid, mineral, vitamin and gross energy content were also determined by the Kansas group (Waggle *et al*, 1967). Biological evaluation was conducted by the Department of Poultry Science at the University of Guelph (Summers *et al*, 1968; Summers, *et al*, 1969). This work has recently been summarized and presented to the feed trade by the Guelph group (Moran and Summers, 1970). As this work will probably be reported by other speakers at this Symposium, it will not be reviewed here. However, the type and source of the wheats used in the Kansas and Guelph experiments and their protein content are of interest and are reported in Table 1. Table 1 shows mean protein levels for a high and low protein hard red winter and hard red spring wheat. The soft white winter wheat grown in the Pacific Northwest, Gaines, contained the lowest level of crude protein. The proximate analysis and mineral content of a typical Gaines wheat are presented in Table 2.

Table 1. Description and Origin of Wheat Samples Used in Cooperative Studies by Kansas State University and Guelph.

Wheat type	Designation	code	Geographical source	Grain protein[1] Level %	
Hard red winter	HRW-L	9001	Blackwell, Okla.	Low	10.8
	HRW-H	9002	Burdett, Kan.	High	13.3
	HRW-R-1[2]	9008	Kansas State University	Avg.	11.5
	HRW-R-2[2]	9007	Kansas State University	Avg.	11.2
	HRW-R-3[2]	9010	Kansas State University	Avg.	11.9
Hard red spring	RHS-L	9009	Choteau, Mont.	Low	11.1
	HRS-H	9003	Valley City, N. D.	High	13.8
Soft white winter	Gaines	9005	Pullman, Wash.	Avg.	9.2
Soft red winter	SRW	9006	Winchester, Ind.	Avg.	11.8

[1] 14% moisture basis.
[2] Composite samples
(Adapted from Moran and Summers, 1970)

Composition of Wheat By-Products

The wheat by-products used most commonly in dairy cattle feeds are wheat mixed feed (mill run), wheat bran, wheat standard middlings (shorts), wheat red dog, and blended products. Fraps (1921) in 1921, summarized compositional and digestion trial data from ruminant digestion trials conducted on wheat millfeeds to that time. These are presented in Table 3. Compositional and digestion coefficients of proximate principles of wheat millfeeds as summarized by Morrison (1956) are presented in Table 4.

Wheat by-products are an excellent source of protein for dairy cattle, and often contain from one and a half to two times as much protein as barley, milo or corn. For monogastric animals the kernel as well as the by-products appear to be inadequate or marginal in methionine lysine and/or isoleucine (Moran and Summers, 1970). Wheat grain is also deficient in Vitamins A, D, riboflavin and B_{12}. Wheat is a fair source of phosphorus but contains little calcium and is low in magnesium and potassium as are many of the cereal grains (Table 2). On the other hand most wheat by-products are an excellent source of phosphorus for dairy cattle and can be used to advantage in balancing rations of lactating cows fed high legume roughages. The energy (total digestible nutrient (TDN)) content of the wheat by-products (Table 4) is variable. The outer portions of the wheat kernel when removed in the milling process are high in crude fiber and thus have the lowest energy content but as the starchy portion of the kernel increases in the by-product feeds the energy content increases correspondingly. Thus, the estimated net energy (ENE) in Therms or Megacalories per 100 pounds of the various wheat feeds for dairy cattle is as follows: wheat 80, wheat bran 67, wheat mixed feed 70.6, and wheat standard middlings 77 (Morrison 1956).

Wheat as a Roughage for Dairy Cattle

In many livestock areas throughout the world, wheat and other cereal grains are used as forage crops in the form of silage, or hay.

Hay made from the wheat plant has been successfully fed to dairy cattle in Australia, South Africa, United States, and Canada. However, wheat hay is low in protein and if over matured or the grain ripened, it will be high in fiber and of low palatability. Wheat harvested for hay should be cut when the wheat is in the soft dough stage for maximum preservation of nutrients and greatest digestibility (Sotola, 1936a). Gen-

Table 2. Composition of Soft Wheat.

Constituent	WSU Gaines Wheat		NRC Publ. 585 (soft wheat)	Morrison, 22nd ed. (soft white wheat)
	Chemical analysis	Spectrographic analysis	1968	1956
Moisture, percent	9.05	---	---	10.9
Ash, percent	1.47	---	1.9	1.9
Protein, percent	10.25	---	10.0	9.9
Ether extract, percent	1.48	---	2.0	2.0
Crude fiber, percent	3.27	---	---	2.7
Gross energy, kcal/gm.	3.983	---	---	---
Metabolizable energy, percent	71.1	---	---	---
	Mineral Analysis, Percent			
Phosphorus	0.25	0.35	0.33	0.39
Potassium	0.40	0.42	0.44	0.42
Magnesium	0.13	0.13	0.11	0.14
Calcium	0.05	0.04	0.10	0.04
Silicon	0.02	0.02	---	---
Sodium	---	0.005	---	0.06
Iron	---	0.002	0.006	0.006
Aluminum	---	0.0008	---	---
Manganese	---	0.0009	0.0006	0.004
Barium	---	0.0009	---	---
Copper	---	0.0006	0.001	0.001
Lead	---	0.0001	---	---
Titanium	---	0.0001	---	---
Strontium	---	0.0001	---	---
Nickel	---	0.00002	---	---
Silver	---	0.000007	---	---
Chromium	---	0.000003	---	---

Table 3. Average Composition and Digestion Coefficients of Wheat Millfeeds Used in Digestion Experiments With Ruminants as Summarized by Fraps.[1]

								Digestion Coefficients			
	No. avgd.	Protein	Ether extract	Crude fiber	Nitrogen free extract	Water	Ash	Protein	Fat	Fiber	Nitrogen free extract
Wheat bran	12	15.7	4.7	9.8	53.1	10.8	5.9	78.1	68.6	32.7	70.4
Wheat middlings and brown shorts	3	19.7	5.2	7.2	54.2	9.5	4.2	81.6	85.9	16.9	79.8
Wheat middlings	5	18.5	4.6	4.4	58.4	11.0	3.1	83.9	87.2	17.6	90.8
Wheat meal	5	11.8	2.1	2.8	70.1	11.6	1.7	81.5	77.4	25.6	90.5
Wheat white shorts	2	16.3	2.5	1.3	68.4	10.3	1.2	90.1	89.1	41.8	98.7
Wheat screenings	2	15.6	6.2	8.2	56.0	9.8	4.4	71.8	88.5	0	73.2
Feed flour	1	21.4	0.7	2.3	54.8	17.9	3.0	79.1	---	---	75.5

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[1] Fraps, G. S. Texas Bul. 282, 1921.

Table 4. Average Composition and Digestion Coefficients of Wheat By-Products Commonly Fed to Dairy Cattle.[1]

								Digestion Coefficients					
	No. avg.[2]	Protein	Ether extract	Crude fiber	Nitrogen free extract	Water	Ash	Protein	Fat	Fiber	Nitrogen free extract	TDN[3]	ENE[4]
					%								
Wheat bran, all analysis	10	16.4	4.5	10.0	53.1	9.9	6.1	81	83	49	76	67	67
Wheat brown shorts	6	16.4	4.0	6.8	57.1	11.5	4.2	85	85	60	85	74	67
Wheat flour middlings	4	17.5	4.5	4.3	60.0	9.9	3.8	88	86	54	88	79	75
Wheat white shorts	2	16.5	3.0	2.4	65.1	10.6	2.4	88	92	34	99	86	86
Wheat screenings	10	13.9	4.7	9.0	58.2	9.6	4.6	72	88	6	84	69	58
Wheat mixed feed, all analyses	4	15.8	4.3	8.3	57.1	9.3	5.2	83	86	--	78	70	88
Wheat, average all types		13.2	1.9	2.6	69.9	10.5	1.9	84	81	70	91	80	80

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[1] Morrison, F. B. Feeds and Feeding, 22 Ed. 1956.

[2] Digestion trials.

[3] Total digestible nutrients.

[4] Estimated net energy—megacalories per 100 pounds.

erally, cereal hays are fed to supply about one-third of the forage dry matter and are preferably offered with other roughages such as alfalfa hay or corn silage.

The entire wheat plant, like other cereals, has been successfully ensiled when the grain is at the early dough stage and provides a palatable ensilage. Mixtures of winter wheat and sweet clover harvested as hay and silage in Washington resulted in forage mixtures containing 48% total digestible nutrients (TDN) and a crude protein content of 7% (Sotola, 1936). Ohio workers seeded wheat into a poor first year stand of alfalfa. The mixture was harvested when the grain was in the dough stage and the alfalfa in early bloom. The wheat-alfalfa silage (two parts wheat — one part alfalfa) was compared to alfalfa hay in a 40-day trial with lactating cows. Dry matter intake was very similar on the two roughages. Milk and fat production were essentially identical (Ohio Bulletin 617).

Research workers in India have successfully ensiled wheat-bhoosa (screenings-like product) and green guar and fed it to steers. Animals consumed 1.7 pounds per 100 pounds body weight daily and gained 0.3 pounds per day (Kehar and Jahri, 1959).

The digestibility of dough-stage wheat silage, ensiled sudan grass and drouth corn silages was investigated by Pfander and co-workers (1957) of the Missouri Station. Forty pounds of molasses was added per ton of wheat at time of ensiling. The wheat silage averaged 38.5% dry matter. On a dry matter basis, wheat silage contained 7.9% crude protein, 3.9% ether extract, 59% nitrogen free extract, 23% crude fiber, and 6% ash. Digestibility of the crude protein of wheat silage was 46% compared to 49% and 71% for the sudan grass and corn silage, respectively. Protein digestibility for wheat silage was lower than previously reported values for oat silages. Total digestible nutrient content of the wheat silage, at 56.4% on a dry matter basis, was lower than corn silage at 68.5% but above sudan grass silage at 54.3%. Sheep used in the digestion trials consumed more dry matter from wheat silage than from the other forage crops. In feed lot trials animals fed wheat silage outgained those fed drough corn silage.

McCullough and Sisk (1967) ensiled wheat silage at three stages of maturity; early heading (5% of the heads had emerged), full bloom (10 days after the early heading silage, or about milk stage), and dough stage (20 days after early heading). The silage averaged 9.6, 11.7, and 8.1% crude protein; 29.9, 30.0, and 36.0% crude fiber. Early heading wheat silage was fed to lactating Guernsey cows for 21 days at three grain to silage dry matter ratios: 20:70, 35:65, and 50% grain:50% silage. The three silages were fed for 18 days to heifers in a 3X3 latin square design. The silages were fed alone, or at 30% grain:70% silage, or 50% grain:50% silage dry matter ratio. The effect of stage of maturity and grain to forage ratio on consumption of wheat silage dry matter was evaluated. Digestibility of all rations was also determined with dairy steers.

Dry matter digestibility (64% vs 58%) and intake of metabolizable energy (2.28 vs 2.07 Mcal) were greatest for early heading wheat silage. A ratio of 35:65 of concentrate to roughage (early heading silage) also permitted the greatest increase in dry matter intake by the cows compared to the 20:80 ratio. Maximum response in dry matter intakes was obtained with heifers fed the early heading silage at a 35:65 concentrate to roughage ratio.

Many areas throughout the world utilize cereal grains for all year pastures. Winter wheats grown in many areas of North America are often grazed from fall to spring and are subsequently harvested as a grain crop. In some of the dairying areas winter wheat provides early spring pastures or late fall pasture depending on date of seeding.

Successful rearing of cattle and lambs in Kansas on winter wheat pasture developed from a small industry in the early 1930's into a very extensive industry by the mid 1940's, and included other Plains States. Large numbers of lambs were often fattened on these pastures and sold directly to meat packers (Cox and Weber, 1948). Winter wheat, when eaten at the pasture stage, will contain over 18% digestible protein and 63.5% TDN (Morrison, 1956).

Winter wheat has been used extensively in South Africa and Australia as a forage for rearing sheep, as well as for emergency forage for beef, sheep and dairy cattle (Badenhorst, 1949).

Verbeek (1946), of the Vaalhartz Experiment Station in South Africa, obtained greater milk production when lactating cows were fed limited alfalfa hay and no concentrate and grazed on wheat pasture than when they were fed alfalfa hay and concentrates without access to pasture; 29.5 vs 24.7 pounds of milk daily per cow, respectively.

Wheat as a Feed for Lactating Cows

Early Research in Feeding Wheat to Dairy Cattle. Much of the research on feeding wheat to dairy cattle dates to the early 1930's and again in the 1940's when wheat was a surplus commodity and the price competitive with other feed grains at the time.

One of the early papers on the use of wheat as a livestock feed was a report by Bartlett (1896) from Maine State College Agricultural Experiment Station in 1895. Following drouth year in 1894 when corn was in short supply, wheat was available as an alternate feed. Bartlett fed five Jersey cows 18 pounds of timothy hay and a mixture of five pounds of wheat meal or five pounds of corn meal plus two pounds of cottonseed meal daily in a double reversal trial of three 21-day periods. Cows fed wheat meal produced as much milk as those fed corn meal and gained more weight. From this early experiment Bartlett concluded that wheat meal, pound for pound, furnishes more food than corn meal, mostly more digestible protein. The cows averaged between 17 and 19 pounds of milk daily.

In early experiments conducted by the Ontario Agricultural College, Guelph (1893), rations of either eight or ten pounds of ground wheat or four pounds of bran and four pounds of ground wheat plus about 50 pounds of corn silage and six pounds of hay were fed in three different short term (three to four weeks) experiments with two cows per treatment. Results indicated that the wheat rations provided favourable results but a combination of wheat and bran was more economical to feed. In another experiment conducted at Guelph and reported the same year, four cows were placed on a standard ration for 10 days then two cows were fed for 60 days a mixed grain ration of ground oats, barley and peas while the other two cows were fed ground wheat. The same forages were fed to both groups, mainly hay, straw and ensilage. At the end of 60 days the rations for the groups were reversed. The results indicated that milk flow was maintained at a somewhat higher level on the mixed ration than on the wheat ration.

In 1930, wheat prices were at a low and surplus wheat was available as a feed grain in the Great Plains States. Jacobs (1931) of the Oklahoma Panhandle Station compared a mixed ration containing 53% wheat with a ration containing 60% milo for lactating Holstein cows on native short-grass pasture in a 15-day changeover experiment. Cows on both treatments consumed on the average eight pounds of each grain ration per day. Animals on the wheat ration produced 37.6 pounds per day while those fed milo produced 36.2. Jacobs concluded that at least two-thirds of the daily grain ration may be comprised of wheat and not cause a decline in milk production and that wheat was equal to milo for dairy cows. He also stated that wheat did not need supplementing with bran to be a satisfactory feed for lactating cows.

