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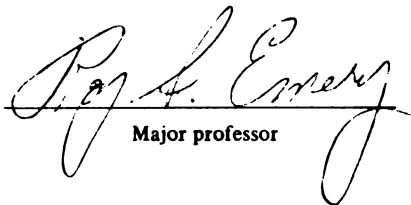
EVALUATION OF THE NUTRITIVE VALUE OF WET
POTATO PROCESSING WASTES IN TOTAL MIXED
RATIONS FOR DAIRY CATTLE

presented by

Chris N. Onwubuemeli

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of the requirements for

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RATIONS FOR DAIRY CATTLE

By

Chris N. Onwubuemeli

A THESIS

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ABSTRACT

EVALUATION OF THE NUTRITIVE VALUE OF WET POTATO PROCESSING WASTES IN TOTAL MIXED RATIONS FOR DAIRY CATTLE

By

Chris N. Onwubuemeli

The nutritive value of wet potato processing wastes (PPW) was determined in two experiments. In experiment 1, rations contained on a dry matter basis 0, 10, 15 and 20% PPW and were fed to 32 lactating cows for 12 weeks. Level of PPW did not significantly affect milk yield, milk composition, milk production persistency or dry matter intake. Cows fed PPW tended to shift in molar proportions of rumen VFA; acetate:propionate ratios decreased at 20% PPW.

In experiment 2, six steers in a 3x3 Latin square design and four steers in a 4x4 Latin square design were used separately to test the effects on digestibility, nitrogen utilization and rumen fermentation of substituting PPW for high moisture corn at 0, 10, 20 and 30% of the ration dry matter. Level of PPW did not significantly affect digestibility of crude protein or dry matter. A trend towards higher propionate and lower pH was observed with increased PPW.

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INTRODUCTION

A large number of by-products of food industries are used in livestock feeding. Klopfenstein and Owen (1975) and Huber et al. (1980) reviewed crop residues and by-products currently being fed advantageously to livestock. Feeds mentioned in these reviews include apple pomace, beet pulp, corn distiller's grain, fresh carrots, rice straw, sugarcane bagasse, whole cottonseed and many others. These crop residues and by-products have been found to be highly utilizable by dairy cattle. For instance, corn cob was found to contain the same amount of energy as corn grain when the cob is in the ration in amounts normally contained in ear corn (Klopfenstein and Owen, 1975). Studies with beet pulp as a replacement for corn showed no differences in digestibility of dry matter, energy or protein. Milk production averaged about 1 kg higher for the highest substitution of beet pulp.

Though not included in the above list, by-products of potato processing have been used albeit to a smaller extent in cattle feeding (Brugman and Dickey, 1961; Dinusson et al., 1969; Crickenberger as quoted by Brown et al., 1983). The large amount of by-product utilization in cattle rations is because of the ability of the ruminant to convert materials unusable by humans to high quality food.

By-products of potato processing come in different forms, depending on the processing plant. They may be potato pulp, peelings, slivers, potato culls, potato chips and fragments. The United States produces

about 1 billion pounds of potato wastes annually (Michigan State University, 1981). Potato processing wastes are a disposal problem to the processor, but if properly incorporated into animal rations, they may serve as valuable feed for livestock. In the past, such wastes were disposed of by running them into sewers and rivers. Reddy, as reported by Michigan State University (1981), thinks that if recycled into livestock feed supplement, all the potato wastes produced annually in the State of Michigan would have the nutritional value of 30,000 tons of soybeans.

As stated above, the use of potato waste by-products in livestock feeding has been documented. But reports on the use of such wastes in dairy cattle feeding are scarce. Allender (1948), in a review of the work done on the use of potatoes for livestock feed in the United States, presented data on the value of fresh whole potatoes compared to corn silage, shelled corn and mixed grain. He gave the following values: 100 pounds of shelled corn was equal to 450 pounds fresh potatoes, 100 pounds of corn silage was equal to 100 pounds of fresh potatoes, 100 pounds of mixed grain was equal to 350 pounds of fresh potatoes when fed 2 to 1 with grain to swine. Allender (1948) also suggested that because of their high moisture content, raw potatoes should not replace all the grain or hay in animal rations. For cattle, raw potatoes may replace a portion of nutrients in grain, i.e. 4-5 lb potato might replace 1 lb of an average grain mixture. And in a review of the use of potatoes as stock feed, the Ministry of Agriculture, Fisheries and Food of the United Kingdom (1976) stated that up to 11 kg

per head per day may be fed to dairy cows. The review also stated that potatoes are a useful source of energy for beef cattle and sheep. The feeding value of potatoes for pigs and poultry was increased by cooking which burst the starch granules and rendered them more digestible. For laying hens in particular, 120-180 g potatoes may replace grain in the daily ration. The same review stated that dried potato by-products such as potato flakes, potato starch or potato screen wastes are similar to cereals in energy content though protein contents may vary. These by-products may be used as partial substitutes for cereals in concentrates. Dinusson et al. (1969) presented data to show that potato pulp can be used at 25% of the dry matter in rations for fattening cattle. The authors also indicated that potato pulp is lower in protein but higher in acid detergent fiber than common feed grains.

In the past, potato wastes or by-products used for livestock were fed as dried pulp mixed in rations or as potato meal. Drying requires large expenditures in energy. Interest is currently centered on finding ways for successful and economic utilization of previously unused wastes in the wet form. Substitution of such wet wastes for concentrates in livestock feed is a way of utilizing them. Such products may also be ammoniated to yield protein-rich products which could be substituted for soybean, as water from potato chip plants has been fermented and concentrated to produce a syrup which contains up to 45% crude protein (Michigan State University, 1981). Data presented by Brown et al. (1983) indicate that potato processing wastes may be used in dairy cattle feeding without adverse effect on milk yield. The present

study was undertaken to evaluate the feeding value of potato processing wastes obtained from a plant in the State of Michigan. The waste came as a mixture on a dry matter basis of 60% peel and sludge, 30% raw potato screenings and 10% cooked packaging wastes. It was delivered in large polythene sacks of 500 kg each fitted into wooden crates. Increasing cost of grain and improvements in by-product utilization point to a high utilization potential for crop residues and by-products in dairy cattle feeding. Potato waste is one such waste or by-product.

REVIEW OF THE LITERATURE

Potato Wastes/By-Products or Whole Potatoes in Livestock Feeds

Potato wastes or whole potatoes in livestock feeds come in a variety of forms. Woodman et al. (1943) used potatoes as dried flakes, slices and cossettes and potato dust. Bickel and Church (1975) fed raw comminuted potatoes without adverse effects.

Potatoes and potato wastes are high in moisture and low in fiber. They may therefore, be considered as watery concentrates, comparable to beet pulp and wet brewer's grains. The wastes vary in composition and characteristics depending on the plant and its products. Hinman and Sauter (1978) identified and nutritionally characterized three types of wastes on a dry matter basis: Filter cake - starch was 60-65%, crude protein was 4.8%, fiber was 1.6%, and fat content was 2.4%; Lye peeling - waste from plants that use sodium hydroxide - fiber was 7.6%, starch 50-65%, crude protein, 5.6%, ash 6.9% and fat less than 1%; Screening wastes and culls - whole potatoes discarded because of size with some peelings included. Dry matter content was about 20% which approximates that of whole potato crop.

Pulp from potato processing plants has a moisture content of as much as 94% (Brugman and Dickey, 1961). Crude protein content of wastes falls between 4 and 8%. Brown et al. (1983) reported a crude protein content of 4.7% against Brugman and Dickey's (1969) values of 1.2 and 6.0% for wet and dried pulp, respectively. Dinusson et al. (1969)

worked with dried potato pulp and reported a crude protein of 7.8%.

