Nutritive Value and Suitable Levels of Wheat for Dairy Cattle

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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]

	No. avgd.	Protein	Ether extract	Crude fiber	Nitrogen free extract	Water	Ash	Digestion Coefficients			
								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

[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]

	No. avg.[2]	Protein	Ether extract	Crude fiber	Nitrogen free extract	Water	Ash	Digestion Coefficients					
								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

[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.

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

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]

	Treatment					
Ingredient	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.

		Composition of Dry Matter					
Feed	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

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

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)	3.7c	4.2b	4.6a	4.4ab	4.8a	4.8a
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 ($P<0.05$).

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.

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 (%)	3.7ab	3.7ab	3.9a	3.6b	3.7ab	3.6b
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)	0.44b	0.88a	0.44b	0.22c	0.22c	0.66a

[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

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

Ingredient	Barley: Meal and pellets	Wheat mixed feed: Meal and pellets	Control: 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.

ratio.

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	100% Dry mater basis					
	Dry matter	Crude fiber	Crude protein	Ash	Ether extract	N-free extract
			%			
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 start-

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

er 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.

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

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

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.

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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