Copeland (1933) compared a ration containing 50% coarsely ground soft winter wheat with a ration containing 50% ground milo in three double reversal experiments of six cows per treatment at the Texas Experiment Station in 1931. Sorghum silage and alfalfa hay were fed as roughage and grain was fed at one pound for every two and a half pounds of milk produced daily. Each grain ration was consumed readily. In the three experiments cows fed milo produced slightly but not significantly more than those fed wheat. However, body weight increase was greater for the wheat fed cows. The productive energy value for the wheat was calculated at 84.9 therms per 100 pounds compared to milo at 83.3. It was concluded that wheat could replace milo pound for pound when not more than 50% of the grain ration consisted of wheat.

Hayden and Monroe (1931) of the Ohio Station compared a grain ration containing corn and oats as the main cereal grains with a ration where 75% of the corn was replaced with wheat (wheat comprised 33% of the grain or concentrate mixture) . Six cows were fed each experimental ration for 75 days then switched to the opposite ration and fed for 75 days. Four cows from each group were continued on the experiment for a further 75 days .Alfalfa hay and corn silage were fed to both groups at 1 and 3 pounds, respectively, per 100 pound live-weight. During the three periods, cows fed the two grain rations produced almost equal amounts of 4% fat-corrected milk (FCM) , averaging over 33 pounds per day for the seven months. At a ratio of one pound of grain to two and a half pounds of milk produced (41 pounds of grain were used to produce 100 pounds of milk.) This would amount to a consumption of about 13 pounds of the grain mixture per day or approximately 4.3 pounds of wheat per day. At peak production the cows could have consumed seven pounds of wheat per day. Live-weight gain favored the cows receiving the corn grain mix. The effect of continuous wheat feeding on performance and reproduction of lactating cows was evaluated in a second experiment by the Ohio workers. A group of 11 cows in various stages of lactation were given a ration containing 40% wheat, 30% oats, 10% bran, and 20% linseed oil meal. The cows produced normally on the ration and 8 of the 11 cows dropped normal calves. Level of grain intake or milk production was not given. Hayden and Monroe concluded that wheat and corn were nearly equal in feeding value. The wheat and corn rations were of equal palatability.

In a subsequent wheat feeding experiment at Ohio in 1932, conducted by Monroe, Hayden and Knoop (Ohio Bull. 516) , a corn-oats-bran-linseed meal ration was compared to a second ration containing 50% wheat. Two per cent bone meal was added to the wheat ration while no bonemeal was used in the control ration. During a 150 day single reversal feeding trial, the cows consumed an average of 11.5 pounds of grain per day, or an intake of 5.7 pounds of wheat daily. Four per cent fat-corrected milk production averaged close to 29.5 pounds for each treatment group. Weight gain favoured the corn grain group. In a further trial (Ohio Bull. 532) two Jersey cows were fed for a full lactation on a ration of ground wheat containing 2% steamed bonemeal. Alfalfa hay was the only roughage fed. One cow produced over 9,800 pounds of milk and 474 pounds of butterfat and consumed about two tons of wheat in the 365-day lactation. This would be an average of 11 pounds of wheat per day and probably well above this at lactation peak. No digestive problems were encountered with either cow.

Research workers at the Kentucky Experiment Station (1931) and the University of Guelph (Ontario Dept. Agric., 1932) as well as workers at Federal Experimental Farms in Canada (Rennie, 1960) in the early 1930's found wheat to be a suitable grain for dairy cattle. Levels of wheat in concentrate rations, in comparison with other feed grains, were as high as one-third.

Fitch and Cave (1932) of the Kansas Station reported that wheat could replace corn pound for pound up to 57% of the ration. However, there was a slight tendency for cows to go off feed when the wheat ration was fed.

Dice (1932) of the North Dakota Station determined the palatability of grain rations when ground wheat made up one-third, one-half, and two-third of the ration. Cows ate the rations readily. Levels of intake were not reported. In two feeding trials, ground durum wheat at 40% of the grain mix was compared to either ground barley or wheat bran. Feed intake values were not reported. In both experiments production was comparable, but low for both groups.

In 1933, Bateman of the Utah Experiment Station (1942) studied the effect of an all-chopped-wheat grain ration on feed intake and performance of four lactating cows for a complete lactation. Alfalfa hay was fed as the only roughage. Three cows were average producers and received only a moderate amount of grain. The fourth cow was a high producer, in relation to average production at that time, and yielded 14,031 pounds of milk and 430 pounds of fat. During her lactation she consumed 2,892 pounds of wheat and at peak production was eating 14 pounds of chopped wheat per day. All cows ate their chopped wheat readily throughout the lactation and at no time did a significant refusal occur. Cows were in good condition throughout the experiment.

Further interest in the use of wheat as a feed grain for dairy cattle arose in the Pacific Northwest at the outset of World War II when overseas export markets were lost. As a result, a surplus of soft wheat was available to the feed trade. Conditions were similar in many other wheat growing areas of North America at this time.

A series of trials on Pacific Northwest soft wheat were undertaken by the Oregon Agricultural Experiment Station as a result of a grant of 350 tons of surplus wheat from the Federal Surplus Commodities Corporation for experimental livestock feeding in 1939. Part of this work included feeding trials with dairy heifers and lactating cows conducted by Dr. I. R. Jones of the Department of Dairy Husbandry, Oregon State University (Oregon Station Circ., 137, 1940). Two trials of approximately 60 days each were conducted by the Oregon workers with 36 dairy heifers fed five pounds of wheat daily in different physical forms to supplement poor quality hay, or hay plus silage. The wheat was fed as rolled, coarsely ground, medium ground, or finely ground forms. Feed consumption on all forms of the wheat was good with no off-feeds. Heifer gains ranged from 0.33 to 1.77 pounds daily, depending on the quality of the forage.

In studies with lactating cows of the Ayrshire and Holstein breeds at Oregon, three cows were assigned to one of three treatment groups and fed the regular herd ration (mainly oats, barley and protein supplement) plus hay and silage for 20 to 30 weeks. This was followed by the same forage and either a 25%, 50% or 75% wheat grain mix for 14 weeks, then pasture, plus the same wheat grain mix to the end of the lactation. Medium-ground wheat was the only grain present in the 75% wheat mix. When cows were switched to either of the three different wheat levels, milk production was maintained as well as, and in some instances better than, when the cows were fed the regular herd mix. Cows fed the 75% wheat ration were receiving up to 10 pounds per day or an intake of 7.5 pounds of wheat. No off feeds were recorded. A tendency for the 75% wheat ration to be slightly less palatable than the regular herd mix was observed when this group was on pasture. Jones concluded that wheat could replace up to 50% of the barley, oats, and wheat bran in a concentrate mixture for lactating cows fed 8 to 10 pounds of the mixture daily. Higher levels of wheat could be fed but with some loss of palatability.

Feeding trials with lactating cows fed hard red spring wheat were conducted by Bowstead (1942) of the University of Alberta in the early 1940's. Two double reversal trials of three weeks with a week change over were conducted with 12 cows of three breeds. In the first trial an essentially oat concentrate (grain) ration was compared to a 30% wheat ration while in the second trial the oat ration was compared to a 30% and 60% wheat ration. Alfalfa and oat silage were the only roughages fed. Concentrate intakes reached 12 pounds per day for top producers on 30% wheat and 10 pounds daily for cows eating 60% wheat concentrate mixtures, or an intake of six pounds of wheat daily. Milk production and body weight gains were comparable at the 0%, 30% and 60% wheat levels. In earlier experiments, Bowstead (1930) found that wheat maintained milk and butterfat production as well as oats or barley, but based on digestion trials that he conducted wheat contained 84% total digestible nutrients (TDN) while oats and barley contained 71.5% and 78.7% TDN, respectively.

In summarizing the results of some of these earlier experiments, Morrison (1956) stated that "ground wheat is equal to ground corn for dairy cattle and is a satisfactory feed, even for long periods, if fed in a suitable concentrate mixture and in a properly balanced ration. — Because of its rather pasty nature, the best results are probably secured when wheat does not form more than one-third to one-half of the concentrate mixture. However, wheat has been fed successfully to cows as the only concentrate, with plenty of legume hay for roughage."

Feeding Wheat Under Conditions of Low Forage Intake. In early 1944 after severe drouth conditions, followed by extensive fires that destroyed much pasture and stored forage, dairy farmers in Victoria, Australia were faced with extreme feed shortages for their herds. Wheat by-products could not be supplied in sufficient quantities. However, ample wheat stocks were available and released to tide the stricken areas over the difficult period. Many dairymen were faced with the problem of feeding lactating and dry cows essentially on all wheat rations. In the early stages when no green forage, alfalfa, clover hay, or silage were available, the following rations were recommended (Hewitt, 1944) : 1) 3 lb. linseed meal, or 1 lb. meat meal and 5 lb. of ground wheat; 2) 10 lb. good quality oaten chaff, 12 lb. ground wheat, 2 lb. meat meal, 1 oz. ground limestone; 3) 6 lb. chaff, 12 lb. ground wheat, 12 lb. bran, pollard, linseed meal, or other protein supplement fed up to 24 lb. per cow per day for cows producing 30 lb. of milk daily; 4) Dry cows could be maintained on 8 lb. of ground wheat daily or less wheat plus dry forage.

In the subsequent months a survey was made of dairy farmers in the area by the Victoria Department of Agriculture (Hewitt and Turner, 1944) . The survey covered over 1,400 milk cows, being fed wheat as part of the grain mixture. The average herd size was 33 cows. About 60% of the farmers had been feeding wheat six months or more. Over 50% of the dairy men fed between 7-14 pounds of a wheat ration daily. Fifty per cent fed wheat as the only concentrate material. Of those dairymen interviewed, most off-feed problems were first associated with rations. However, after application of some general guidelines in feeding wheat to dairy cows, further problems were not encountered. In areas where wheat was fed most heavily, due to the acute shortage of other feeds, milk production was 25% higher than normal during the winter months.

The practices of four of the heaviest wheat feeders as reported by Hewitt and Turner (1944) of the Victoria Department of Agriculture are shown in Table 5.

The State Research Farm at Werribbee, Australia (Hewitt, 1944) fed a ration containing 59% wheat, 27% pea meal, 5% bran, 4% oats, 4% barley, and 1% meat meal to 80 lactating cows at rates from 4-21 pounds daily with excellent cow health and performance. This represented an intake of up to 12½ pounds of wheat daily.

In contrast to the excellent results obtained by the Victorian Agricultural advisors following the drouth and fires of 1943-44, Bailey (1965)

Table 5. Practices of Dairymen Feeding Heavy Quantities of Wheat in Victoria, Australia, 1944.

Farm	Cows milked (no.)	Wheat fed per cow per day (lb)	Other concentrates	Roughage fed in bails per cow per day	Roughage fed in paddock	Type of ground wheat	Period of feeding wheat	Occurrence of feed sickness
1.	52	At least 6 up to 16	Meatmeal	Nil	Grass hay in winter	Fine	3 years	Very rare and mild
2.	40	12-14	Nil	Nil	Grass hay	Fine	3 months	Occasional cases. Not serious
3.	10	14	Nil	5 lb oaten chaff	Grass hay	Coarse	6 months	No cases.
4.	14	Up to 15	Meatmeal	13 lb oaten chaff	Nil	Medium	12 months	Two cases at first. None since.

(Selected from data of Hewitt and Turner, J. of Agric., Victoria 42: 437. 1944.

of the New South Wales Milk Board advised in 1965, when wheat was again in demand as a supplementary feed during another drouth period, to feed only up to four pounds of wheat per cow daily and to keep the proportion of wheat at not over one-third of the concentrate or grain mixture. These recmmendations were based on research conducted in 1944 at the McGarvie-Smith Animal Husbandy Farm of the University of Sydney. Cases of short term "off-feeds", longer term "feed-sickness" with a large reduction in milk yield, and laminitis or founder (shown as lameness) were reported. Similar rather stringent recommendations for feeding wheat have not been put forth as a result of most wheat feeding research with dairy cows.

Recent Research in Feeding Wheat to Dairy Cattle. In reviewing the early literature it is apparent that, in many experiments, the level of milk production was low compared to that obtained today; and the total intake of wheat, or for that matter any other cereal grain, was minimal and in many cases did not exceed four to seven pounds of actual wheat consumed per day. Only in the early research of Monro and Hayden at Ohio (Ohio Bull. 516, 532) and Bateman (1942) at Utah, where selected cows were fed a full lactation, did wheat intake on all-wheat rations reach values of 8-14 pounds per day. Comparable intakes were also obtained in Australia (Hewitt and Turner, 1944) when wheat was fed in substantial amounts in certain drouth years. Only very recently has the use of wheat been investigated under today's conditions of heavier grain feeding and somewhat different management.

Weather Damaged Wheat. Edgerly (1966) of North Dakota State University compared the feeding value of a mixture of equal parts damaged durum wheat and oats with a mixture of barley, oats and corn, for lactating cows. Alfalfa hay and silage were the major sources of roughage and were fed daily at two pounds of hay equivalent per 100 pounds of body weight. Additional energy requirements were supplied by the grain rations according to National Research Council Requirements for Dairy Cattle (1958). Two trials were conducted, the first, a double reversal trial with three 21-day periods and a 7-day adjustment period between experimental periods, and the second, a 90-day continuous trial. The wheat and oats concentrate mixture contained 1% salt and 1% bonemeal and had a crude protein content of 11.6%. The concentrate ration also contained mineral and salt as well as 10% of each of soybean oil meal and wheat bran, and had a crude protein content of 13.1%. Cows were adjusted to the grain over a seven-day period. Feed intake and performance on each trial are shown in Table 6 and 7.

Edgerly (1966) reported that palatability of the ground wheat-oat concentrate mixture was not as good as for the control ration and as a result the cows on the wheat-oats ration required longer to adjust to this mixture. Production of 4% fat corrected milk (FCM) was comparable for cows on each treatment in the double reversal trial, while cows fed wheat and oats out-produced those fed the control mixture in the continuous trial. Weight gains in both trials favored cows fed the control ration. From feed intake figures, the heavier producers in the continuous trial would be eating at peak production close to 10 pounds of durum wheat per day. Other than slight palatability problems when cows were started on the wheat-oat mixture, results from adding 50% wheat to the grain ration were entirely satisfactory.

Table 6. Feed Intake and Performance of Lactating Cows Fed Damaged Durum in the 21-Day Double Reversal Trial.[1]

Item	Treatment	
	Control Barley-Oats-Corn	Wheat and Oats
Feed intake		
Hay — (lb)	14.4	13.8
Silage — (lb)	23.4	23.4
Grain — (lb)	15.7	15.7
Average daily 4% fat corrected milk — (lb)	30.7	31.3
Average daily change in body weight — (lb)	1.06	0.88

[1] (Edgerly, 1966).