Brugman and Dickey (1961) reported a fiber content of 1.6% for wet potato wastes. Brown et al. (1983) reported on a dry matter (DM) basis an acid detergent fiber content of 17.5% for potato and corn processing by-product. The material used by Brown et al. (1983) however contained corn kernels and cob fragments as it was from a corn and potato handling plant. Dinusson et al. (1969) also reported an acid detergent fiber content of 17.5% in dried potato pulp along with an ash content of 6.0% which corroborates the 6.9% of Hinman and Sauter (1978). However, the value of 17.5% acid detergent fiber is difficult to explain, but their material must have included a high percentage of peelings.

The initial pH of potato wastes depends on food plant procedures and the type of product. However, irrespective of the product the pH of the waste drops rapidly, reaching a low level at which it remains over a long period. Brugman and Dickey (1961) reported that the pH of potato pulp drops rapidly to 3.5 after which it changed very little. The initial pH was not stated. A low pH value of 3.5 was confirmed by Hinman and Sauter (1978) who reported initial pH of 12.5 and 6.5 for lye peeling waste and filter cake wastes, respectively.

Nutrient loss occurs on storage in all types of waste because of enzymatic and microbial action. A starch loss in potato wastes of up to 56.2% can occur during a 3-week storage period (Hinman and Sauter, 1978). During this same period, the bacterial count in a filter cake storage may rise to 10^{10} . Counts in wastes of

potatoes treated with lye are much lower and average about 10^3 . The authors attribute the lower counts to the high pH in lye peel which prevents bacterial multiplication.

Effect of Roughage to Concentrate Ratio

Changes in the forage to concentrate ratio of complete mixed ration have noticeable effects on the production and composition of milk as well as on the rumen fermentation pattern in ruminants.

Milk Yield: Balch et al. (1952) showed significant increase in milk yield by switching from a ration of 17-21 lb hay, 30 lb mangold and 4 lb concentrates/10 lb milk yield to one of 6 lb hay plus 9 lb extra concentrates. When the hay was reduced to 2 lb per day, just a small decrease in milk yield was noticed. The same authors in another experiment (1954) fed a control ration of 18 lb hay plus 1 lb grain per 4 lb of milk. When 6 lb of grain replaced 14 lb of the hay, there was no significant change in milk yields. Hernandez-Urdaneta et al. (1976) reported an increase of 2.75 kg of milk when cows were switched from a ration of 60:40 forage to concentrate ratio to one of 40:60. However, the change to a higher concentrate proportion may not always cause an increase in yield. Storry and Rook (1965) noted a decrease in milk yield on a low hay diet and Mosley et al. (1976), in an abrupt change of ration, reported a nonsignificant increase in milk yield as forage to concentrate ratios were decreased as follows: 95:5, 80:20, 60:40 and 40:60. Jenny et al. (1974) reported a nonsignificant difference in milk

yield when a ration of 35% concentrate dry matter was substituted for one of 85% concentrate.

Milk Fat and Protein: While the effect of higher concentrate feeding on yield may not always be noticed, its effect on milk fat and protein percent of milk is normally observable. Powell (1938) first reported the depression of milk fat when low roughage or roughage in a finely ground state was fed to cows. Loosli et al. (1945) fed about 5 lb of hay plus enough grain to meet energy requirement and produced a significant decrease in milk fat. Boyd and Mathew (1962) fed high, low and no grain diets and reported the highest increase in fat percent in the no grain diet while the highest increase in protein percent occurred in the high grain diet. Satter et al. (1969) reported an increase in the solids-not-fat and protein content of milk of cows fed low roughage rations. The observation was confirmed by Hoogendoorn and Grieve (1970) who fed roughage at levels of 0.75, 1.50 and 2.50 kg/kg body weight. Jorgensen et al. (1965) caused a depression of fat percent when they changed from a high roughage ration to one high in pelleted corn. There was also an accompanying increase in milk protein percent. Cows may show variable responses to low roughage rations which may be influenced by stage of lactation. Lathan et al. (1974) fed low roughage rations to Friesian cows and reported that not only did cows differ in the proportion of grain required to induce milk fat depression, but that they also differed in the way fat content changed. They found that at a level of 1 kg hay/day, the amount of

concentrate and flaked maize required to depress fat percent below 2% varied between 1-6 and 4-6 kg/day. Two of the animals in their study showed abrupt fall in milk fat while the other two showed a gradual decrease. Jenny et al. (1974) reported no significant difference in early lactation in fat percent between cows fed low roughage and high concentrate rations. However, they reported a consistent decrease in fat percent of cows in mid-lactation which were fed high concentrate to forage ratios. Hernandez-Urdaneta et al. (1976) reported an increase in milk protein percent with high grain rations. They explained the increase in protein to result from a greater availability of substrates for gluconeogenesis, which spares amino acids for the synthesis of milk protein.

Blood Glucose: Ruminants do not absorb enough glucose from the gut to meet their requirements. They meet a large percentage of their glucose requirement by gluconeogenesis, using as substrates volatile fatty acids from the rumen fermentation and amino acids from tissues. In cows, propionate contribute about 60% of the blood glucose (Wiltrout and Satter, 1972). Blood glucose concentration varies among herds and was reported to range from 42-86 mg/dl (Anonymous, 1975), 38.8-52.5 mg/dl for non-lactating cows (Campbell and Kronfeld, 1961), and 43-69 mg/dl (Kronfeld et al., 1982).

A change of roughage to concentrate ratio may produce a variable effect on the blood glucose in ruminants. Van Soest et al. (1954) fed a low roughage, high concentrate diet and found no significant increase in blood glucose. When Balch and co-workers (1955) replaced

a control ration of 16 lb hay and 20 lb concentrate with a ration of 2 lb hay and 24 lb concentrate of which 50% was flaked corn, there was no increase in blood glucose. Storry and Rook (1965) reported an increase in blood glucose on a high maize diet. As reported by Jenny et al. (1974), cows in early lactation showed no significant difference in blood glucose when fed normal or high grain diets. However, in mid-lactation, cows responded to the high grain ration by an increase in blood glucose and a decrease in milk fat. The authors also reported a negative correlation between blood glucose and milk production. They suggested that the lack of response to glucose to high grain in early lactation may be related to the glucose need for high production. Thus, cows in early lactation which are in negative energy balance metabolize circulating compounds for energy of which glucose is the primary one.

Volatile Fatty Acids and pH: About 80% of the organic matter digested in the rumen is fermented to volatile fatty acids (Sutton, 1971). Rumen volatile fatty acid production depends on extent of organic matter digestion. Bath and Rook (1963) noted that a marked variation in the pattern of fermentation with a given diet may be observed among animals. A similar observation was made by Hernandez-Urdaneta et al. (1976), who also noted that the level of the individual acids was affected by level and frequency of feeding.

Balch and Rowland (1957) reported that rumen pH fluctuated inversely with the concentration of volatile fatty acids. With a low hay diet, they reported the lowest rumen pH. A decrease in the hay

to concentrate ratio caused a decrease in the percentage of acetate, and an increase in the percentage of propionate and butyrate. With hay to concentrate ratios of 4:1, 3:2, 1:3 and 1:4, Brown et al. (1958) observed a decrease from 60% to 40% in molar proportion of acetate and an increase of 20 to 40% in propionate. Butyrate and the other acids showed no noticeable change. Higher concentrate rations cause an increase in total volatile fatty acids which is associated with an increase in the proportions of propionate; also noticed was a decrease in the butyrate concentration, the acetate:propionate ratio and rumen pH (Davis, 1967; Annison and Bickerstaffe, 1974).