High Moisture Wheat. With the advent of gas-tight storage facilities, emphasis has been placed on harvesting, storing and feeding high moisture grains for ruminants. Recently Marx and Youngquist (1967) of the University of Minnesota, Crookston Station, compared high moisture wheat as part of the grain ration with a standard dry grain ration. The high moisture wheat was combined at 28% moisture, passed through a hammer mill blower, and stored in a Harvester silo. After a two-week

Table 7. Feed Intake and Performance of Lactating Cows Fed Damaged Durum in a 90-Day Continuous Trial.

Item	Treatment	
	Control	Wheat and Oats
Feed intake		
Hay — (lb)	13.2	11.7
Silage — (lb)	23.2	19.6
Grain — (lb)	17.7	17.3
Average daily 4% fat corrected milk — (lb)	36.6	38.9
Average daily change in body weight — (lb)	0.96	0.74

standardization period, twenty cows were paired and assigned to one of two treatment groups in a continuous 92-day feeding trial. The wheat group were fed 12 lb. of high moisture wheat per animal daily with the balance of the grain ration consisting of equal parts oats, barley, beet pulp and corn plus 1½% dicalcium phosphate, 1½% urea and 1% trace mineralized salt. In the second treatment, high moisture wheat was replaced by equal parts oats and barley and fed to the same dry matter level with the two grain mixtures fed at one pound of grain to three pounds of 4% FCM. Cows fed high moisture wheat produced slightly less (36.1 vs. 37.8 lb) 4% FCM per cow per day than those fed the dry grain ration. Yields of total milk, total fat, and total solids as well as daily weight gain by treatment groups were not significantly different. High moisture wheat appeared to be well liked by the cows but some cows required three to four days to become accustomed to the wheat.

The most recent information on the nutritive value of wheat for dairy cattle comes from a series of studies made by McPherson and Waldern (1969), Tommervik and Waldern (1969) and Waldren and Cedeno (1970) at Washington State University, Pullman.

Most research on the nutritive value of wheat for lactating cows was conducted over 25 years ago, as can be seen from the foregoing review. Average production per cow was low in terms of today's standards and the amount of grain or concentrate fed was rather limited, and in most instances did not exceed six to eight pounds. Recommendations were that wheat not exceed one-third to one-half of the concentrate mixture. During the past 25 years there has been a marked change in feeding and management practices employed by the dairyman and in the production of his cows. Considerably more grain is now being fed to lactating cows in North America to meet their energy needs for higher levels of milk production. Are wheat feeding recommendations adequate under today's management practices where heavy producers may be fed up to 30 pounds of grain per day? This could mean that cows would be consuming from 15 to 22 pounds of wheat daily. What level of wheat could today's cows handle in relation to the total roughage and grain feeding program without going off feed or showing digestive disorders or laminitis? How does the acceptability and feeding value of wheat compare with other feed grains? These were some of the questions that the Washington State group attempted to answer.

Levels of Wheat in the Concentrate Ration. In the first Washington State University study*, McPherson and Waldern (1969) determined the acceptability and nutritive value of Gaines soft white wheat for high producing lactating cows when the concentrate ration contained 20, 53, 63, 73, 83, and 93% wheat. Three major trials were conducted: 1) a series of seven digestion trials to determine the total digestible nutrient (TDN) content of the six grain rations and the roughage; 2) a continuous feeding trial with 24 cows in which the acceptability of each concentrate was determined; and 3) a double reversal lactation trial with 30 cows to determine the effect of levels of wheat on cow performance and milk composition.

The composition of the six concentrate or grain mixtures is shown in Table 8.

Rations containing 83, 73, 63 and 53% wheat were balanced to an approximate equal protein content of 12%, based on the protein content of the alfalfa hay, while the control ration (20% wheat) was a standard 14% protein mixed grain ration. The 93% wheat ration was used to evaluate wheat as the only cereal grain without supplemental protein when alfalfa was the only roughage fed. The wheat came from one field grown near Pullman, Washington. The cereal grains were steam rolled, mixed with other ingredients, then compressed into one-fourth-inch pellets.

Table 8. Composition of Concentrate Rations.[1]

Ingredient	Treatment 1	2	3	4	5	6
			%			
Wheat	93	83	73	63	53	20
Barley	--	--	10	20	30	40
Oats	--	--	--	--	--	22
Cottonseed meal	--	10	10	10	10	11
Cane molasses	5	5	5	5	5	5
Salt, trace-mineralized	1	1	1	1	1	1
Dicalcium phosphate	1	1	1	1	1	1

[1] Each ration contained 2,784 IU vitamin D and 3,095 IU vitamin A/kg of mix.

Table 9. Proximate Analysis and Total Digestible Nutrients of Alfalfa Hay and Concentrates.

Feed	Dry matter	Composition of Dry Matter: Crude fiber	Crude protein	Ether extract	N-free extract	Ash	TDN
				%			
Alfalfa hay	88.1	24.7	18.7	3.0	43.1	10.6	62.3
Grain rations wheat (%)							
93	89.0	3.3	11.0	2.2	79.9	3.9	81.4
83	89.2	3.4	12.3	2.1	78.3	3.8	86.2
73	88.9	3.7	12.4	2.0	78.1	3.8	80.9
63	88.9	4.0	12.4	2.0	77.5	4.1	81.8
53	88.5	4.2	12.8	2.0	76.8	4.3	81.8
20	88.8	5.8	14.1	3.2	71.9	5.0	83.3

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*Supported in part by a grant from the Washington State Wheat Commission.

The chemical composition of the rations offered and their TDN content as determined in the digestion trials with heifers fed at a 55:45 ratio of hay to grain are shown in Table 9.

In this and succeeding studies the cows were housed in an open concrete lot with an attached loafing shed. They were tied four times daily 5:00 and 9:00 a.m. and 2:45 and 7:30 p.m. for approximately 1 to 1½ hours for feeding. Grain was fed four times daily, twice in the milking parlor at 2:30 a.m. and p.m. and at the 9:00 a.m. and 7:30 p.m. roughage feeding periods. Only five pounds of concentrate were fed at each milking to ensure complete consumption Daily milk weights were recorded on all experimental animals and composite milk samples were collected at four consecutive milkings, weekly, and analyzed for milk fat, solids-not-fat, and protein. All cows were weighed on three consecutive days at the beginning and end of all experimental periods.

During the first week of a three-week preliminary period of the acceptability trial in which the relative palatability and maximum acceptability of each ration was determined, all cows received alfalfa hay ad lib and control (20% wheat) concentrate ration at 1 lb. per 3.5 lb. of 4% fat-corrected milk (FCM) produced daily. During the second and third weeks, hay was reduced to 1 lb. per 100 lb. of body weight and the cows were switched to one of the five wheat concentrate rations or remained on the control concentrate. Grain intake was increased gradually until all cows reached maximum consumption approximately three weeks later.

In the lactation trial, thirty cows were selected from the WSU dairy herd and placed on a double switchback desgin to evaluate the effect of the six wheat concentrate rations on feed intake, milk production, milk composition, efficiency of FCM production, and body weight gain. During the first week of a three-week preliminary period the cows were fed alfalfa hay free choice and the control ration at the rate of 1 lb. per 3.5 lb. of 4% FCM produced daily. In the next week, hay was reduced to 1.7 lb. per 100 lb. body weight and grain increased to meet the cows' energy requirements for maintenance, growth and production (National Research Council, Pub. 464, 1958). During the third week the cows were switched to the assigned grain ration for the first period of the double reversal experiment. Experimental periods were four weeks with a two-week adjustment period between each experimental period.

Table 10. Daily Nutrient Intake, Milk Production, Composition, and Body Weight Gain of Cows Fed Various Levels of Wheat in the Acceptability Trial.

	Wheat in the concentrate ration (%)					
Criteria	93	83	73	63	53	20
Highest sustained grain dry matter intake (lb)	27.3	28.2	29.1	28.4	28.4	26.9
Total dry matter intake (lb)	37.7	39.5	40.8	39.7	38.4	37.9
Crude fiber intake (lb)	3.7^{c}	4.2^{b}	4.6^{a}	4.4^{ab}	4.8^{a}	4.8^{a}
4% FCM produced (lb)	45.2	46.9	43.2	44.5	45.4	47.6
Milk fat (%)	2.6	2.5	2.8	2.4	2.8	2.6
Solids-not-fat (%)	8.8	8.6	8.8	8.4	8.4	8.6
Milk protein (%)	3.3	3.4	3.5	3.2	3.3	3.2
Body weight gain (lb)	1.7	2.6	2.4	2.8	2.6	1.7

^{abc}Treatment means of a given variable with different superscripts are statistically different ($P < 0.05$).

The chemical composition of the feeds offered in the digestion, acceptability, and feeding trials (Table 9) indicate that percentage crude fiber content increased as wheat was replaced by barley and oats. A similar increase was noted in the ash content while nitrogen free extract declined. Digestibility of dry matter for the six alfalfa-wheat mixtures fed in the digestion trial ranged between 71.5 and 72.3 with the exception of the 83% wheat-alfalfa mixture which was 77.7. Total digestible nutrient content of the wheat rations reflected dry matter digestibilities, with the 83% wheat ration being highest. An examination of digestion coefficients of proximate principles (not shown) revealed no specific patterns as related to level of wheat, protein content, etc.

Daily feed intake and performance of cows fed the various concentrate rations in the acceptability trial and lactation trial are shown in Table 10 and Table 11, respectively.

Table 11. Daily Nutrient Intake, Milk Production, Composition, and Body Weight Gain of Cows Fed Various Levels of Wheat in the Lactation Trial.

	Wheat in the concentrate ration (%)					
Criteria	93	83	73	63	53	20
Grain dry matter intake (lb)	16.9	15.8	17.4	16.5	16.9	15.4
Total dry matter intake (lb)	36.7	35.4	38.1	36.9	37.4	37.4
Crude fiber intake (lb)	5.5	5.5	5.7	5.7	5.7	5.5
4% FCM produced (lb)	46.8	45.9	48.4	48.3	48.5	48.3
Milk fat (%)	3.7^{ab}	3.7^{ab}	3.9^{a}	3.6^{b}	3.7^{ab}	3.6^{b}
Solids-not-fat (%)	8.8	8.8	8.9	8.8	8.7	8.8
Milk protein (%)	3.6	3.6	3.6	3.6	3.5	3.6
Body weight gain (lb)	0.44^{b}	0.88^{a}	0.44^{b}	0.22^{c}	0.22^{c}	0.66^{a}

^{abc}Treatment means of a given variable with different superscripts are statistically different ($P < 0.05$).

In the acceptability trial where hay was restricted to 1 lb. per 100 lb. body weight and concentrate offered essentially free choice, cows did appear to crave more forage. Concentrate (grain) dry matter intake averaged 25.8 pounds per cow daily over all treatments while highest sustained daily concentrate intakes averaged over 28 pounds per cow per day. Concentrate consumption at all levels of wheat in the concentrate mixture was similar (P> 0.05), somewhat in contradiction to the Oregon (1940) research but in agreement with early Ohio (Ohio Bull. 576, 532) and Utah (Bateman, 1942) experiments where wheat was fed for a complete lactation. Rations containing 93 and 83% wheat were slightly less but not significantly less palatable than those containing lower levels.

Total milk production ranged from 55.3 to 62.4 pounds while production of 4% FCM ranged from 43.2 to 47.6 pounds per cow per day due to the low-fat tests. However, differences in milk production and composition, due to level of wheat in the concentrate ration, were not significant (P> 0.05). As anticipated, fat tests were depressed in the acceptability trial, due in part to the high ratio of concentrates to roughage (65:35) plus the high starch and low fiber intakes.

Consumption of digestible protein and total digestible nutrients was more than adequate (National Research Council Pub. 464, 1958) to meet the requirements of the cows. Excess TDN intake above requirements for production and maintenance were reflected in substantial daily gains on all treatments.

Results obtained in the lactation trial (Table 11) were very comparable to those from the acceptability trial as far as treatment differences were concerned. Concentrate (grain) intake averaged 45.3% of total dry matter intake over all treatments and the means of the treatments ranged from 15.4 to 17.4 pounds of concentrate per cow per day. Average consumption of the 93% wheat concentrate ration was only slightly lower than that of the 73% wheat mixture, while consumption of most wheat rations was greater, but not significantly, than for the control ration.

Although the mean concentrate consumption by treatment is shown in Table 11, many cows, in early lactation at the start of the trial, were eating over 24 pounds of concentrate per day, or an intake of 22 pounds of wheat per day, without digestive disturbances.

Energy intake was adequate, or nearly so, for most treatments, while mean crude fiber intake ranged from 5.5 to 5.7 pounds per cow daily or about 15% of the total daily dry matter intake, which has been indicated (Kesler and Spahr, 1964) as adequate to help sustain normal fat test. Although the crude protein content of the 93% wheat concentrate mixture was lower than the control (20% wheat), milk production was not affected as the level of crude protein intake on all treatments was in excess of requirements.

Average actual daily milk production over all treatments was 51.4 pounds with differences between treatments being non-significant (P> 0.05). Milk production expressed as 4% FCM, was comparable (P> 0.05) on all treatments. Although slight differences existed in fat test, with cows fed 73% wheat concentrate producing milk of a higher fat content than those fed 63 or 20% wheat, ration fiber level or intake was not related to fat test. Differences between treatments in pounds of fat produced daily were negligible (P> 0.05) as those cows with the lower test also produced slightly but not significantly more milk than other wheat groups. Changes in milk production have been associated with changes in milk composition, that is as milk production increases milk fat content decreases (Castle *et al* 1959; Holmes *et al* 1957). The effect of the different levels of wheat in the grain mixture on per cent milk non-fat solids and per cent protein were small and non-significant (P> 0.05). Similarly, differences in mean daily solids-not-fat and protein production due to treatment were non-significant. Although the cows fed the six wheat concentrate rations gained at slightly different rates, treatment differences did not appear to be related to TDN or protein intakes above requirements.

Bloat did occur with some of the animals at the outset of the trial. Since leafy, low fiber, high protein third-cutting alfalfa was believed to be the cause of the problem, 20% of each cow's daily allotment of Columbia Basin alfalfa was replaced with an equal amount of first-cutting Pullman alfalfa hay, which contained less leaf and more stem. In most cases this prevented further bloat; however with four cows it was necessary to replace from one-half to all of the leafy alfalfa with local Pullman alfalfa to prevent further bloat. "Bloat Guard" (poloxalene) was fed to so-called chronic bloaters during the later phases of the study. The greatest problem occurred with cows fed only 20% wheat in the concentrate. McArthur and Milimore (1964) have shown that a certain protein fraction in alfalfa is closely associated with bloat. It was also interesting that most bloat problems were encountered with cows in the feeding trial rather than with those fed higher levels of wheat in the acceptability trial.

Wheat vs. Other Feed Grains for Lactating Cows. In the second study, conducted by Tommervik and Waldern (1969), the nutritive value of Gaines soft white wheat was compared to that of corn, oats, barley, milo and a mixed concentrate ration for lactating cows. Digestion, acceptability, and lactation trials were conducted on the six concentrate rations in a manner as outlined in the previous study (McPherson and Waldern, 1969).

Each of the five single grain mixtures contained 95.7% of wheat, corn, milo, oats or barley plus 3.0% sodium tripolyphosphate, 1% trace mineralized salt plus vitamins A and D. The control ration contained 38% barley, 20% wheat mixed feed, 25% peas, 3.2% cottonseed meal, 9.5% molasses plus mineral, salt and vitamins as in the single grain mixture.

All grains were steam or dry rolled and then mixed with other ingredients and pelleted. The chemical composition of the rations offered and the total digestible nutrient content as determined in digestion trials with heifers fed at a 55:45 ratio of hay to grain are shown in Table 12.

Table 12. Proximate Analyses and Total Digestible Nutrient Content of Grain Mixtures.[1]

Feed	Dry matter	Crude protein	Crude fiber	Ether extract	N-free extract	Ash	TDN
				%			
Wheat	87.3	10.8	2.7	1.7	79.1	5.7	87.7
Corn	85.8	11.1	3.3	4.4	73.6	7.5	85.1
Milo	86.7	11.1	3.1	2.7	76.5	6.6	89.2
Oats	90.0	14.2	9.2	4.8	64.5	7.5	79.5
Barley	89.5	10.4	5.3	2.3	75.0	7.1	83.3
Control	90.2	16.4	6.0	1.8	67.2	8.5	84.3

[1] Values reported on a 100% dry matter basis.

In the acceptability trial during a three-week preliminary period alfalfa hay was adjusted to 1 lb. per 100 lb. body weight and concentrate consumption increased to *ad libitum* intake. Feed consumption and performance were then recorded for four to six weeks.

Following a three-week preliminary period in the lactation trial, hay was restricted to 1.7 lb. per 100 lb. of body weight and concentrate fed at an average of 1 lb. of concentrate (grain) to 2.7 lb. of the previous weeks mean daily fat-corrected milk production. The final ratio of concentrate to forage was 45:55. Experimental periods lasted four to five weeks.

Table 13. Daily Feed Intakes, Milk Production, and Composition and Body Weight Gain in the Lactation Trial for Cows fed Various Cereal Grains.

Criteria	Wheat	Corn	Milo	Oats	Barley	Control
Grain DM intake (lb)	23.3ab	21.6b	26.8a	26.6a	24.2ab	25.1ab
Total DM intake (lb)	34.3	33.7	38.7	38.3	36.3	36.5
CF intake (lb)	4.2c	4.6	4.6bc	5.9a	5.1b	5.1b
Total milk produced (lb)	53.2	57.2	60.9	57.6	52.4	51.0
4% FCM produced (lb)	40.7	46.8	49.9	47.9	42.4	42.2
SNF (%)	8.8	8.6	8.8	8.6	8.6	8.9
Milk protein (%)	3.5	3.3	3.2	3.1	3.3	3.5
Body weight gain (lb)	1.10	0.44	0.22	0.44	0.66	1.10

[abc] Values within the same category with a common superscript are not statistically different (P>.05).

The TDN values of the concentrate or grain mixes as determined in the digestibiltiy trials, when calculated on a 90% dry matter basis and the grain mix corrected for the additional salt and mineral, were similar to the values listed by Morrison (1956).

Daily feed intake and performance of the cows on the acceptability trial are shown in Table 13, while the intake and performance of those cows used in the lactation trial are shown in Table 14.

The major purpose of conducting the acceptability trial was to determine the relative palatability of the five cereal grains when they constituted over 95% of the concentrate or grain mixture.

Table 14. Daily Feed Intakes, Milk Production, and Composition and Body Weight Gain in the Lactation Trial for Cows fed Various Cereal Grains.

Criteria	Wheat	Corn	Milo	Oats	Barley	Control
Grain DM intake (lb)	17.4ab	16.7b	16.9ab	18.0a	17.4ab	17.8ab
Total DM intake (lb)	36.9ab	36.3b	36.5ab	37.6a	36.9ab	37.4ab
CF intake (lb)	6.6c	6.6c	6.6c	7.9a	7.0b	7.3b
Total milk produced (lb)	51.3	52.6	52.1	51.0	51.7	52.1
4% FCM produced (lb)	48.6	49.1	47.9	50.4	49.3	49.1
Milk fat (%)	3.93ab	3.83ab	3.77b	4.13a	3.97ab	3.91ab
Milk fat (lb)	1.98	1.76	1.76	1.98	1.98	1.98
SNF (%)	9.1a	9.0ab	9.0ab	8.8b	9.0ab	9.0ab
SNF (lb)	4.62	4.62	4.62	4.62	4.62	4.62
Milk protein (%)	3.69a	3.63ab	3.66ab	3.45b	3.58ab	3.53ab
Milk protein (lb)	1.76	1.76	1.76	1.76	1.76	1.76
Body weight gain (lb)	1.10	0.22	0.22	0.88	0.88	0.88

[abc] Values within the same category with a common superscript are not statistically different (P>0.05).

Under the system of restricted forage intake and free-choice concentrate, the concentrate to forage ratio averaged 67:33 for all treatments. As indicated by the results in Table 13, milo and oats were consumed in greatest amounts with the least tendency for cows eating these concentrates to go off feed, whereas cows fed corn in both the acceptability and lactation trial (Table 14) consumed the least amount of grain and were the most difficult to maintain on constant grain intake. The steam rolled and pelleted wheat was consumed at about the same level as the control ration and all other concentrate mixtures in both the feeding and acceptability trials. Jacobs (1931) and Copeland (1933) reported equal acceptance of wheat and milo by dairy cattle while Brown *et al* (1966, 1967) found pelleted milo and barley to be of equal palatability with no difference in the ability of the two grains to support milk production.

In both the acceptability and lactation trials daily milk yield, 4% FCM yield, solids-not-fat, and milk protein yield were not significantly different (P> 0.05). Per cent milk fat did not differ between treatments in the acceptability trial but cows fed the oat ration in the lactation trial had a higher fat test (P> 0.05) than those fed milo. Body weight gain was least for cows fed corn and milo.

In experiments by Seath and Henderson (1947), oats were found to compare favourably with corn or a mixture of corn and oats for lactating cows. Oats could replace most, if not all, the corn in the grain ration.

After reviewing early wheat feeding experiments with beef cattle Heinemann (1957) stated, "Usually on a pound-for-pound basis, cracked wheat, when fed at relatively limited levels, has had fully the value of cracked corn for fattening cattle." In many of the early wheat feeding experiments with beef cattle (Heinemann, 1957; Morrison, 1956) and even in more recent experiments (Oltjen, 1965; Bris and Dyer, 1967; Brethour, 1970), as the level of wheat in the diet has been increased and/or as the level of total concentrate fed was increased, consumption of wheat grain rations tended to decrease. Gains on wheat rations were often maintained comparable to or slightly less than those made when other grains were fed. However feed efficiency on wheat has often been greater than that obtained from other grains. Research by Oltjen (1965) with finishing steers fed all-concentrate rations of all-corn, all-wheat, or 60:30 ratios of each in a 98-day feeding trial, indicated that feed intake and performance of all groups was comparable to 70 days. After this time feed intake and performance of those animals fed over 60% wheat tended to decline below the other groups. There is also some indication that fiber level is important in maintaining adequate feed intake when wheat is fed (Bris and Dyer, 1967).

A greater incidence of digestive disorders is often evidenced among cows as the level of concentrate fed is increased (Ward and Wilson, 1967). This was true in the Washington State University experiments, and, irrespective of grain treatments, cows would sometimes suddenly reduce their grain intake with or without a corresponding decline in milk production. Feces were sometimes rather fluid in nature. Balch *et al* (1952) also reported this condition when low-hay high-grain diets were fed.

Milk fat percentages were considerably lower in the acceptability trial than in the lactation trial. This response was expected since generally low-roughage high-concentrate rations cause a depression in milk fat content (Balch *et al* 1952; Bishop *et al* 1963). However, Brown *et al* (1967) did not obtain a significant difference within seasons when lactating cows were fed milo or barley at 40:60 or 60:40 concentrate to roughage ratios. It is also interesting to note from Tables 13 and 14 that cows fed wheat concentrate produced milk with a higher protein and solids-not-fat content than those fed the oat concentrate, although daily yields of these milk fractions were not significantly different due to differences in milk production. Cows fed milo and corn gained significantly less than cows in all other groups.

From the two wheat studies conducted at Washington State University (McPherson and Waldern, 1969; Tommervik and Waldren, 1969), it is apparent that high-producing cows can be fed rather substantial levels of steam rolled and pelleted wheat. Rations containing 20% to 95% wheat were entirely satisfactory for lactating cows in short term trials as far as palatability, consumption, performance, and milk composition are concerned. Lactating cows fed a concentrate ration containing 96% wheat performed as well as those fed rations containing corn, milo, oats, barley or a mixed concentrate ration, with negligible differences between the concentrates as to palatability or effect on milk production and composition.

It is apparent however, that more research is required on the effect of wheat and the other cereal grains when fed at high levels in different physical forms and for a full lactation on performance of lactating cows and on the composition of the milk produced.

Wheat By-Products for Dairy Cattle

Wheat by-products have been popular feeds in dairy concentrate rations for over 70 years. Wheat bran, wheat-mixed feed, and wheat shorts have been some of the most popular by-product feeds used in dairy cow rations. Other by-products, (for example, wheat red dog, wheat white shorts, and middlings), are used in calf meals or calf starter rations because they are higher in energy and lower in fiber content than wheat bran.

Most of the wheat by-products fed to dairy cattle are normally fed in combination with other cereal grains and protein supplements. They are an excellent natural source of phosphorus and they are higher in protein than the whole grain or the starchy portions of the kernel.

Bran has been used for years to supply bulk to the concentrate ration and to improve the palatability of grain mixtures when a large proportion of the grains were ground and fed in meal mixtures. Bran and oats were often used interchangeably. Bran was always recommended for cows just prior to and after calving. However, with greater use of rolled grains and pelleted grain mixtures, larger herd size, and greater labor demands and costs, less attention has been paid to special rations and feeds at calving time, with the result that often the milking ration is used for dry cows as well as milking animals. However, a recent survey of dairy departments at state universities and dairy extension personnel reveals that wheat mixed feed (mill run), middlings, bran, red dog, and other wheat by-products continue to be used up to about one-third of the concentrate mixture in wheat growing and adjacent areas throughout North America and in other parts of the world, as long as the price warrants their inclusion.

Little information exists on the value of the wheat milling by-produts when they constitute the major portion of the concentrate mixture. Battaglini (1954) compared defatted wheat bran and regular wheat bran when included in rations for lactating cows at 60% of the concentrate mixture over a four-month period. Only small differences were noted in weight gain and performance between cows fed the two types of bran as a major portion of the concentrate.

Wheat Middlings. The acceptability of wheat middlings for dairy cattle was evaluated in a preliminary study conducted some ten years ago at the Cornell University Experiment Station (Loosli, 1970). When middlings were fed in a finely ground form at much over 40% of the concentrate mixture a palatability problem was encountered. The addition of molasses up to 9% or 10% of the concentrate overcame, in part, much of the palatability problem. When the middlings were pelleted, lactating cows accepted the material well as the only concentrate.

Wheat Mixed Feed. Wheat mixed feed is available for feed purposes in large amounts in the Pacific Northwest as a by-product of the soft wheat industry. Waldern and Cedeno (1970), at Washington State University, investigated the nutritive value and acceptability of wheat mixed feed in comparison with rolled barley and a mixed concentrate ration for lactating cows in meal and pelleted forms. The composition of the rations compared is shown in Table 15.

The cereal grains were steam rolled at atmospheric pressure for approximately six seconds before mixing. The rations to be pelleted were passed through 4.83-mm-diameter dies of a California pellet mill under a steam pressure of 6.33 kg/cm^2 for approximately five seconds. No binding agent was used. Wheat mixed feed formed a good firm pellet.

Alfalfa was the only forage offered. As in the previous Washington studies on soft wheat, digestion trials, an acceptability trial and a lactation trial were conducted on the six rations. The numbers of animals and methods of feeding and management were similar to those outlined in the research of McPherson and Waldern (1969) where different levels of wheat were used in the concentrate mixture.

The concentrate to roughage ratio in the digestion trials and lactation trial averaged 45:55, while it averaged 70:30 for cows fed in the acceptability trial. After the three-week preliminary period in the lactation trial, grain or concentrate mixtures were fed according to forage intake (1.75 lb. per 100 lb. body weight) and energy requirements for maintenance and milk production based on Morrison's upper levels (1956).

Rumen volatile fatty acids were determined at hourly intervals for 12 hours following feeding on samples drawn from three rumen fistulated steers fed the six experimental rations at a 45:55 concentrate to forage ratio.

Table 15. Composition of Meal and Pelleted Grain Rations.[1]

	Barley	Wheat mixed feed	Control
Ingredient	Meal and pellets	Meal and pellets	Meal and pellets
		%	
Steam-rolled barley	98.0		40.0
Wheat mixed feed		98.0	
Steam-rolled wheat			20.0
Ground peas			25.0
Cottonseed meal (41% protein)			3.5
Molasses			9.5
Steamed bonemeal	1.0	1.0	1.0
Trace-mineralized salt	1.0	1.0	1.0

[1] Each ration contained 4,494 IU vitamin D/kg of mix.

The average chemical composition of the feeds offered in the experiments is shown in Table 16, while the digestion coefficients and total digestible nutrient content are given in Table 17.

Crude protein digestibility of meal rations was slightly but not significantly greater for meal than for pelleted rations. The digestibility of nitrogen-free extract of wheat mixed feed rations was lower ($P < 0.05$) than for the barley or control mixtures. The digestion coefficient for energy of wheat mixed feed in both meal and pelleted forms was lower ($P < 0.05$) than for the other mixtures, whereas the TDN content of wheat mixed feed meal was lower than for wheat mixed feed pellets and all other rations ($P < 0.05$). Barley meal and pellets had a higher TDN content than wheat mixed feed rations ($P < 0.05$).

In the acceptability trial where hay was restricted to 1 lb. per 100 lb. of body weight and grain rations fed free choice, cows offered wheat mixed feed meal consumed less of this ration than cows offered the other five rations ($P < 0.05$) (Table 18). This indicated lower palatability of wheat mixed feed in the meal than in the pelleted form, plus the excellent acceptance of pelleted wheat mixed feed.

Digestive disturbances were observed in some cows consuming higher levels of grain, but these were associated mainly with changing rations too rapidly at the beginning of the trial. Least difficulty was encountered with wheat mixed feed.