Fermentation patterns in the cow may be affected by stage of lactation. Wiltrout and Satter (1972) reported different fermentation patterns for dry and lactating cows fed identical diets. They reported molar proportions of acetate, propionate and butyrate as 63:18:17 and 53:30:11 for the lactating and dry periods, respectively. Jenny et al. (1974) observed no significant differences in volatile fatty acids in early lactation but a significant difference in mid-lactation. Oshio et al. (1977) confirmed the variation in fermentation pattern and also reported a wide diurnal variation in total acid concentration, pH, and proportion of individual acids. They speculated that the variations may be due to instability of numbers, types and functions of microorganisms in the rumen. Alternatively, they suggest that the variations may be influenced by feed intake or physiological condition of the animal.

Effect of Whole Potatoes and Potato Wastes in Beef Cattle Feeding

As stated earlier whole potatoes have been used in livestock feeding (Allender, 1948; Great Britain Ministry of Agric. Fisheries and Food, 1976). The use of potato wastes or by-products have been reported more in beef than dairy cattle feeding (Brugman and Dickey, 1961; Dinusson et al., 1969; Hinman and Sauter, 1978). Brugman and Dickey reported that potato pulp alone or a mixture of dried potato pulp and corn in equal proportions makes excellent beef fattening rations. They also noted that steers fed wet potato pulp gained approximately 1 kg per day. Dinusson et al. (1969) reported that the potato pulp can be used effectively at 25% of the ration for fattening cattle. Hinman and Sauter (1978) drew attention to the variability in the nutrient content of potato wastes and the possible loss of nutrients during storage. They estimated that on a dry matter basis fresh potato waste has about the same energy value as barley.

Milk Yield of Dairy Cattle Fed Potatoes

Data on the use of potato waste in dairy cattle feeding are listed. However, the use of whole potato crop has been documented with varied results on production and composition. Milchvieh (1940) fed about 15 kg potatoes and caused a 5% decrease in milk yield. The effect on the fat percent was not definite, but a tendency towards an increase was noticed. The amount of other feeds was not reported. Whole potatoes in combination with silage and some concentrate have been reported to sustain milk yield, or make no significant change. Wokes et al. (1942) fed 150 ounces of potato

slices daily plus an unspecified concentrate mixture and observed no change in milk production. Keyes and Nelson (1951) fed 24 kg potatoes per day, Chikun (1976) fed a mixture of 22% potatoes and 30% silage and recently, Brabander et al. (1983) fed grass silage and 10-20 kg potatoes. In all three cases, the effect on milk yield compared to control rations was not significant. In combination with other succulent feeds, notably beet and turnips, or as substitute for them, whole potatoes caused no significant change in milk production (Bezenko et al., 1956; Karapetyan and Gukasyan, 1952; Piatkowski and Voigt, 1979). When fed as silage or steamed, potatoes maintained milk production (Dammers, 1955; Ulvesli, 1951). Nicholson and Curtis (1960) compared whole potatoes and grass silage as feed for dairy cattle and reported no significant difference in milk yield between rations. On a dry matter basis, they fed hay and silage or hay and potatoes at a ratio of 1:3. Bickel and Schurch (1975) observed no adverse effect on milk yield when a mixture of 10 kg potatoes and 200 g protein concentrate was fed. However, Skjevdal (1974) compared potatoes with Swedes (Bassica napus L. rapifera) and reported that raw potatoes caused a nonsignificant decrease in total and fat corrected milk while steamed potatoes caused a significant increase.

Brugman and Dickey (1961) found no difference in fat corrected milk when dried potato pulp was substituted for yellow hominy. Brown et al. (1983) also worked with potato by-product, and found no significant difference in milk production or persistency between control and potato treatments.

Milk Fat As Affected By Feeding Potatoes

Milchvieh (1940) reported that the effect of potatoes on milk fat was controversial, but there tended to be an increase. Subsequent data from feeding trials with raw potatoes or potato wastes confirmed a lack of difference (Keyes and Nelson, 1950; Nicholson and Curtis, 1960). However, with a 20% potato and 30% silage ration, Chikun (1976) reported a significant decrease in fat content. The same observation was confirmed by Piatkowski and Voigt (1979), who substituted potatoes for beet pulp in a mixed ration and reported 4.05% fat for the potato ration versus 4.25% for the beet pulp ration. In contrast, Dammers (1955) and Bezenko et al. (1956) reported a tendency toward an increase in fat percent. Also, Skjevdal (1974), Brabander et al. (1983) and Brown et al. (1983) reported a tendency toward an increase in fat percent from feeding potatoes.

Although feeding raw potatoes or potato wastes caused variable response in milk fat, steamed potatoes definitely appear to have a decreasing effect (Dammers, 1955; Skjevdal, 1974). Along with the change in fat content is a decrease in the amount of unsaturated fatty acids in the milk fat. Forsogmejeri (1940) reported an iodine number of 26.4 for potato fed cow's butter versus 27.7 for the control animal's butter. Browner et al. (1947) confirmed the observation when they reported a decrease of 4.8 ± 1.5 in iodine number of butter from potato-fed cows.

Milk Protein

The variable response seen in milk fat was also noted for milk

protein. Piatkowski and Voigt (1979) reported no difference in the milk protein when 2.5 kg potatoes substituted for 2.5 kg beet pulp in mixed ration for dairy cows. However, Brabander et al. (1983) fed grass silage and 10-20 kg potatoes and caused a significant decrease in milk protein percent. Brown et al. (1983) fed corn or potato chipping by-products and reported no difference between treatments in milk production.

Live Weight Gains in Cattle as Affected by Potatoes

Although the results are not always conclusive, potatoes/potato waste appear to increase live weight gains when compared to control rations. Keyes and Nelson (1950) fed 24 kg potatoes per day and noticed an average daily weight gain slightly greater than the control ration which was not reported. Dammers (1955) fattened cows on ensiled steamed potatoes and raw potatoes and found no difference in live weight gains. Brugman and Dickey (1961) and Dinusson et al. (1969) found no difference in average daily live weight gain when potato pulp substituted for yellow hominy or a mixture of barley and oats, respectively. Dinusson et al. (1969) reported that steers fed potato pulp gained 95% as fast as the non-potato group. They suggested that 33% of the ration may be the upper limit at which potato pulp may be used for best results. However, Orskov et al. (1969) observed erratic live weight gain on potato rations. They attributed this to wide variations in total feed intake. But on a mixed ration of oats, barley, soybean meal, potato pulp and apple pomace, Nicholson et al. (1964) increased rate of gain by substituting potato pulp for oats

in the ration. They also noted that the potato-fed animals required less feed per pound of gain. In contrast, steers fed potato silage ate more dry matter but gained less weight than those fed corn silage (Nicholson et al., 1977). Creep-fed calves on 40% potatoes ate less, but had an average daily gain of 14-18% higher than those on 40% flaked maize (Hinks and Armishaw, 1975). In another creep feeding experiment with calves, the same authors compared 67% cooked potatoes with 67% cooked maize and reported that weight gain was unaffected by ration composition or dry matter content. Brown et al. (1983) fed corn and potato chipping by-products to lactating cows and reported a tendency toward higher gain than the control ration.

Volatile Fatty Acid and pH of Cattle Fed Potato Rations

Replacing barley with potatoes had no significant effect on total rumen volatile fatty acid concentration. There was, however, an increase in the propionic acid concentration. No significant difference in pH was observed from feeding potatoes (Orskov et al., 1969).

Digestibility of Potatoes

Woodward et al. (1938) worked with steers and reported that the nitrogen of raw potatoes was more digestible than dried or dried and soaked potatoes. Their result may have been influenced by the denaturation of protein as the potatoes were dried at 165-180°F. They also reported that the carbohydrate nutrients of potatoes are highly digestible. In studies with sheep, Woodman and Evans (1943)

reported low digestibility coefficients for crude protein in three forms of dried potato products. Values were 45.5, 43.5 and 51.0% for potato flakes, slices and cossettes, respectively. They stated that inclusion of any of the three forms in ruminant rations may significantly depress apparent protein digestibility because of an increase in metabolic fecal nitrogen. For potatoes, Nicholson and Friend (1965) reported 31% crude protein digestibility in sheep and 52.0% in horses. In creep feed for calves, substitution of potatoes for flaked maize at 40% level had no significant effect on dry matter digestibility. However, calves on potato had more bloat (Hinks and Armishaw, 1975). In swine studies, addition of sweet potato chips to rations caused a decrease in apparent nitrogen digestion (Wu, 1980). Ryan and Balls (1962) isolated a powerful inhibitor to chymotrypsin from potato (Solanum tuberosum) juice. The authors stated that this inhibitor is stable to acid, alkali and heat and completely inhibits proteolysis. The low digestibility of potato nitrogen and the depression of ration digestibility may be explained in part by the presence of this enzyme inhibitor.

MATERIALS AND METHODS

The potato processing wastes used in this study consisted on a dry matter basis of 60% peel and sludge, 30% raw potato screenings and 10% cooked packaging wastes. Steam treatment was used for peeling of potatoes with no added alkali. Whole potatoes in the PPW were minced at the plant. The wastes were received weekly from the plant in polythene sacks which contained 500 kg fitted into wooden crates. The wastes kept well for the 12 weeks duration of the lactation study and 7 weeks of the digestibility and rumen fermentation experiments as shown by absence of gas accumulation or production of undesirable odors in the sacks. Analysis of wastes is shown in Table 1A. The study was separated into two experiments: 1) a lactation experiment and 2) a digestibility experiment in which normal rumen fermentation parameters were also characterized.

Lactation Experiment: Thirty-two lactating Holstein cows were used in a randomized block design. Blocks were formed on the basis of milk yields during a 2-week pre-experimental period. There were four animals per block and eight animals per treatment. Four rations - A, B, C and D - were composed as follows:

A - Control: 50% of the dry matter as forage and 50% as concentrate

B - Low potato processing wastes (PPW): 50% of the dry matter as forage, 40% as concentrate and 10% as PPW

C - Medium PPW: 50% of the dry matter as forage, 35% as concentrate and 15% as PPW

D - High PPW: 50% of the dry matter as forage, 30% as concentrate and 20% PPW.

Table 1A. Chemical analysis of potato processing waste used in these studies^a

	<u>Range</u>	<u>Mean</u>	<u>SD</u>
Dry matter (%)	24.30-27.99	26.00	1.4
Crude protein (% DM)	4.1 - 6.6	5.00	1.1
Acid detergent fiber (% DM)	4.6 - 8.3	6.00	1.40
pH	3.60- 4.21	3.96	0.30

^aComposed of (on a dry matter basis) 60% peel and sludge, 30% potato screenings, 10% packaging waste (from french fries and potato tots).

Rations were formulated to be isonitrogenous at 14% crude protein. Concentrate in all rations was made up of high moisture corn and a commercial protein supplement. Processed potato wastes replaced part of the high moisture corn in rations B, C and D. Forage made up 50% of the total ration dry matter in all rations consisting of 25% corn silage and 25% haylage. Analyses of PPW, ration ingredients and analysis of complete mixed rations are shown in Tables 1A, 1B and 2, respectively.

Cows were randomly assigned to the four rations based on their 2-week pre-treatment milk production. Because an insufficient number

Table 1B. Ingredient composition of rations used in the lactation experiment

Ingredients	Rations			
	A	B	C	D
Corn silage (% of DM)	25	25	25	25
Haylage (% of DM)	25	25	25	25
High moisture corn(% of DM)	43	33	28	23
Protein supplement ^a (% of DM)	7	7	7	7
Trace mineralized salt ^b (% of DM)	1	1	1	1
Potato processing wastes (PPW) (% of DM)	0	10	15	20

^aGuaranteed analysis:

Minimum crude protein	44.0%	Minimum NaCl	1.8%
Maximum crude fiber	8.0%	Minimum vitamin A	15,000 UPS
Minimum calcium	2.9%		units/lb
Minimum phosphorus	1.5%	Minimum vitamin D ₃	3,000 USP

^bGuaranteed analysis:

Zinc, Min	0.350%	Manganese, Min	0.200%
Iron, Min	0.030%	Copper, Min	0.005%
Cobalt, Min	0.005%	Iodine, Min	0.007%
Salt, Min	96.00%		

Table 2. Chemical analysis of complete mixed rations fed in the lactation experiment

Item	Rations			
	A	B	C	D
	-----% of DM-----			
Dry matter	48.15	44.12	40.70	36.70
Crude protein	14.25	14.17	14.23	13.97
Acid detergent fiber	19.63	19.65	19.70	19.73

of cows were available at the beginning of the experiment, 16 started treatment initially and blocks of four were added as soon as they were ready. For this reason, 16 cows completed the experiment in winter while the other 16 completed the experiment in spring or summer. Cows were housed in confinement stalls at the Michigan State University Dairy Cattle Research Center. Groups B, C and D were adapted to ration B, 10% of the dry matter as PPW for 1 wk, then C and D were increased in PPW level. The experiment lasted 12 wk and cows were fed twice daily. Orts were collected and weighed once daily. Feeding rate was adjusted to allow for about 10% ors. Water was available at all times.

Feed samples were collected and composited for a 2-wk period. All feed composites were kept at -5°C until analyzed. Animals were milked twice daily and milk weights recorded. Cows were weighed for 2 consecutive days during the first and last weeks of treatment. At biweekly intervals milk was sampled from AM and PM milkings. Samples were composited and analyzed for fat, protein and total solids.

Rumen fluid samples were collected via stomach tube on day 60 of treatment. Rumen fluid was strained through four layers of cheesecloth, the pH was determined and 25 ml was acidified with 0.5 ml 50% sulfuric acid. Samples were then centrifuged and frozen at -5°C until analyzed for volatile fatty acids. Blood was sampled from tail vein on day 60 of treatment. Samples were collected in tubes treated with heparin-sodium fluoride and prepared according

to the Sigma Technical Bulletin (1982). Blood samples were also centrifuged and plasma stored at -5°C until analyzed for glucose.

Digestibility Experiment - Trial 1

Six yearling steers were used in a 3x3 Latin square to test the effect on digestibility and nitrogen utilization of replacing high moisture corn with PPW at 0, 10 or 20% of the ration dry matter. Rations were isonitrogenous at 14% crude protein and formulated as follows on a dry matter basis: 1) Control, 25% corn silage, 25% haylage, 43% high moisture corn, 7% protein supplement; 2) 25% corn silage, 25% haylage, 33% high moisture corn, 7% protein supplement, 10% PPW; 3) 25% corn silage, 25% haylage, 23% high moisture corn, 7% protein supplement, 20% PPW (Tables 3 and 4).

Steers were gradually adapted to the rations for 7 days and feces and urine were collected for 5 days. Steers were housed in metabolism stalls at the Michigan State University Beef Cattle Research Center. They were weighed at 8 AM on the beginning day of each period. Animals were fed once daily in the morning. Feed and orts were collected, weighed and sampled once each day. Feces were collected in metal pans placed directly behind the steer and urine in a metal funnel device connected with rubber tubes to plastic jars. Jars contained 50 ml of concentrated sulfuric acid to prevent nitrogen loss. Urine volume was measured and recorded daily. Samples were frozen until composited and analyzed.