Since the crude fiber of wheat mixed feed concentrates was higher and the nitrogen free extract lower than in other concentrates (Table 16), crude fiber intake on these rations exceeded that when other concentrates were fed. With greater fiber intake and lower starch (NFE) intake, milk fat test was maintained at a higher level in the acceptability trial when wheat mixed feed was fed than when other concentrates were

Table 16. Proximate Analysis of Rations Fed.

Ration	Dry matter	Crude fiber	Crude protein	Ash	Ether extract	N-free extract
	100% Dry mater basis					
			%			
Alfalfa hay	86.9	32.0	17.3	9.5	3.6	37.5
Rolled barley						
Meal	87.1	5.5	10.4	3.7	2.6	77.8
Pellets	87.7	5.8	11.9	4.4	2.8	75.0
Wheat mixed feed						
Meal	87.7	8.9	16.7	6.9	5.0	62.5
Pellets	88.5	9.4	17.1	7.1	4.9	62.4
Control ration						
Meal	87.1	5.0	15.1	4.9	2.5	71.4
Pellets	88.4	5.1	15.7	5.2	2.5	71.5

Table 17. Mean Digestion Coefficients and Total Digestible Nutrients Content of Alfalfa Hay and Concentrate Rations.

Feed	Dry matter	Crude protein	Crude fiber	Ether extract	N-free extract	Energy	Total dig. nutr.
				%			
Alfalfa hay	62.3	76.6	45.5	43.1	73.6	60.3	56.5
Rolled barley							
Meal	83.8bc	86.5	57.2	88.3	89.4b	86.5b	88.3c
Pellets	85.9c	81.6	52.2	86.4	90.1b	83.7b	86.9c
Wheat mixed feed							
Meal	78.9ab	86.6	55.5	87.7	77.8a	79.3a	76.6a
Pellets	77.3a	82.6	54.1	96.1	81.2a	78.1a	82.4b
Control ration							
Meal	85.8c	79.7	54.1	82.7	90.2b	84.4b	85.4bc
Pellets	86.3c	76.7	51.4	92.7	92.2b	85.0b	85.2bc

[abc] Treatment means with a common letter within a column are not statistically different ($P > 0.05$).

fed. These same differences in concentrate composition also help explain the differences obtained in milk fat depression when concentrate rations fed as a meal were pelleted. Pelleting wheat mixed feed meal resulted in less fat depression than when the barley or control concentrate were pelleted. Changes in milk protein and SNF percentages from pre-trial levels were small and non-significant in relation to treatment.

In the lactation trial grain dry matter intake, as a percentage of total dry matter intake, averaged 45.8% for the six treatments (Table 19). Since the estimated energy content of wheat mixed feed (Morrison, 1956) was lower than that of other concentrate rations, the amount fed in the lactation trial should have exceeded that of other concentrate rations. However, as shown in Table 19, the consumption of wheat mixed feed in a meal form was significantly lower ($P < 0.05$) than the same concentrate in the pelleted form. Thus the palatability was less for wheat

Table 18. Mean Daily Nutrient Intake, Body Weight Change, and Milk Production and Composition Changes of Cows on the Acceptability Trial Meal and Pelleted Concentrates.

Criteria	Treatments					
	Rolled barley		Wheat mixed feed		Control ration	
	Meal	Pellets	Meal	Pellets	Meal	Pellets
Grain DM intake	28.5b	27.6b	20.7a	26.6b	26.1b	27.4b
Grain intake, percent of total DM	71.2	72.2	61.0	68.9	71.7	70.1
Total CF intake (lb)	4.9a	4.8a	6.1b	6.1b	4.7a	5.2ab
CF, percent in the DM	12.8a	12.5a	18.0c	15.8b	12.9a	13.2a
Body weight change (lb)	0.8b	2.7cd	—1.3a	0.7b	1.2cd	3.0d
Total milk produced (lb)	51.4	46.1	40.3	43.0	48.7	48.3
Difference*	2.4b	—0.4ab	—2.4a	—1.3ab	1.8b	2.2b
4% FCM produced (lb)	42.0	32.4	35.9	35.9	39.6	33.7
Difference	0.2c	—11.1a	—6.4abc	—4.5abc	—1.4bc	—7.9ab
Milk fat (%)	2.8	1.9	3.3	2.9	2.7	2.0
SNF (%)	8.4	7.8	8.1	8.2	8.5	8.6
Difference	—0.1	—0.4	—0.2	—0.0	—0.1	0.0

[abcd] Treatments of a given variable within a row with different superscripts are statistically different ($P \leq 0.05$).
* Difference refers to mean change in milk production and composition from pretrial levels.

mixed feed as a meal than for the pelleted form, similar to the results obtained in the acceptability trial. Some cows ate all the wheat mixed feed offered as a meal while other cows demonstrated a marked dislike for the meal, with smaller variations in the lactation trial than observed in the acceptability trial.

Average daily milk production and 4% FCM production (except for cows fed the control ration) (Table 20) was higher from cows fed the pelleted form of each concentrate than from cows fed the meal form ($P < 0.05$).

In most instances the percentage of milk fat was lower for cows fed pelleted rations than for animals fed meal rations. Cows fed wheat mixed feed meal had a slightly but not significantly higher fat test than all other groups, while the pellet fed cows showed a fat depression similar to that of other groups. Due to diametrically opposed factors of increased total milk production and reduced fat test on pelleted rations, daily fat production was comparable across treatments.

Non-fat solids (SNF) content of milk produced on each treatment was not significantliy different. However, due to differences in actual milk production, cows fed pelleted concentrate rations produced more pounds of SNF daily than those fed meal. A similar situation existed for daily protein production.

Cows in all groups gained weight except those fed wheat mixed feed meal, reflecting the lower intake and the lower energy content of wheat mixed feed meal compared to other rations.

Rumen volatile fatty acid (VFA) studies (Table 21) revealed a lower production of rumen VFA in nearly all cases when meal rations were fed than when pelleted rations were fed. Similarly, the molar percentage of rumen acetate was higher on pelleted than on meal rations (except for wheat mixed feed) while the reverse situation occurred for rumen butyrate and to a somewhat lesser extent, rumen propionate.

These results are contradictory to earlier findings of other investigators (Bishop *et al* 1963; Yamdagni *et al* 1967). However in the present experiments rumen samples were collected hourly rather than once daily as in many other studies.

From the foregoing trials it is rather evident that wheat mixed feed can be used as the only cereal ingredient in the concentrate ration for lactating cows. Many other wheat by-products may be used to a greater extent in concentrate rations for lactating cows. The blending of various wheat components, for example, bran and shorts and other by-products, would permit their use if prepared and fed in a pelleted form. Further research is required to study the suitability of these products for lactating cows.

Table 19. Mean Daily Nutrient Intake of Cows on the Lactation Trial Fed Meal and Pellet Concentrates.

Criteria	Treatments					
	Barley		Wheat mixed feed		Control ration	
	Meal	Pellets	Meal	Pellets	Meal	Pellets
Hay DM intake (lb)	19.6	19.5	19.6	19.5	19.8	19.5
Grain DM intake (lb)	15.7a	15.8a	16.7a	18.6b	16.5a	16.8a
Grain intake, % of total DM	44.6a	44.1a	46.1ab	48.6d	45.4ab	46.3bc
TDN intake above required (lb)	—1.7	—1.9	—2.0	—0.7	—0.8	—1.6
Total CP intake (lb)	7.1a	7.1a	7.9b	7.7b	7.1a	7.0a
CF, % in the DM	19.8ab	20.2b	21.8c	20.2b	19.7ab	19.1a
Total DP intake (lb)	4.1a	4.2a	4.8c	5.2d	4.6b	4.7cd
DP intake above required (lb)	1.2	1.2	1.9	2.2	1.7	1.7

[abcd] Treatments of a given variable within a row with different superscripts are statistically different ($P < 0.10$).

Table 20. Mean Daily Milk Production, Milk Composition, and Body Weight Change of Cows on the Lactation Trial Fed Meal and Pelleted Concentrates.

Criteria	Treatments					
	Barley		Wheat mixed feed		Control ration	
	Meal	Pellets	Meal	Pellets	Meal	Pellets
Milk produced (lb)	44.9a	48.8c	44.4a	48.3bc	47.1b	51.0d
4% FCM produced (lb)	42.1a	44.9a	42.3a	44.8ab	44.3ab	45.2b
Milk fat (%)	3.66bc	3.59abc	3.77b	3.55ab	3.65bc	3.40a
Milk fat (lb)	1.6	1.7	1.6	1.7	1.7	1.7
SNF (%)	8.60	8.56	8.58	8.50	8.61	8.65
SNF (lb)	3.9ab	4.2c	3.8a	4.1bc	4.1bc	4.4d
Milk protein (%)	3.41a	3.50ab	3.45ab	3.50ab	3.55ab	3.63b
Milk protein (lb)	1.5ab	1.7c	1.5a	1.6bc	1.6c	1.8d
Body weight change (lb)	0.7ab	0.5ab	—0.2a	1.2b	0.7ab	0.5ab

[abcd] Treatments of a given variable within a row with different superscripts are statistically different ($P < 0.10$).

Table 21. Effect of Meal and Pelleted Barley, Wheat Mixed Feed, and Control Grain Mixtures on Diurnal Mean Rumen Volatile Fatty Acids.

Ration	Total volatile fatty acids	Volatile fatty acids				
		Acetic	Propionic	Butyric	Valeric	C_2/C_3
	(μ moles/ml)		(molar %)			
Barley						
Meal	66.8b	66.8c	14.8a	13.1b	2.87b	4.51
Pellets	82.6c	70.8d	14.7a	10.9a	1.68a	4.81
Wheat mixed feed						
Meal	50.2a	63.9b	17.2c	12.9b	2.85b	3.71
Pellets	60.4ab	65.9bc	16.8bc	11.1a	3.25bc	3.92
Control ration						
Meal	59.5ab	57.2a	17.8c	18.7c	4.02d	3.21
Pellets	85.6c	66.0bc	15.4ab	12.9b	3.54cd	4.28

[abc] Treatment means with a common letter within a column are not statistically different.

Wheat and Wheat By-Products for Calves

Wheat and wheat by-products like bran, middlings, wheat mixed feed, and wheat shorts have all been used in limited quantities by dairymen as part of calf starter and calf grower rations. The quantities of by-products used have ranged from one-fourth to one-third of the grain mixture. Wheat has also been used as the only cereal grain in starter rations for early weaned calves. Asplund (1961), at the University of Alberta, studied the value of a simple calf starter containing 64% wheat, 28% soybean meal, 4% dehydrated alfalfa meal, minerals, and vitamins for calves weaned from whole milk at five weeks of age. The starter contained 20% digestible protein and 72% TDN, 4% crude fiber, and 0.65 and 0.60% calcium and phosphorus respectively. Whole milk was fed to five weeks of age up to a maximum of 250 pounds. Two lots of calves with five calves per lot were fed either a commercial calf starter or the 64% wheat starter, free choice to four months of age. Later, a second lot of 10 calves was fed the high wheat starter. Water and good quality hay were available at all times. The results are presented in Table 22. From these results Asplund concluded that dairy calves fed limited whole milk and a simple calf starter of wheat and soybean meal would grow as satisfactorily and economically as calves fed an expensive commercial calf starter.

In recent studies at the University of Alberta, Grieve and Winchell (1970) compared a wheat calf starter ration with a barley starter for dairy calves weaned from milk replacer at four weeks of age. Soybean meal (28% of the starter) was the only protein source in the wheat starter while 5% fishmeal and 0.5% urea were the nitrogen sources used in the barley starter. The crude protein content of the wheat and barley starters were 22% and 16%, respectively. Brewers yeast was added at 1.0% of both diets plus 0.5% of a vitamin-antibiotic premix. Daily gains between birth and 60 days averaged 0.96 pound on the wheat starter compared to 0.74 pound on the barley starter. The difference was significant statistically ($P < 0.05$). Calves fed wheat meal consumed more feed and required less feed per pound of gain than those fed barley meal. However, the feed cost per pound of gain for calves fed wheat starter was 1.7 cents more than for those fed barley starter.

Table 22. Weight Gains of Early Weaned Calves Fed a 64% Wheat Starter Compared to a Commercial Starter.

	Commercial starter	Experimental starter	
		Lot 1	Lot 2
Number of calves	5	5	5
Average weight at 5 weeks (lb)	123	123	
Average weight at 4 months (lb)	259	297	275
Average daily gain 5 weeks to 4 months (lb)	1.55	2.00	1.78

In an experiment conducted by Waldern (1970) at the Research Station, Agassiz, B.C., wheat mixed feed was compared with five other starters as a complete feed for Holstein calves weaned at five weeks from whole milk. The rations compared were:

1. Complex 20% protein calf starter containing milk and cereal products fed up to four pounds per calf daily plus chopped local grass hay to appetite.
2. Wheat mixed feed fed to appetite, no hay.
3. Dehydrated grass fed to appetite, no hay.
4. Complex starter (Ration 1) mixed equally with dehydrated grass and fed to appetite, no hay.
5. Simple barley-soybean meal ration fed up to four pounds daily plus free choice hay.
6. Dehydrated grass, barley, beet pulp and soybean meal fed to appetite, no hay.

All grain rations contained Vitamins A and D, salt and minerals, and were pelleted. Six male calves were fed each ration in digestion trials conducted between the 4th and 5th week and again between the 12th and 13th week of age to determine nutrient digestibility and energy utilization. A minimum of 24 calves were used on each treatment over two years. Calves were allotted equally to treatments during a given season. Performance on each treatment is shown in Table 23.

Calves fed dehydrated grass and wheat mixed feed as the only concentrate rations gained at a slower rate than calves in all other groups.

There was little difference in rate of gain between calves fed the complex ration plus hay and those fed barley-soybean meal plus hay or those fed the complete ration of dehydrated grass-beet pulp-barley-soybean meal. Daily gains of calves in all treatments were depressed during the second year of the trial due to the presence of enzootic pneumonia in almost all calves. Daily gains on the wheat mixed feed ration and on the dehydrated grass ration were close to 1.1 pounds per day to 12 weeks of age before enzootic penumonia was a problem. This rate of gain is nearly satisfactory for replacement heifers of this age. Cost of the wheat mixed feed was about $40.00 per ton less than the complex starter. Calves offered wheat mixed feed as a complete ration consumed less feed than those offered the complete ration of dehydrated grass-beet pulp-barley-soybean meal. The use of molasses with the wheat mixed feed could possibly have increased consumption. Laboratory analyses are presently being conducted on feed and fecal samples from calves used in the digestion trials in order to determine energy utilization, starch utilization, fiber digestion, and nitrogen balance at 4 and 12 weeks of age.

Table 23. Feed Intake and Performance of Calves Fed Simple Starter Rations.

Ration		Milk intake to 5 wks	Grain intake	Hay intake	Average daily gain
		lb			
1. Complex + hay	— 12 wk	312	179	37	1.29
	— 16 wk		294	90	1.37
2. Wheat mixed feed	— 12 wk	313	192		0.90
	— 16 wk		341		0.90
3. Dehydrated grass	— 12 wk	310	202		0.88
	— 16 wk		366		0.98
4. Complex + dehy. grass	— 12 wk	308	212		1.10
	— 16 wk		399		1.27
5. Barley-soybean meal + hay	— 12 wk	314	182	28	1.27
	— 16 wk		292	28	1.27
6. Dehy. grass, beet pulp, barley, soybean meal	— 12 wk	327	222		1.23
	— 16 wk		405		1.38

It is quite possible that many other wheat by-products feeds could be used to a greater extent as all or part of a complete ration for early weaned calves. Amino acid supplementation (Moran and Summers, 1970) as well as supplementation with certain vitamins may be necessary if maximum use is to be made of these wheat by-products in starter rations for early weaned calves where limited or no green roughage is fed.

Additional research is required on the effect on processing (steaming, cooking, flaking, popping, etc.) many of the wheat by-products on the digestion and utilization of the various carbohydrate and protein fractions by the early weaned calf (Lima, *et al,* 1968; Shuh, *et al,* 1970, Walker, 1970, USDA). Processing could enhance acceptability and utilization and thus improve rate and economy of gain of young calves (Lima *et al,* 1968; Schuh *et al,* 1970). At the same time feed and labor costs could be reduced during rearing through the use of a complete ration.

Preparation of Wheat for Dairy Cattle

General recommendations derived from early research on feeding wheat to dairy and beef cattle were to feed wheat in a coarsely ground or crushed form. Care was to be exercised that wheat was not finely ground or floury. Early research from the University of Guelph (Rennie, 1960) recommended that rolled wheat be used in place of ground wheat as the rolled wheat made the ration light and bulky and improved palatability. Recommendations to dairymen of Australia (Hewitt, 1944) when limited forage was available and wheat was fed in large amounts were to roll the wheat.

In the series of studies by the Washington State group on wheat for lactating cows (McPherson and Waldren, 1969; Tommervik and Waldern, 1969), rations containing wheat were first steam or dry rolled, then pelleted. This probably affected the palatability of the rations when offered essentially free choice in the acceptability trials. Far more research has been conducted recently on the use of different physical forms of wheat in rations for beef cattle. Rations have been fed as all-concentrate rations or as different combinations of concentrate and roughage. These papers will be reviewed by other members of this Symposia. However, Oltjen (1965) reported that coarsely cracked or rolled wheat produced best results in all-concentrate rations for beef cattle. Bris and Dyer (1967) found no difference in feed consumption by steers fed a 50% soft white wheat (70% concentrate ration) in a pelleted, dry rolled, or steam rolled form. Walker (1970) recently discussed the processing and advantages of popped wheat that had been subsequently rolled and fed to finishing steers.

Further research is required on the use of processed wheats in dairy cattle concentrate rations. The effect of different forms of processed wheats, when fed at various concentrate to roughage ratios, on ration acceptability, digestive disturbances, and milk production and composition should receive early attention by nutritionists if wheat is to be used to a greater extent in dairy cattle rations.

Summary and Conclusions

The literature on the nutritive value of wheat for dairy cattle was reviewed. Much of the research conducted in North America dates to periods (the late 1920's, early 1930's, early 1940's, and mid 1960's) when wheat was a surplus commodity and available for livestock feed at a price competitive with other feed grains. In the early research with wheat for dairy cattle, actual levels of wheat consumption were low and seldom exceeded four to seven pounds. In recent research dairy cows have been reported to consume in excess of 22 pounds of wheat per day in a rolled and pelleted form without digestive disorders after having been adjusted to concentrate mixtures containing up to 95% wheat and at a concentrate to roughage ratio from 45:55 to 67:33.

Wheat compares favorably with the other feed grains for dairy cattle and can replace corn, barley, milo, or oats in the concentrate mixture.

Wheat can be used as the only cereal grain in a concentrate ration for lactating cows. However, fewer problems will probably be encountered by the average feeder if wheat forms not over 65% of the concentrate mixture. Good feeding and management practices are required when high levels of any cereal grain are fed to lactating cows. When cows are switched from a concentrate (grain) ration with no or a low level of wheat (30%) to a high level of wheat, the adjustment to the new mixture should be made gradually over a two-week period; especially for cows consuming large amounts of concentrate.

Preparation of the concentrate ration is important if cows are to maintain maximum intakes. Wheat should be rolled or ground coarse. Pelleting will also enhance acceptability and consumption of concentrate rations containing a high proportion of wheat. Wheat mill feeds like middlings, and wheat mixed feed, can be used as the main cereal source in the concentrate ration for lactating cows if fed in a pelleted form.

Wheat can be grown very successfully as a forage crop and fed as pasture, silage, or hay to lactating cows.

Wheat or wheat mixed feed properly supplemented with vitamins and minerals, can be used as the only cereal component in calf starter rations for early weaned calves.

Attention must be paid to the mineral balance and levels of the whole ration (roughage plus concentrate) when large amounts of wheat or any cereal grain are used in the concentrate mixture and fed to lactating cows.

Further research is required on different methods of preparing and processing wheat for dairy cows and calves and the effects of processed wheats on feed consumption, digestive disorders, milk production and composition, body weight gain, and feed efficiency.

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The Use and Value of Wheat In Beef Cattle Feeding

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Since wheat is used predominantly for human food, there is not as much information about feeding wheat to beef cattle as has been accumulated about other grains. However, the failure of domestic usage and export demand to keep pace with expanded production potential (29) has stimulated interest in feeding wheat to livestock. Even though this seems a logical outlet for wheat when prices are low, feed usage has not been greatly increased. Probably this is due to several factors. Orderly marketing channels for feed wheat are absent because of low levels of "free" wheat not under government loan and because wheat has a greater tendency to move into terminal storage than other grains. There is some reluctance to consider wheat as a feed grain rather than human food (for ethical reasons as well as possible changes in federal agricultural programs). Uncertainty as to proper management of wheat in beef cattle rations probably decreases its usage. The depressed intake of wheat-containing rations, even though associated with increased efficiency, can be disconcerting to the cattle feeder. It is difficult to assign a definite relative value to wheat to determine if it is competitively priced. Wheat does not seem to respond to the various heat treatments that are readily available for processing other grains.

When an oversupply of wheat caused it to be priced competitively with other feed grains, interest in feeding wheat has brought spurts of wheat-feeding research. These efforts have become more intense in recent years. The purpose of this paper is to briefly review and' attempt to amalgamate the results of these experiments.

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Table 1. Relative Performance of Wheat and Other Feed Grains—Summary of 87 Comparisons.

Control grain	Average daily gain, %		Average air-dry intake, %		Pounds concentrate replaced by 1 pound wheat		Number of comparisons	
	Wheat alone	Wheat mixed	Wheat alone	Wheat mixed	Wheat alone	Wheat mixed	Wheat alone	Wheat mixed
Corn	97	102	91	96	1.09	1.17	30	12
Milo	90	96	84	90	1.15	1.22	4	9
Barley	98	98	92	97	1.10	1.04	18	11
Rye	104	---	98	---	1.06	---	3	---

References:

Control grain	*Wheat alone*	*Wheat mixed*
Corn	1, 3, 4, 5, 23, 24, 39, 40, 41, 59, 64, 66, 67, 72	1, 4, 66, 72
Milo	9, 10, 39, 61	6, 9, 10, 12, 61
Barley	21, 28, 39, 41, 42, 55, 57 58 59, 71	21, 28, 42, 55, 59, 71
Rye	2	

Most experimental trials with wheat have been comparisons with other grains to define the relative value of wheat for feeding beef cattle. A summary of 87 such comparisons is shown in Table 1. These were conducted prior to 1966, involved rations relatively high in fiber content, and are detailed in a Kansas review bulletin (6). The list includes all comparisons that could be located in the literature up to that time except a few that were excluded because the wheat was not ground (34, 35, 62, 65, 68, 70) or there seemed to be flaws in the experimental design (44, 45, 53, 56). The data were standardized by adjusting average gains for differences in dressing precent, relating intake on an air-dry basis, and reducing relative feed efficiency to a common denominator by citing the pounds concentrate replaced by substituting 1 pound wheat into the ration. Approximate concentrate equivalents of other ration ingredients were estimated from net energy values (48). However, the relative values of wheat presented in Table 1 would also include nutritional effects other than net energy.

Wheat has been compared with corn more frequently than with other grains. As shown in Table 1 total consumption of wheat rations was 91% of corn rations and average daily gain was slightly reduced; however, wheat-containing rations were more efficient and an average of 1.09 pounds corn was replaced by each pound of wheat used. (Morrison (52) summarized nine comparisons and concluded wheat was worth 9% more than corn.) In only two of the 30 comparisons was more wheat than corn required per unit gain. The relative gain of wheat rations ranged from 80% to 108% of corn rations.

Most comparisons of wheat and barley have been made in the Northwest. In the 18 trials there was practically no difference in rates of gain for cattle fed barley or wheat. Cattle receiving wheat averaged 1.6 pounds less intake per day and were 10% more efficient than those fed barley (Table 1).

In three Nebraska trials (2) feed value of wheat was greater than rye (Table 1). Rye was definitely inferior to wheat in a Minnesota test (43) but this rye contained ergot. Indirect evidence (46) suggests wheat and triticale are about equal in feeding value.

The most consistent observation in comparisons of wheat with other grains is the reduced intake with wheat. In only three of the 55 comparisons (Table 1) did cattle eat more when fed wheat alone and in those instances the difference was negligible. This was especially apparent in comparisons of wheat and milo (Tables 2, 3 and 4). When wheat alone was fed, the 16% average reduction in intake was enough to depress rate of gain 10%, although wheat rations were more efficient. However, by limiting wheat to 50 percent of the grain in the ration, feed intake was maintained at more satisfactory levels and rate of gain was not depressed.

Table 2. Comparison of 50% Wheat and 100% Wheat in Steer Fattening Rations (Summary of 2 Fort Hays Trials—9, 10).

Treatment	Milo	50% Milo & 50% Wheat	Wheat
Average intake, lb.	35.8	32.0	29.3
Average daily gain, lb.	3.12	3.10	2.88
Average feed efficiency			
Average feed efficiency (Lb. feed/cwt gain)	1146.	1034.	1018.
Lb. milo replaced by 1 lb. wheat		1.32	1.20

Table 3. Graded Levels of Wheat in Steer Fattening Rations (61).

Treatment					
Milo, %	100.	75.	50.	25.	-----
Wheat, %	-----	25.	50.	75.	100.
Average intake, lb.	24.4	24.2	22.7	20.7	21.0
Average daily gain, lb.	2.83	2.85	2.72	2.60	2.62
Average feed efficiency	863.	848.	835.	792.	801.
Lb. milo replaced by 1 lb. wheat	-----	1.09	1.11	1.20	1.13

Table 4. Comparison of Sorghum Grain and a Mixture of Wheat and Sorghum Grain in High-Roughage (43 Percent) Fattening Rations. (Summary of 6 Fort Hays Trials—6, 9, 10, 12).

Treatment	Milo	50% Milo & 50% Wheat
Average intake, lb.	29.5	26.6
Average daily gain, lb.	2.77	2.70
Average feed efficiency	1065.	985.
Lb. milo replaced by 1 lb. wheat		1.24

When wheat is mixed with other grains and fed in limited amounts, it improves feed efficiency proportionately more (Table 1) than when fed alone. This seems especially true of corn-wheat and milo-wheat combinations, and recent data from California (27) (not included in Table 1) shows a mixture of barley and wheat to stimulate gain compared to either grain fed alone.

Attempts to improve palatability by using high levels of silage (1, 5, 22, 59, 66, 67, 72) or adding molasses (1, 25, 60, 64) have been unfruitful. Adding 4% fat to wheat rations has improved performance (19, 58) but appears to involve other factors than intake. In an Idaho study (19) the response to fat was greater when added to a ration containing 70% rather than 50%.

Palatability does not seem to be as much a problem with softer wheats used in California and the Pacific Northwest. In a Washington test (28) Gaines, a soft white winter wheat, was more readily consumed and produced better performance than Burt, a hard red winter (both are weak gluten wheats) (Table 5). Soft wheats have been satisfactorily used as the only grain in high-concentrate and all-concentrate rations (19, 21, 27, 32, 33, 37, 47, 54, 57, 58, 59). Nearly all reports of digestive upset and difficulty in keeping cattle on feed have come from the hard wheat areas (3, 9, 10, 70, 73, 74). Recent Nebraska studies (75) indicate lactic acid production, a factor in rumen acidosis, may be higher with hard than soft wheats.

Table 5. Gaines vs. Burt Wheat (28).

Treatment	Gaines	Burt
Average intake, lb.	23.4	21.8
Average daily gain, lb.	2.89	2.51
Average feed efficiency	810.	870.

Table 6. Golden-50 vs. Red Chief Wheat (16).

Treatment	Milo	Golden-50	Red Chief
Average intake, lb.	25.7	26.3	25.5
Average daily gain, lb.	2.77	3.20	2.93
Average feed efficiency	925.	820.	873.

Factors other than kernel softness may cause differences in feeding value among types and varieties of wheat. Lambs in a Washington study (36) grew faster and more efficiently when fed Baart, a hard white spring, than Turkey, a hard red winter, or Jenkins, a soft white winter. At the Hays station performance on Golden-50 was superior to Red Chief wheat (Table 6). Both are hard red winter wheats although the Golden-50 was superior to Red Chief wheat (Table 6). Both are hard red winter wheats although the Golden-50 used was much softer than the Red Chief. On the other hand, the former is also a stronger gluten wheat though crude protein content was the same. When fed to sheep, nitrogen retention was greater with Golden-50. Ration dry matter digestibility was significantly increased when Golden-50 was compared with Gaines, a soft white winter (preliminary data from our laboratory). In this study wheat comprised 18% of a high-roughage ration. A general observation of the accumulated data suggests that soft wheats may not improve efficiency of gains as much as wheats of the Great Plains; however, this observation may be confounded by differences in overall management such as ration crude fiber content.