Feed and feces were analyzed for dry matter, crude protein and acid detergent fiber and urine for crude protein. Animals were weighed

at 8 AM on the last day of each collection period.

Table 3. Ingredient composition of rations fed in digestibility and rumen fermentation experiment

Ingredients	Rations ^b			
	1	2	3	4
Corn silage (% DM)	25	25	25	25
Haylage (% DM)	25	25	25	25
High moisture corn (% DM)	43	33	23	23
Potato processing waste (PPW) (% DM)	0	10	20	30
Protein supplement ^a (% DM)	7	7	7	7

^aGuaranteed analysis

Minimum crude protein	44.0%	Minimum NaCl	1.8%
Maximum crude fiber	8.0%	Minimum vitamin A	15,000 USP units/lb
Minimum calcium	2.9%	Minimum vitamin D ₃	3,000 USP units/lb
Minimum phosphorus	1.5%		

^bRations 1, 2 and 3 were fed in digestibility trial. All rations were fed in the rumen fermentation trial.

Table 4. Chemical composition of rations fed in the digestibility and rumen fermentation experiments

Analysis	Rations ^b			
	1	2	3	4
	-----% of DM-----			
Dry matter	50.17	46.05	43.05	36.60
Crude protein	14.13	14.07	14.01	13.77
Acid detergent fiber	19.53	19.61	19.74	19.77

^aSame as footnote on table 3.

Rumen Fermentation Experiment - Trial 2

For an evaluation of certain rumen fermentation parameters, four rumen-fistulated steers were used in a 4x4 Latin square. Three rations were similar to those of Trial 1. The fourth contained 30% of the ration dry matter as PPW, 13% high moisture corn, 7% protein supplement, 25% corn silage and 25% haylage. Steers were adapted to the rations for 9 days and rumen contents sampled at 0, 2, 4 and 8 hr postfeeding on day 10. Samples were strained through four layers of cheesecloth into containers containing 0.1 ml mercuric chloride to stop further fermentation. The pH of rumen fluid was taken and 2 ml mixed with 2 ml sodium tungstate and 2 ml of 1N sulfuric acid. The mixture was then centrifuged at 1200 g and frozen until analyzed for VFA and rumen ammonia. Ration composition and ingredients are shown in Tables 3 and 4.

Analysis of Samples

Feed sample dry matter was determined at 100°C overnight in a forced air oven. Potato wastes and feces were dried at 60°C to a constant weight for dry matter determination. Crude protein (total nitrogen x 6.25) determination on all samples was by the macro-Kjeldahl technique. Acid detergent fiber was determined by the method of Van Soest et al. (1963). Milk samples were analyzed for fat, protein and total solids by the DHIA Milk Testing Laboratory, Michigan State University, by the infrared method using multi-spec (Berwind Inc., California). Plasma glucose was determined by the glucose-oxidase method (Sigma Technical Bulletin No. 510, 1982).

Rumen fluid analysis for the volatile fatty acids acetate, propionate and butyrate, was by gas chromatography in a column packed with 10% SP 1200/1% H_3PO_4 on 100/120 Chromosorb. Rumen ammonia was determined by the method of Chaney and Marbach (1962).

Statistical Analysis of Data

All data were subjected to statistical comparison by analysis of variance techniques described by Gill (1978) for randomized block, split plot or Latin square designs.

RESULTS AND DISCUSSION

Lactation Experiment

Ration dry matter decreased as percent PPW in ration increased. In formulating the rations, PPW was substituted for high moisture corn on a dry matter basis. The decrease in ration dry matter was therefore due to the wet waste product.

Milk Yield

Table 5 shows milk production and composition values. Total milk production, 4% fat-corrected milk and milk production persistency were not significantly different between control and PPW rations. These results agree with those of Brown et al. (1983) who reported no significant change in milk production and persistency when potato processing by-products were fed to dairy cows. Also, Brugman and Dickey (1961) reported no difference in fat-corrected milk production when potato pulp in a dairy ration replaced yellow hominy at 22.5% of the ration dry matter. However, in the present study, in contrast to the data by Brown et al. (1983), total milk yield was highest at the highest level of PPW substitution. The difference here may be due to the difference in dry matter intake in the two studies. Whereas, Brown et al. (1983) reported a significant decrease in dry matter intake as percent by-product increased in the ration, dry matter intake in the present study was

Table 5. Performance^a of cows fed potato processing wastes (PPW)^b

Items	Rations ^c				SEMd
	A	B	C	D	
Milk yield (kg/day) ^e	27.24	26.15	25.65	27.42	1.39
4% fat-corrected milk(kg/day) ^e	24.22	22.82	22.84	23.45	1.11
Milk production persistency ^e	99.02	94.65	92.02	98.94	6.77
Milk fat (%) ^e	3.31	3.20	3.20	3.01	0.14
Change in milk fat(%) ^{ef}	-0.54	-0.57	-0.54	-0.82	0.18
Milk protein (%) ^e	3.08	3.05	3.06	3.10	0.07
Dry matter intake(kg/day) ^e	18.20	19.00	18.30	18.7	2.78
Weight gain(kg/day) ^e	0.47	0.68	0.70	0.69	0.14
kg milk/kg dry matter ^e	1.51	1.38	1.44	1.49	0.06
Plasma glucose (mg/dl) ^e	60.54	57.85	60.63	59.94	1.89

^aValues are means of treatments.

^b8 cows per treatment for 12 weeks.

^cA = control; B = 10% PPW; C = 15% PPW; D = 20% PPW.

^dSEM = standard error of differences of means.

^eMeans on the same row were not significantly different ($P > .5$).

^fPre-treatment - treatment.

not significantly affected by PPW. It is also possible that the 24 and 36% levels of substitution used by Brown et al. (1983) were high and depressed milk yield. However, Brown et al. (1983) fed a mixture of potato and corn wastes so the results may not be directly comparable.

Raw potatoes in dairy cows' rations have been reported to cause no significant differences in milk production (Brabander et al., 1983; Chikun, 1976; Piatkowski and Voigt, 1979; Nicholson and Curtis,

1960). Also, data by Great Britain Ministry of Agriculture Fisheries and Food (1976) indicated that potatoes at between 17 and 24% of the ration dry matter can be fed to a 600 kg Friesian cow in mid-lactation. It is conceivable, therefore, that feeding potatoe processing wastes would not adversely affect milk production. However, Skjevdal (1974) reported that feeding raw potatoes to cows caused a significant decrease in milk production. It appears that the effect of whole potatoes or potato wastes on milk production depends on the other ingredients of the ration. When they were fed in combination with forage, there was no decrease in milk yield (Brown et al., 1983; Piatkowski and Voigt, 1979; Nicholson and Curtis, 1960). But when fed without forages (Skjevdal, 1974) milk production decreased.