In 1958 the National Research Council (49) published a compilation of feedstuff analyses that listed the average crude protein content of 1663 samples of wheat as 12.5% (87.5% dry matter). These samples represented the several wheat-growing sections of the United States and the various types of wheat. The same publication reported that 1873 samples of corn contained 9% protein, 1400 samples barley, 11.5%, and 1160 samples milo, 11%. A more recent survey (50) reflects the reduction in crude protein content (to 9%) of milo since the advent of irrigation and hybrids. While similar changes in wheat production may decrease its average crude protein content and while advances in ruminant nutrition may create greater reliance on cheaper non-protein-nitrogen sources, savings can often be effected by reducing supplemental protein when wheat is a ration ingredient. Several feeding trials (1, 10, 12, 13, 67) prove that wheat protein is well utilized by cattle (Table 7). When wheat is used in feed formulations, protein values calculated by the milling industry (N times 5.7) should be adjusted to values comparable to other feedstuffs (N times 6.25). Adding low levels of wheat seemed to improve both urea and biuret utilization in high-silage growing rations (Table 8).

Table 7. Effect of Omitting Supplemental Protein in Wheat Containing Fattening Rations. (Summary of 3 Fort Hays Trials—10, 12, 13).

Treatment	50% Milo & 50% Wheat	50% Milo 50% Wheat 1½ lb. cottonseed meal
Average intake, lb.	25.8	25.9
Average daily gain, lb.	2.63	2.67
Average feed efficiency	973.	963.

Table 8. Effect of Substituting Wheat for Milo on Utilization of Urea or Biuret in High-Roughage Rations (17).

Nitrogen source	Biuret		Urea		CSM	
Grain	Milo	Wheat	Milo	Wheat	Milo	Wheat
Average intake, lb.	17.3	17.7	17.4	17.6	18.1	18.4
Average daily gain, lb.	1.53	1.81	1.61	1.80	1.84	1.98
Average feed efficiency	1132.	979.	1078.	979.	987.	927.
Percent change when wheat replaced milo:						
Average daily gain		+18%		+11%		+8%
Average feed per unit gain		—14%		— 9%		—6%

Wheat does not appear to respond to heat processing (20, 32, 33). California workers (Table 9) found that popping and steam pressure processing slightly increased dry matter digestibility but did not improve feedlot performance. Arizona workers (38) reported that a thin flake broke down during mixing and resulted in reduced intake. They recommended steam treated wheat be rolled more thickly than milo. In a Texas study (20) neither steam flaked nor micronized flaked processing methods improved wheat digestibility over dry rolling. Pelleting wheat was unsatisfactory for us (10) but seemed advantageous in a Washington test (18). Steam rolled wheat (not flaked) has the same feed value as dry rolled wheat (1, 18, 60). Likewise there has been little difference between rolled wheat and ground wheat (2, 23, 24) although differences in particle size were not described in those tests. Research at Hays has shown no response from feeding reconstituted and ensiled wheat or to ensiling 10% wheat with forage sorghum; however, the results are inconclusive (15 and unpublished data). Sheep may do better on whole wheat (22, 36, 73); and in a Missouri test (70), although efficiency of gain was 7% less, cattle made faster gains on whole wheat (2.28 versus 1.73 pounds per day). However, recent experiences with feeding whole wheat have been so unsatisfactory the tests were not completed. One would have to conclude, until convinced otherwise, that coarse rolling is the most efficient and satisfactory method of preparing wheat for cattle.

Table 9. Effect of Steam Pressure Processing and Popping on Wheat. (32).

Processing Treatment	Popped	1.5 min. 50 psi	1.5 min. 80 psi	8 min. ap
Average intake, lb.	15.0	14.3	14.3	15.8
Average daily gain, lb.	2.79	2.56	2.59	2.83
Average feed efficiency	536.	562.	556.	560.
Energy efficiency (kcal feed per 100 kcal gain-assuming 4 kcal/gm feed)	465.	502.	510.	439.
DM digestibility, %	78.3	78.3	79.3	76.1

Damaged wheat is often available for feeding but few feeding experiments have been conducted with it. Results of such tests would be applicable only to wheat similar to that studied. In a North Dakota test (63) steers fed rejected wheat gained only half as much as those fed corn meal. The authors did not specify the exact condition of the wheat. In a Montana study (71) frosted wheat appeared to be a satisfactory feed, but two-year-old Marquis wheat, which was hard and flinty, was less palatable. Idaho workers (31) substituted low-test-weight, sprouted wheat for normal wheat without affecting performance.

There has been no difference in carcass quality caused by including wheat in the fattening ration except when wheat-fed cattle gained significantly less because hard wheat was fed by itself (10, 12, 39, 40). Differences between wheat-fed and other cattle in marbling score, rib-eye area, backfat thickness, and fat color have been either small and inconsistent or non-existent (1, 19, 32, 38, 51, 54, 61, 69 and personal observation). However, the incidence of abcessed livers has often been increased when wheat was fed (1, 51, 54). On the other hand, urinary calculi may occur less frequently when wheat is substituted for milo (69).

Table 10. Fifty Percent Wheat in All-Concentrate Rations. (Summary of 5 Fort Hays Trials—14, 30).

Treatment	Milo	50% Milo & 50% Wheat
Average intake, lb.	23.2	20.8
Average daily gain, lb.	2.70	2.44
Average feed efficiency	862.	855.
Lb. milo replaced by 1 lb. wheat		1.01

Table 11. Use of Wheat in High-Silage Growing Rations. (Summary of 4 Fort Hays Trials—7, 8, 10, 11).

Treatment	1.9 lb. milo 4.0 lb. alfalfa silage, ad lib	4.0 lb. milo 4.0 lb. alfalfa silage, ad lib	1.9 lb. wheat 4.0 lb. alfalfa silage, ad lib
Average intake, lb.	16.0	17.3	16.5
Average daily gain, lb.	1.18	1.43	1.39
Average feed efficiency	1378.	1222.	1198.

In recent years there has been a trend to reduce roughage in fattening rations to a bare minimum. In five comparisons at Hays (Table 10), substituting 50% wheat for milo in all-concentrate rations has resulted in significantly reduced gain and no improvement in feed efficiency. Similar results were obtained by the Beltsville workers (54).

Wheat has shown the largest advantage in high-silage wintering rations (7, 8, 10, 11, 17, 26). In 4 of our tests an average of 1.68 pounds milo was replaced by 1 pound wheat (Table 11). There appears to be a relationship of relative value of wheat and percent roughage in ration. Wheat appears most valuable in high-roughage rations. The 30 Kansas comparisons of wheat and milo are plotted in Figure 1 with percent roughage in the ration on the abscissa and pounds milo replaced by 100 pounds wheat as the ordinate. The two variables have a high degree of correlation ($r = .71$ — $p < .01$) and a steep regression ($b = .76$). The regression line crosses ordinate at 95%. When 7% roughage is fed, rolled wheat and rolled milo seem equivalent.

This regression may partially explain why wheat has been nearly equal to other grains in recent comparison (27, 37, 38, 42, 47, 54, 59, 69), all of which involved high-concentrate diets, while earlier comparisons (6) indicated that wheat was superior to other grains. It tends to substantiate the findings of Bris and Dyer (18) that fiber levels in wheat rations may be critical and should be above 6%. Crude fiber levels may have been too low for optimal wheat performance in some of the above comparisons. Furthermore, this regression predicts the results of two large tests using over 3200 cattle conducted at a commercial feedlot (51). In these tests 20% to 35% wheat was substituted for corn in a fattening ration containing about 15% roughage. At this level of roughage the regression in Figure 1 indicates one pound of wheat would be equivalent to 1.06 pounds milo. If corn is 8% superior to milo, nearly identical performance would be expected from substituting wheat for corn. Actual average daily gain of 1000 cattle fed cracked corn was 2.66 pounds and of 2200 cattle fed 20% to 35% cracked wheat was 2.65 pounds. Average feed required for 100 pounds gain was 786 and 792 pounds, respectively.

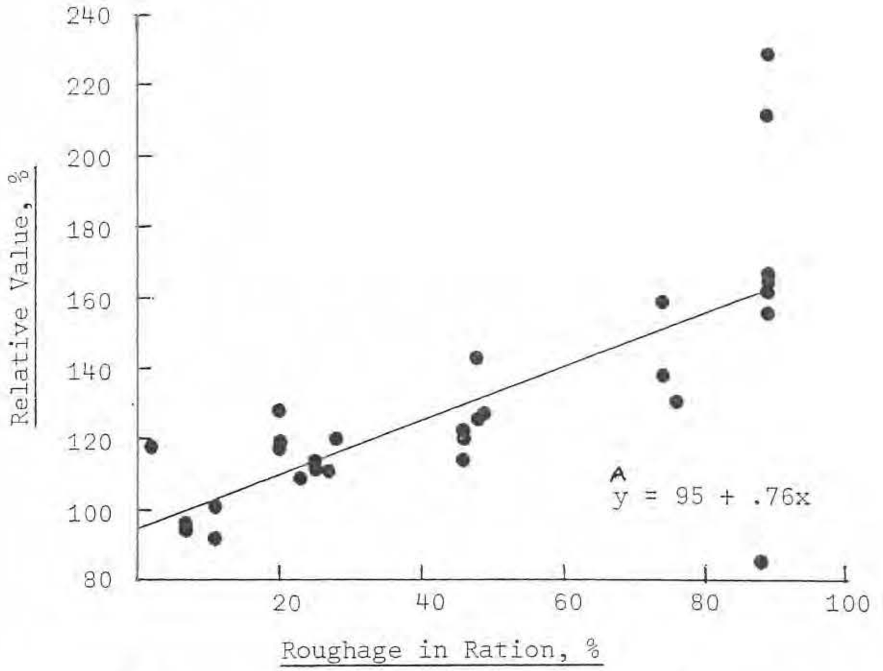

Figure 1. Regression of relative value of wheat to milo on percent roughage in ration based on 30 Kansas comparisons (6117, 30, 61).

Summary

The relative feeding value of wheat to other grains is affected by processing methods used, type and variety of wheat available, and the conditions under which it is to be fed. It is impossible to assign a fixed relative value applicable to all situations. In typical high-concentrate fattening rations, it appears that wheat has been about equal, pound for pound, to corn, barley, or steam flaked milo. In high-roughage growing rations wheat may be worth considerable more than other feed grains.

Because of its potential to cause rumen acidosis, wheat requires more management than other feed grains. Best results are achieved when it is fed mixed with another grain. Possibly, roughage levels should be increased slightly when wheat is added to fattening rations. To obtain maximum value from wheat, the extra protein content should be considered when rations are formulated. The evidence suggests coarse rolling is the best preparation, but more research in processing wheat is warranted. Type and varietial differences apparently affect feed value so there may be an opportunity to develop improved wheats for beef cattle feeding.

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Comparative Net Energy Values of Rations Containing Wheat and Other Grains for Beef Cattle

G. P. LOFGREEN

Introduction

Historically wheat has not been used extensively as a feed for beef cattle in comparison to other grains such as corn, barley, and sorghum grains. This is partially responsible for the almost complete lack of information on the net energy (NE) value of wheat. Morrison (1956) lists an estimated net energy for maintenance plus production (NEm+p) of 80 megcal. per 100 lb. The comparable values for corn (dent. No. 2), barley and milo are 80.1, 70.5, and 77.8. Morrison states that in the hands of an experienced feeder wheat may be fully equal to corn in value although no direct NE comparisons are reported. Brethour (1966) presents an excellent review of results of trials in which wheat has been compared to other grains for beef cattle. He has calculated the amount of grain replaced by one pound of wheat by converting other feeds to a grain equivalent. Although these replacement values will vary depending on the factors used to convert non-grain ingredients to the grain equivalent, his comparisons are of interest. In these tests one pound of wheat replaced the equivalent of 1.10 pounds of barley, 1.09 pounds of corn, 1.06 pounds of rye, and 1.15 pounds of sorghum grain. With wheat as 100 the other grains would, therefore, have relative values of 91, 92, 94, and 87 for barley, corn, rye, and sorghum grain, respectively. Although NE was not determined in any of these trials, the comparisons certainly demonstate wheat is a very good energy source for beef cattle.

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Net Energy Trials

Garrett, *et al* (1968), determined the NE for maintenance (NEm) and NE for weight gain (NEg) of rations containing 64% or 84% of barley, corn, milo, or wheat. All grains were steam processed in the same manner. Although the trials were not designed to determine NE values of the grains, the NE values of the entire rations should be indicative of the value of the grains since all other ingredients were constant. The results of this study are shown in Table 1. At both grain levels the NE values are highest for corn followed by wheat, milo, and barley although in the 84% grain rations milo and barley appeared to be of approximately equal value. It is of interest to note that for maintenance wheat rations were only slightly lower than those containing corn while for gain the rations containing wheat had 94% the energy of the corn rations but approximately 7% and 8% more energy than rations containing milo or barley.

Table 1. Net Energy Value of Rations Containing Barley, Corn, Milo, or Wheat as the Only Grain.

Level of grain	Energy measure	Grain			
		Barley	Corn	Milo	Wheat
%		(megcal. per 100 lb. of DM)			
64	NEm	76	84	79	82
	NEg	54	63	57	60
84	NEm	85	92	86	90
	NEg	65	74	65	69
Means	NEm	81	88	83	86
	NEg	60	69	61	65

At the Imperial Valley Field Station of the University of California three trials have recently been conducted in which the NEm and NEg of wheat has been determined alone and in combination with other grains.

Trial 1: A study was made of Sonora 64 wheat fed alone and in combination with California Mariout barley. The four experimental rations are shown in Table 2. The whole wheat weighed 64 pounds per bushel and the barley 51 pounds.

After steaming for approximately 15 minutes and rolling, the bushel weights were 29 and 22 pounds for wheat and barley respectively, a 55% reduction in weight per unit volume for wheat and 57% reduction for the barley. All cattle were fed for 154 days.

Table 3 presents some of the performance data from this study. It is apparent that the cattle did well on all rations. The cattle fed wheat as the entire grain consumed more feed than those fed barley and gained slightly more and thus the conversion was the same. There appears to be a somewhat larger feed intake with a resultant increased gain on the two mixed grain rations compared with the two pure grains. When such a comparison is made, the results shown in Table 4 are obtained. Although there was significant increase in feed consumption and weight gain obtained by mixing the grains, the feed conversion was not significantly influenced. The data from this study indicate that wheat can be

Table 2. Composition of Rations.[1]

Ingredient	All wheat	2/3 wheat 1/3 barley	1/3 wheat 2/3 barley	All barley
	%	%	%	%
Alfalfa hay	5.0	5.0	5.0	5.0
Sudan hay	5.0	5.0	5.0	5.0
Rolled barley	0	23.0	46.0	69.0
Rolled wheat	69.0	46.0	23.0	0
Beet pulp	10.0	10.0	10.0	10.0
Urea	1.0	1.0	1.0	1.0
Fat	3.0	3.0	3.0	3.0
Molasses	7.0	7.0	7.0	7.0
Totals	100.0	100.0	100.0	100.0

[1] One pound of limestone and 100,000 IU of vitamin A were added to each 100 pounds of the above rations.

Table 3. Performance of Cattle Fed Wheat and Barley Rations.