Milk Fat and Milk Fat Percent Change

Percent milk fat and change in milk fat percent are shown in Table 5. Although there is a decreasing trend in milk fat with increased PPW in the ration, the differences between treatments were not statistically significant. The decreasing trend in milk fat does not agree with the result of Brown et al. (1983) who reported no significant difference in milk fat between treatments but noted a tendency toward higher fat percent in the potato wastes rations. The rations fed in the present study however, were much lower in fiber than those fed by Brown et al. (1983). Also about 10% of the PPW fed was cooked waste. These two factors might explain in the decreasing trend of milk fat percent as PPW increased since low fiber

rations and inclusion of steamed potatoes have been reported to decrease milk fat percent (Skjevdal, 1974). Concerning the effects of whole potatoes on milk fat, conflicting results have been reported. Nicholson and Curtis (1960) reported no significant differences when potatoes and silage were fed to dairy cows compared to control rations. Chikun (1976) and Piatkowski and Voigt (1979) reported significantly lower milk fat percent when cows were fed raw potatoes. In contrast, however, Brabander et al. (1983) and Skjevdal (1974) reported an increase in milk fat percent when cows were fed whole potatoes.

The change between pretreatment and treatment in milk fat percent shows that all groups decreased, but no differences were observed between the control, 10 and 15% treatments (-0.55). However, the 20% substitution resulted in a larger depression (-0.82), but differences were not significant ($P > .05$), probably due to large variability in the data. The trend toward decreased milk fat at 20% PPW will be discussed later in association with observed changes in rumen fermentation.

Milk Protein

Milk protein percent was highest at 20% PPW substitution. However, the difference between groups was not significant. Brown et al. (1983) reported no effect on milk protein when they fed potato by-products. Whole potatoes in dairy rations have also caused no difference in milk protein percent (Piatkowski and Voigt, 1979).

Dry Matter Intake

Differences between treatments in mean dry matter intake were not significant. Brown et al. (1983) reported a significant decrease in dry matter intake as percent by-product in the ration increased. The control of feed intake is a complex phenomenon which depends on many factors including palatability. In the present study, animals receiving the potato wastes ate enough of the wetter ration to balance the dry matter intake of the control group. This fact suggests that even though incorporation of the waste product into the ration reduces dry matter percent feed intake may not be adversely affected if palatability is unaffected or improved.

Weight Gains and Efficiency of Feed Utilization

One animal in each group lost weight during the experiment. Cows fed PPW gained more than the control group, but differences were not significant. These results agree with those of Brown et al. (1983) who fed potato and corn wastes and Brugman and Dickey (1961), who substituted potato pulp for yellow hominy in a dairy grain mix.

Efficiency of feed utilization (kg milk/kg dry matter intake) did not differ between treatments, agreeing with the data of Brown et al. (1983) and Brugman and Dickey (1961). These results suggest that dry matter from potato wastes is utilized as efficiently for milk production as that from high moisture shelled corn within the levels used in this experiment. Data by the Agricultural Development Advisory Service of the United Kingdom (1976) indicated that potatoes at between 17 and 24% of the ration dry matter can be fed to dairy

cows.

Plasma Glucose

Differences between treatment in plasma glucose were not significant. There is no data to compare the effect of potatoes or potato wastes on plasma glucose, but mean values are similar to those reported in the literature (about 60 mg/dl) (Anonymous, 1975; Kronfeld, 1982). The plasma glucose values may also be a reflection of the production levels of the different groups. Kitchenham et al. (1975) reported a negative relationship between blood glucose and milk yield. Thus, mean glucose concentration was lowest for the 20% PPW substitution group in which milk yield was highest and highest for the 15% PPW ration in which milk yield was lowest.

Rumen Volatile Fatty Acids (VFA) and pH

Acetate, propionate and butyrate production and acetate to propionate ratios are shown in Table 6. There are no significant differences between treatments in acetate, propionate and butyrate concentrations. There was, however, a trend toward higher concentrations of propionate (from 17.1 to 20.1 mM) as PPW in the ration increased. The increase in propionate may in part explain the observed increase in plasma glucose at 20% PPW, since propionate is a primary precursor for glucose synthesis in ruminants. The increase in propionate and glucose with increased PPW may also relate to the non-significant increase in milk protein. As pointed out by Hernandez-Urdaneta et al. (1976), the availability of substrates for gluconeogenesis (such as increased propionate) spares amino acids for protein

Table 6. Rumen fermentation characteristics^a of cows fed potato processing wastes (PPW)^b

Items	Rations ^b				SEM ^d
	A	B	C	D	
Total VFA (mM) ^e	76.0	73.6	78.9	78.8	5.36
Acetate (mM) ^e	48.6	46.7	51.1	48.5	0.35
Propionate (mM) ^e	17.1	17.4	18.2	20.1	0.19
Butyrate (mM) ^e	10.2	9.6	9.4	10.2	0.09
Acetate:Propionate ^e	2.93	2.75	2.90	2.57	0.17
pH ^e	7.08	7.03	7.03	6.99	0.12

^aValues are means of treatments.

^b8 cows per treatment for 12 weeks.

^cA = control; B = 10% PPW; C = 15% PPW; D = 20% PPW.

^dStandard error of differences of means.

^eMeans on same row were not significantly different ($P > .5$).

synthesis. The acetate to propionate ratio was not significantly different between treatments, but it decreased from 2.93:1 to 2.57:1 as PPW increased from 0 to 20% of the ration dry matter. This decrease if real was caused by the increase in propionate production and may in part explain the observed decreasing trend in milk fat percent.

pH (Table 6)

The pH was not significantly different between treatments. There was, however, a decline from 7.08 to 6.99 as PPW in ration increased but more variation occurred with treatments. The variation within treatments reflects the individual cows' responses to the potato wastes. It should be noted, however, that the stomach

tube technique for sampling of rumen fluid is prone to errors in pH because of saliva contamination.

Digestibility Experiment

Apparent protein digestibility: Table 7 shows means of nutrient digestibilities. Apparent protein digestibility was not significantly different between rations, but was lowest for 20% PPW. There is no comparable data on the effect of potato processing wastes on protein digestibility. However, Woodward et al. (1938) reported that in steers, the nitrogen of fresh potatoes was more digestible than that of dried and soaked potatoes. Also, Woodman and Evans (1943)

Table 7. Nutrient digestibilities of steers fed potato processing wastes (PPW)^a

Items	Rations ^b			SEMC
	1	2	3	
Apparent protein digestibility, %	72.97	74.36	71.28	2.03
ADF ^d digestibility	54.77 ^e	54.85 ^e	48.62 ^f	2.66
Dry matter digestibility	78.56	79.26	80.35	1.26

^aValues are means of treatment (6 steers/treatment in a 3x3 Latin square).

^b1 = Control; 2 = 10% PPW; 3 = 20% PPW.

^cStandard error of differences of means.

^dAcid detergent fiber.

^{e,f}Means with different superscripts differ (P<.25).

reported low digestibility coefficients for crude protein in three forms of dried potato products fed to sheep. Values of 45.5, 43.5 and 51.0% were shown for potato flakes, slices and cossettes respec-

tively. The authors stated that inclusion of any of the three forms in ruminant rations may depress protein digestibility. Nicholson and Friend (1965) reported 31.0% digestibility for crude protein in potato pulp fed to sheep as opposed to 52% in the horse. Wu (1980) working with swine reported that apparent digestion coefficient for nitrogen decreased with the addition of potato chips to the ration. The low values reported for the digestion coefficient of crude protein in dried products (Woodward et al., 1943) might have been caused by the formation of fiber bound or denatured protein as the products were dried at 165-180°F. Ryan and Ball (1962) isolated a powerful inhibitor to the protease chymotrypsin from potato (Solanum tuberosum) juice. The inhibitor is stable to heat, acids and alkali and forms a complex with trypsin.

In the present study the slight decrease in the apparent protein digestibility at 20% PPW substitution may have been caused by the depressing effect of PPW crude protein on the digestibility of protein in the total ration or by increased excretion of metabolic fecal nitrogen. Assuming a 73% digestibility for the control ration (Table 7), substitution calculation gives a 64.5% digestibility for the crude protein in the PPW at the 20% substitution. This value of 64.5% is higher than the 31.0% reported for potato crude protein in sheep by Nicholson and Friend (1965). The difference here may be that the 20% PPW substitution was not high enough to depress total ration crude protein digestibility.

Acid Detergent Fiber (ADF) Digestibility

The ADF fraction of feed is the sum of cellulose and lignin in the ration, i.e. the lignocellulose. The PPW tended to lower ($P < .25$) ADF digestibility. Previous studies with potatoes or potato wastes did not measure fiber digestibility. However, Montgomery and Baumgardt (1965) reported that diets high in readily digestible carbohydrates depressed cellulose digestibility. Bailey and Macrae (1970) noted that diets high in soluble carbohydrates and starch increased the level of hemicellulose reaching the caecum because of alteration in rumen microbial population which decreased hemicellulose digestion. El-Shazly et al. (1961) reported that 1 g of starch partially inhibited the in vitro digestibility of 100 g cellulose and that 2 g starch caused complete inhibition. Stewart (1977) reported that cellulose digestion was inhibited by a fall in pH as cellulolytic microorganisms failed to grow in acid media.

In the present study pH though lowest in the control ration, also decreased at 30% PPW. The PPW is primarily an energy source and contains a similar amount of starch as the high moisture corn for which it substituted, but that starch was probably more digestible in the rumen than corn starch. Woodward et al. (1938) reported that the carbohydrates of potatoes were highly digestible. Sutton (1971) noted that 25% of the raw maize in a ruminant's ration may escape digestion in the rumen. Hence the higher percent PPW might have effectively provided more readily fermentable carbohydrate and/or starch for breakdown in the rumen. In summary, the de-

pression in ADF digestibility was probably due to an increased fermentation of readily digestible carbohydrate which resulted in a decrease in rumen pH.

Dry Matter Digestibility (DMD)

Differences in DMD were not significant but values increased as percent PPW in the ration increased. There are no dry matter digestibility data for rations containing processed potato wastes for comparison. However, Hinks and Armishaw (1975) and Orskov et al. (1969) reported no significant differences in ration dry matter digestibility when whole potatoes were incorporated into creep diets for calves or lambs respectively. Nicholson and Friend (1965) reported that inclusion of potato pulp into sheep ration decreased feces dry matter, which may imply an increase in the amount of feed dry matter digested.

Nitrogen Balance

Table 8 shows the nitrogen balance of the steers. Fecal nitrogen was decreased ($P < .10$) in the 20% PPW ration. However, urinary nitrogen did not differ significantly between treatments, nor was nitrogen retention significantly affected.

Daily fecal nitrogen was 34.7, 32.0 and 29.6 g and urinary nitrogen was 49.6, 43.2 and 32.0 g for 0, 10 and 20% PPW. The lower intake and digestion of nitrogen on high PPW was associated with the lower urinary nitrogen on 20% PPW.

Nitrogen retained was lowest at 20% PPW, values were 44.8,

Table 8. Nitrogen balance^a, weight change and efficiency of feed utilization of steers fed potato processing wastes (PPW)^b

Items	Rations, % PPW			SEM ^c
	0	10	20	
Nitrogen intake (g/day)	129.6 ^d	124.8 ^d	99.2 ^e	6.4
Urinary nitrogen (g/day)	49.6	43.2	32.0	11.2
Fecal nitrogen (g/day)	34.7 ^f	32.0 ^f	29.6 ^g	1.47
Digested nitrogen (g/day)	94.1	90.7	70.1	8.1
Nitrogen retained (g/day)	44.8	51.2	38.4	12.8
Urinary nitrogen as % of digested nitrogen	52.3	43.8	48.0	15.57
Fecal nitrogen as % of digested N	38.0 ^f	35.5 ^g	40.9 ^f	3.58
Nitrogen retained as % of digested N	47.7	56.2	52.0	14.25
Dry matter intake (kg/day)	5.69 ^f	5.78 ^f	4.45 ^g	0.4
Weight gain (g/day)	444.2	541.6	430.8	148.3
Weight gain/kg DM digested(g)	110.0	130.0	130.0	40.0
Weight gain/g nitrogen digested(g)	5.1	6.2	4.6	1.47

^aValues are means of treatments.

^bSix steers per treatment in a 3x3 Latin square.

^cStandard error of differences of means.

^deMeans in same row with different superscripts differ (P<.05).

^fgMeans in same row with different superscripts differ (P<.10)

51.2 and 38.4 g for 0, 10 and 20% PPW. Differences were not significant. However, the fraction of digested nitrogen retained was highest at 10% PPW. Nitrogen retained as percent of digested nitrogen were 47.7, 56.2 and 52.0% for 0, 10 and 20% PPW. Differences were not significant. PPW caused a nonsignificant de-

crease in the urinary nitrogen as percent of digested nitrogen. However, incorporation of PPW into the rations caused an increase ($P < .10$) in the fecal nitrogen as percent of digested nitrogen. Fecal nitrogen as percent of digested nitrogen were 38.0, 35.5 and 40.9% for 0, 10 and 20% PPW. There are no data to compare these results. However, Woodman and Evans (1943) suggested that the decrease in apparent protein digestibility in rations containing potato products was partly due to the increased excretion of metabolic fecal nitrogen.

Weight Gain and Efficiency of Feed Utilization

Daily weight gain was not significantly affected by treatment (442.6, 541.6 and 430.8 g/day for 0, 10 and 20% PPW). Brugman and Dickey (1961) reported that steers may gain as much as 2 lb per day when fed wet potato pulp. Nicholson et al. (1977) fed steers potato silage and corn silage and reported that even though the steers fed potato silage ate more, they did not gain more weight. Daily weight gain/kg dry matter digested were 110, 130 and 130 g for 0, 10 and 20% PPW, while weight gain was 5.1, 6.2 and 4.6 g/g digested nitrogen. Differences were not significant in either case. These results suggest that the PPW in complete rations is as well utilized for live weight gain as high moisture shelled corn, even though its protein may not be as efficiently used as that of high moisture shelled corn.

Rumen Studies

Volatile Fatty Acids (VFA) and pH: Table 9 shows the effect of PPW on some rumen parameters. Inclusion of the higher percentages of PPW decreased ($P < .005$) total rumen VFA (52.26, 51.05, 44.97 and 46.12 mM for 0, 10, 20 and 30% PPW) and acetate (33.74, 31.75, 27.60 and 26.48 mM) and acetate to propionate ratios (2.74, 2.65, 2.50 and 2.01). A trend towards higher ($P < .10$) propionate was observed with increased PPW in the ration. Orskov et al. (1969) observed an increase in propionate when they substituted potatoes for barley in cattle rations. The decrease in total rumen VFA may be explained by the decrease in dry matter intake (9.27, 9.64, 8.78, and 8.17 kg/day for 0, 10, 20 and 30% PPW). Approximately 80% of organic matter digested in the rumen is fermented to volatile fatty acids (Sutton, 1971) and level of individual acids may be affected by level and frequency of feeding (Bath and Rook, 1963). Total VFA increased with time after feeding (Table 10) and was inversely related to rumen pH. The shift in rumen fermentation towards higher propionate and lower acetate fermentation at 20 and 30% PPW was associated with the decrease in the milk fat percent observed in the lactation study. Even though mean pH values were not depressed, a trend towards higher pH was noted with increased PPW. pH decreased as hours postfeeding increased. The inverse relationship between pH and total VFA is supported by the results of Hoogenboom and Grieve (1970), who reported that pH was inversely proportional to rumen VFA concentration.