Item	All wheat	2/3 wheat 1/3 barley	1/3 wheat 2/3 barley	All barley
Number of steers	16.	16.	16.	16.
Initial weight, lb.	557.	561.	540.	548.
Daily feed intake, lb.	18.05b	18.90c	18.22b	17.56a
Daily weight gain, lb.	3.11	3.20	3.22	3.03
Feed per pound gain, lb.	5.80	5.91	5.66	5.80
Yield, %	60.4	61.0	60.0	61.7
Carcass grade scores:				
Quality grade[1]	8.2	8.4	8.3	8.2
Cutability grade[2]	2.4	2.3	2.3	2.5

[1] 8 = low choice, 9 = choice

[2] Grade 1-5, with 1 being the highest cutability.

a, b, c means having different superscripts are significantly different ($P < 0.05$).

Table 4. Comparison of Pure and Mixed Grains.

Item	Pure	Mixed
Number of steers	32.	32.
Initial weight, lb.	553.	556.
Daily feed intake, lb.	17.81a	18.56b
Daily weight gain, lb.	3.07a	3.21b
Feed per pound gain, lb.	5.80	5.78
Yield, %	61.1	60.5
Carcass grade scores:		
Quality grade	8.2	8.4
Cutability grade	2.5	2.3

fed satisfactorily as the only grain in a high energy ration or that a mixture of barley and wheat will also yield satisfactory results and may stimulate a somewhat higher rate of gain but with no benefit on feed conversion.

The NE values of the 4 rations are shown in Table 5. The values determined in this study from the data on energy deposition are compared to predicted values of the ration calculated from the NEm and NEg values of the ration ingredients published by Lofgreen and Garrett (1968a). The differences between determined and predicted values and the differences among rations are all well within experimental error and show no differences among rations or between the determined and predicted values. The NEm and NEg values for wheat and barley of Lofgreen and Garrett (1968) are 90 and 59 for wheat and 87 and 58 for barley. Since there was essentially no difference between the determined and predicted values of the entire rations, these data furnish no evidence that the values for wheat and barley are different than the values quoted above. The data, however, also gives no evidence that the NE values of wheat and barley are different since there were no real differences among rations. The results of this trial differ somewhat from those of Garrett *et al* (1968) in which wheat had somewhat higher energy values than those obtained for barley. It is important to note, however, that the barley used in this study was high quality. The bushel weight was 51 pounds and the crude protein was 12.4% for the barley and 12.5% for the wheat.

Table 5. Net Energy of the Rations.

		All wheat	2/3 wheat 1/3 barley	1/3 wheat 2/3 barley	All barley
		(megcal. per 100 pounds)			
NEm	Determined	83	83	82	84
	Predicted	85	84	83	83
NEg	Determined	55	56	55	56
	Predicted	55	54	54	54

Trial 2: The design of this trial was similar to trial 1 but involved a comparison of Sonora 64 wheat with a red Texas milo of unknown variety. The wheat in this study again weighed 64 pounds per bushel while the milo weighed 60 pounds. The wheat was steamed approximately 15 minutes prior to rolling and the milo approximately 20 minutes. The weights following rolling were 30 and 28 pounds per bushel for the wheat and milo respectively. The crude protein content of the wheat was 12.3% and the milo 10.4% on an air dry basis. Because of this difference in protein content, the nitrogen content of the rations was equalized by increasing the urea content of the ration as the milo content increased. The composition of the rations is shown in Table 6.

The determined crude protein content of the four rations was 10.6, 11.2, 11.3, and 11.1 for the all wheat, ⅔ wheat, ⅓ wheat, and all milo rations, respectively.

Table 6. Composition of Rations for Trial 2.

Ingredient	All wheat No milo	2/3 wheat 1/3 milo	1/3 wheat 2/3 milo	All milo
	(percent composition)			
Alfalfa hay	5.00	5.00	5.00	5.00
Sudan hay	5.00	5.00	5.00	5.00
Rolled wheat	67.67	45.04	22.46	0
Rolled milo	0.	22.50	44.93	67.27
Beet pulp	10.00	10.00	10.00	10.00
Urea	0.49	0.63	0.77	0.89
Fat	3.00	3.00	3.00	3.00
Molasses	7.00	7.00	7.00	7.00
Minerals	1.84	1.84	1.84	1.84
Vitamin A	1000 IU per lb. of ration			

All cattle were fed for a period of 28 days on an intermediate energy ration containing 45% roughage prior to starting on the four experimental rations which were fed for 196 days.

The performance data are shown in Table 7.

Table 7. Performance Date for Trial 2.

Item	All wheat No milo	2/3 wheat 1/3 milo	1/3 wheat 2/3 milo	No wheat All milo
Number of steers	15.	15.	15.	15.
Initial weight, lb.	392.	396.	401.	392.
Daily feed consumed, lb.	15.61a	15.83a	16.64b	16.54b
Daily weight gain, lb.	2.84	2.85	2.91	2.82
Feed per pound gain, lb.	5.50a	5.55a	5.72ab	5.87b
Yield, %	60.4	60.2	62.2	61.1
Carcass grades:				
Quality grade[1]	8.5	8.6	9.1	8.9
Cutability grade[2]	2.9	2.9	3.3	2.8

a, b means having different superscripts are significantly different ($P < 0.05$).

[1] Low choice = 8, choice = 9, top choice = 10.

[2] Graded 1-5, with 1 being the highest cutability.

It is apparent that the cattle fed rations in which the grain was either all wheat or ⅔ wheat ate significantly less feed than those fed the higher levels of milo. It is a commonly observed fact that when the energy concentration of a ration increases feed consumption tends to decrease. This is because within the zone of thermal neutrality animals eat to satisfy their energy needs. Thus, if palatability is no problem, as energy concentration increases, feed consumption decreases. From this observation one would conclude that the high wheat rations had a higher energy content than the high milo rations, or that the feed consumption was reduced because of a reduced acceptability of the rations. The feed conversion adds evidence that increasing the wheat concentration increased the energy since the feed conversion was improved with each increase in wheat.

Although the yields tended to be somewhat lower on the two high wheat rations, these differences were not statistically significant. There were no significant differences among either the quality grades or the cutability grades.

From data developed at the California station it is possible to determine the NE of the rations from the daily gains, mean body weight, and feed consumption. This procedure differs somewhat from that used in previously published trials and is illustrated in the following example:

	All wheat ration	All milo rations
Daily feed intake, lb.	15.61	16.54
Daily weight gain, lb.	2.84	2.82
Mean body weight, lb.	710.	708.
Daily NEm intake, megcal.[1]	5.91	5.90
Daily NEg deposited, megcal.[2]	5.66	5.61
NE per 100 lb. of feed, megcal.		
NEm	37.86	35.67
NEg	36.26	33.92

Calculations

1. 100 lb. of wheat ration = 100 lb. of milo ration + 2.19 megcal. NEm and + 2.34 megcal. NEg.
2. Since the only variable in the rations is the source of grain, all differences can be attributed to the approximately 67.5% grain in the ration.
3. Thus, 67.5 lb. of wheat = 67.5 lb. of milo + 2.19 megcal. NEm and + 2.34 megcal. NEg.
4. Therefore, 100 lb. of wheat = 100 lb. of milo + 3.24 megcal. NEm and + 3.47 megcal. NEg.
5. Previously determined values of NEm and NEg for milo are 87 and 58 megcal. /100 lb.
6. Therefore, 100 lb. of wheat = 87 + 3.24 megcal. NEm and 58 + 3.47 megcal. NEg or approximately 90 and 61 megcal. per 100 lb. for NEm and NEg respectively.

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[1] $NEm = 0.043\ W^{0.75}_{lb.}$

[2] $NEg = 2.0385g + 0.006061\ W\ lb. - 4.4288.$
(Determined by Garrett and Lofgreen from the relationship of NEg deposited, daily weight gain, and body weight from the data on 1742 steers.)

Using this procedure, the NE values shown in Table 7 were determined.

Table 8. Net Energy Content of the Grains Used in Trial 2.

Grain	NEm	NEg
	(megcal./100 lb.)	
All wheat	90	61
2/3 wheat, 1/3 milo	90	61
1/3 wheat, 2/3 milo	88	60
All milo (standard)	87	58

Thus, in this trial wheat had a NEm approximately 3% greater than milo and a NEg approximately 5% greater. These findings agree well with those reported by Garrett *et al* (1968) in which wheat had an average NEm approximately 4% higher than milo and NEg approximately 7% higher. The addition of milo did not depress the NE values at the ⅓ level but did at the ⅔ milo level.

Trial 3: Since the results of Garrett *et al* (1968) suggested that steam processing may not be beneficial to the energy value of wheat, a trial was conducted to compare a ground wheat with steam rolled wheat. Milo was again used as a standard but rolled to two degrees of flatness after steaming for 30 minutes. The wheat was ground in a hammer mill through a ⅜″ screen and the steam rolled wheat was steamed approximately 15 minutes and rolled to a flake weighing an average of 28 pounds per bushel. The weight of the whole grain was 64 pounds per bushel. The whole milo weighed 60 pounds per bushel and was rolled to either 36 or 28 pounds per bushel after 30 minutes of steaming. The rations contained 7.0% alfalfa hay, 3.0% sudan hay, 58.33% wheat or milo, 5.5% hominy feed, 6.67% cottonseed meal, 8.0% wheat mill run, 3.0% fat, 7.0% molasses, and 1.5% minerals. The test ran for 168 days. The performance data are shown in Table 9.

Table 9. Performance of Cattle in Trial 3.

Item	Wheat		Milo	
	Ground	Steam rolled	36 lb. per bu.	28 lb. per bu.
Number of steers	12.	12.	12.	12.
Initial weight, lb.	612.	637.	646.	595.
Daily feed consumed, lb.	17.51a	17.60a	18.68b	17.22a
Daily weight gain, lb.	2.94	2.88	2.88	2.96
Feed per pound gain, lb.	5.95a	6.10a	6.48b	5.82a
Yield, %	61.4	61.0	60.4	60.4
Carcass grade scores:				
Quality grade[1]	8.6	8.1	8.0	8.1
Cutability grade[2]	2.4	2.6	2.8	2.7
Marbling grade[3]	6.3	5.9	6.3	6.3

[1] 8 = low choice, 9 = choice.
[2] Cutability is scored 1 through 5 with 1 being the highest.
[3] 5 = small minus, 6 = small, 7 = small plus.

These results confirm the suggestion of Garrett *et al* (1968) that steaming may not improve the value of wheat since the gains and feed conversion on the steam rolled wheat were not significantly different from those observed on the ground wheat.

There were no significant differences among the daily gains of any of the four treatments. The cattle on the milo rolled only to a 36 pound per bushel product ate significantly more feed which resulted in a lowered efficiency on this treatment. One would conclude that the wheat fed in this study was approximately equal to well processed milo and superior to milo not adequately processed.

It is possible to determine the net energy of the grains using the previously described procedure. In this case the 28 pound milo was used as the standard and assigned the previously determined NEm and NEg values of 87 and 58 megcal. per 100 lb., respectively. Using this procedure the following values were obtained:

	NEm	NEg
	Megcal. per 100 lb.	
Ground wheat	87	57
Steam rolled wheat	88	57
36 lb. rolled milo	84	54
28 lb. rolled milo	87	58

These values confirm the earlier conclusion that the NE of the wheat was equal to properly processed milo and superior to the milo not adequately rolled. They also confirm the lack of influence of 15 minutes of steaming and rolling on the utilization of wheat.

Another means of comparing the energy values of the grains fed in the trials discussed is to calculate the expected rate of gain based on the feed consumption, mean body weight, and previously published energy values. This procedure has been described by Lofgreen and Garrett (1968). The previously published energy values for the grains in question are

	NEm	NEg
	Megcal. per 100 lb.	
Wheat	90	59
Barley	87	58
Milo	87	58
Corn	92	60

Table 10 presents a comparison of the expected and observed gains for all four trials discussed in this paper. The observed gains obtained on the wheat rations ranged from 97 to 103% of the expected gains with the average of all rations containing wheat as the only grain being 100%. This means the NEm and NEg values of 90 and 59 megcal. per 100 pounds accurately expresses the NE value of wheat. The comparison of the expected and observed gains achieved on the milo rations indicates that rolling to a final weight of 36 pounds per bushel did not permit optimum energy utilization. Rolling to 28 pounds per bushel allowed the milo ration to be utilized at the expected rate. If the 36 pounds per bushel milo is eliminated from the comparison, the mean observed gain on the other three all milo rations is 100% of the expected. This indicates that the NEm and NEg values of 87 and 58 megcal. per 100 pounds accurately predict the performance of properly processed milo. For the two rations containing barley as the only grain, the observed gain was 96% of the expected in one comparison and 106% in the other. The ration containing ⅔ barley and ⅓ wheat produced the expected rate of gain. These studies, therefore, give no evidence that the NEm and NEg values of barley are different than those used. In the one trial involving corn the observed gain was 110% of the expected. If repeated trials result in the same finding, the NE values for corn will need to be revised upward.

Table 10. Comparison of expected and Observed Rate of Gain.

Trial	Daily empty weight gain		
	Expected	Observed	Observed as % of expected
	lb.	lb.	%
Garrett *et al* (1968)			
Wheat	2.28	2.25	99
Barley	2.26	2.18	96
Milo	2.33	2.40	103
Corn	2.24	2.47	110
Trial 1			
All wheat	2.86	2.78	97
2/3 wheat, 1/3 barley	2.97	2.90	98
1/3 wheat, 2/3 barley	2.90	2.89	100
All barley	2.70	2.86	106
Trial 2			
All wheat	2.52	2.49	99
2/3 wheat, 1/3 milo	2.48	2.53	102
1/3 wheat, 2/3 milo	2.56	2.65	104
All milo	2.65	2.51	95
Trial 3			
Ground wheat	2.54	2.62	103
Steam rolled wheat	2.46	2.49	101
Steam rolled milo:			
36 lb. per bu.	2.69	2.48	92
28 lb. per bu.	2.48	2.51	101

Summary

In the four tests discussed in which NE values were determined either for the complete ration or the grain portion of the ration, wheat was slightly superior to milo in the test of Garrett *et al* (1968) and in one of the Imperial Valley Field Station tests and equal to well processed milo in the second Imperial Valley Field Station test. Compared to barley wheat was slightly superior in the test of Garrett *et al* and equal to barley in the Imperial Valley Field Station test. In the one comparison involving corn and wheat the wheat had slightly lower NE values. On the basis of these studies there appears to be no valid reason for modifying the NE values for beef cattle published by Lofgreen and Garrett (1968a) which give wheat a NEm value approximately 3% higher than barley or milo but 2% lower than corn, and a NEg value 2% higher than barley or milo and 2% lower than corn.

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