Table 9. Rumen fermentation characteristics^a of steers fed potato processing wastes (PPW)^b

Items	Rations ^c				SEM ^d
	1	2	3	4	
Total VFA (mM)	52.26 ^e	51.05 ^e	44.97 ^f	46.12 ^f	0.36
Acetate (mM)	33.74 ^e	31.75 ^e	27.60 ^f	26.48 ^f	0.28
Propionate (mM)	12.60 ^j	12.34 ^j	11.60 ^k	13.41 ^l	0.08
Butyrate (mM)	5.92	6.96	5.77	6.23	0.08
Acetate:Propionate	2.74 ^m	2.65 ^m	2.50 ^m	2.01 ⁿ	0.16
Rumen ammonia (mg/dl)	4.88 ^m	3.98 ^m	2.98	2.35 ⁿ	0.58
pH	5.78 ^j	6.06 ^k	6.28 ^k	6.13 ^k	0.20
DMI (kg/day)	4.21 ^e	4.38 ^f	3.99 ^g	3.17 ^h	0.06

^aValues are means of treatment which include all sampling times.

^bFour steers/treatment in a 4x4 Latin square.

^c1 = control; 2 = 10% PPW; 3 = 20% PPW; 4 = 30% PPW. 1, 2, and 3 were used in digestibility trials.

^dStandard error of differences of means.

^{efgh}Means in same row with different superscripts differ (P<.025).

^{ijkl}Means in same row with different superscripts differ (P<.10).

^{mn}Means in same row with different superscripts differ (P<.005).

DMI = dry matter intake.

Table 10. Effect of time of sampling on VFA and pH of steers fed potato processing wastes (PPW)

Rations ^a		Hours Postfeeding			
		0	2	4	8
1	VFA (mM)	44.62	46.71	49.04	55.97
	pH	6.36	5.77	5.55	5.43
2	VFA (mM)	49.78	47.60	48.85	57.97
	pH	6.69	6.01	5.88	5.68
3	VFA (mM)	47.52	47.00	42.42	52.95
	pH	6.80	6.33	6.20	5.80
4	VFA (mM)	38.80	44.92	49.67	49.10
	pH	6.80	6.08	5.81	5.82

^a1 = control; 2 = 10% PPW; 3 = 20% PPW; 4 = 30% PPW.

Rumen Ammonia

Inclusion of the higher percentages of PPW in the ration decreased ($P < .005$) rumen ammonia concentration (4.88, 3.98, 2.98 and 2.35 mg/dl for 0, 10, 20 and 30% PPW). Rumen ammonia concentration peaked 2 hr postfeeding. Tagari et al. (1964), using an artificial rumen, noted that addition of carbohydrates as starch caused a decrease in rumen ammonia concentration and that the extent of decrease depended on the amount of carbohydrate added. Lewis (1962) and Phillipson et al. (1962) also reported that addition of starch to rations decreased rumen ammonia concentration. This decrease may be associated with greater uptake of ammonia into microbial protein because of the higher readily available carbohydrates in the rumen.

SUMMARY AND CONCLUSIONS

The study was separated into two experiments: 1) a lactation experiment and 2) a digestibility and rumen fermentation experiment.

In the lactation experiment, 32 lactating Holstein cows were used in a randomized block design to determine the effects on milk production and composition of substituting potato processing wastes (PPW) for high moisture corn in a total mixed ration fed to dairy cattle. Rations contained on a dry matter basis, 0, 10, 15 and 20% PPW. Cows were randomly assigned to the rations based on milk yield during a 2-week pre-treatment period. The experiment lasted 12 weeks and cows were fed twice daily at 10% in excess of appetite. Cows were milked twice daily. Samples from an AM and PM milking were composited at biweekly intervals and analyzed for fat, protein and solids by infrared analysis. Feed samples were also composited every 2 weeks for analysis. Rumen fluid and blood were sampled on day 60 through stomach tube and tail vein, respectively. Rumen fluid was analyzed for acetate, propionate and butyrate and blood for plasma glucose. Cows were weighed on 2 consecutive days during the first and last weeks of the experiment.

Ration dry matter percent decreased as PPW increased in the ration. Dry matter intake, milk yield, percent fat corrected milk, milk production persistencies, milk fat percent and milk protein

percent were not significantly different between rations. These results agree with those of other workers (Brugman and Dickey, 1961; Brown et al., 1983). Also, liveweight gain and feed efficiency were not different between rations. Cows fed 20% of their dry matter as PPW shifted in rumen volatile fatty acid proportions towards lower acetate and higher propionate. Ratios of acetate to propionate were 2.93, 2.75, 2.90 and 2.57 for the respective rations. Total VFA concentrations and pH were not affected by treatment, but there was a trend towards increased propionate concentration as PPW increased.

Experiment 2 was separated into two trials. In trial 1, six yearling steers were used in a 3x3 Latin square design to determine the effect of PPW on digestibility and nutrient utilization. PPW was substituted for high moisture in the ration at 0, 10 and 20% of the dry matter. Rations were formulated to be isonitrogenous at 14% crude protein. Steers were adapted to rations for 7 days and feces and urine were collected for 5 days. Steers were fed once daily and weighed at the beginning of each feeding period and on the last day of each collection period. Feed and orts were collected and sampled once daily. Feces and urine were kept at -5°C until composited and analyzed. Feed and feces were analyzed for dry matter, crude protein (total nitrogen x 6.25) and acid detergent fiber and urine for crude protein.

In trial 2, four rumen-fistulated steers were used in a 4x4 Latin square design to characterize some rumen fermentation para-

meters. Three rations used were similar to those of trial 1 and the fourth contained 30% of the ration dry matter as PPW. In addition to PPW and high moisture corn (43, 33, 23 or 13% of the DM) all rations were composed of 7% protein supplement, 25% corn silage and 25% haylage. Steers were adapted to rations for 9 days and rumen contents sampled at 0, 2, 4 and 8 hr post-feeding on day 10. To stop fermentation, 0.1 ml mercuric chloride was added to the rumen liquor which was then strained through four layers of cheesecloth and stored frozen at -5°C until analyzed for VFA by gas chromatography.

Level of PPW did not significantly affect digestibility of dry matter (78.6, 79.3 and 80.3% for 0, 10 and 20% PPW), crude protein (72.97, 74.22 and 71.28%), nitrogen retention (44.8, 51.2 and 38.4 g), daily weight gain or efficiency of feed utilization. Digestibility of ADF (54.77, 54.88 and 48.62% for 0, 10 and 20% PPW) tended to decrease ($P<.25$) at the highest level of PPW. Also, the higher percentages of PPW in the ration decreased ($P<.005$) total rumen VFA (52.2, 50.4, 45.0 and 46.1 mM for 0, 10, 20 and 30% PPW); acetate (33.74, 31.75, 27.60 and 26.48 mM) and acetate to propionate ratios (2.74, 2.65, 2.50 and 2.01). Propionate increased ($P<.10$) as PPW increased and rumen ammonia decreased ($P<.005$) (4.88, 3.98, 2.98 and 2.35 mg/dl). A trend towards higher ($P<.10$) pH was also observed with increased PPW.

Results of the lactation experiment show that wet potato processing wastes can replace part of the grain in a total mixed ration for dairy cattle. However, milk fat may be depressed if 20% or more

of the ration dry matter is potato wastes. The digestibility study indicates that feeding potato processing wastes up to 20% of the ration dry matter will not adversely affect nutrient digestibility. However, more than 20% of the ration dry matter as PPW may depress ADF digestibility and cause a shift in rumen fermentation which was associated with the depression of milk fat.

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