THE DIGESTIBILITY OF ENGLISH AND CANADIAN WHEATS WITH SPECIAL REFERENCE TO THE DIGESTIBILITY OF WHEAT PROTEIN BY MAN

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The digestibility of protein is usually determined by measuring the intake by mouth and the output in the faeces. Then the expression 'food N − faecal N × 100/food N' is said to give the apparent or percentage digestibility. It has been appreciated for a long time that the true digestibility must be higher than the apparent digestibility, because some of the N in the faeces must have come from the intestinal secretions (Rubner, 1918). This fraction of the faecal N has been referred to variously as Stoffwechselproducte, metabolic N, endogenous N, etc., and attempts have been made to measure it from time to time. Some have placed the experimental persons or animals upon N-free diets (Rubner, 1916; Martin & Robison, 1922; Boas-Fixsen & Jackson, 1932; Hutchinson & Morris, 1936). Attempts have even been made to subdivide the endogenous faecal N into a constant fraction, which was excreted even during starvation, and a fraction which varied with the quantity (Mitchell, 1924; Schneider, 1934) and nature (Rubner, 1918; Hutchinson & Morris, 1936) of the food.

The digestibility of wheat is an important subject in human nutrition, and has been studied by a number of investigators. These experiments have mainly been inspired by a desire to compare the digestibility of white with that of various shades of brown bread. They have been limited to apparent digestibility, and their results have been summarized by Macrae, Hutchinson, Irwin, Bacon & McDougall (1942) and by McCance, Widdowson, Moran, Pringle & Macrae (1945). The older experiments were not carried out with the ritual which is now considered essential for metabolism studies, but the general conclusions are clear. Raising the extraction of the wheat always lowers the apparent digestibility of calories and of protein. The separate investigators agree quite well among themselves over the figures for calories (McCance *et al.* 1945), but there are wide disagreements about protein. Thus the digestibility of the N in whole wheat has been found to vary from 63 to 79·2 % and in white flour from 75 to 90·1 %. Macrae *et al.* (1942) obtained high digestibilities and advanced a reason for this. 'The proportion of N in the foodstuff under investigation seriously influences the apparent digestibility. If small, the endogenous contribution of N to the faeces is proportionately high.... The white and whole meal bread used in our experiments contained 2·70 and 2·91 % N respectively on a dry matter basis, an exceptionally high percentage.' They supported these conclusions by referring to the work of Snyder (1901, 1905), the only investigator who had at that time compared the digestibility of a low-protein with that of a high-protein wheat. Unfortunately, Snyder's technique was far from satisfactory by modern standards. Although he tried three different extractions of each wheat, he used only short, 4-day periods on each, and there were no 'preliminary' or 'after' days. Furthermore, the subjects were allowed to drink as much milk as they wished, and some of them were getting half their calories and up to three-quarters of their protein from this source.

The present experiments were planned to determine the true digestibility of wheat protein. In order to do this two wheats were procured containing very different amounts of N. Their apparent digestibilities were compared at two levels of extraction. From this data—assuming the wheats to be equal in all important respects apart from protein—it should be possible to calculate the true digestibility at each level of extraction, and also the metabolic or endogenous nitrogen on each particular diet. For, assuming equal amounts of each flour to have been eaten, if all the N in the faeces were unabsorbed wheat N, the ratio of the two faecal nitrogens should be the same as that of the two food nitrogens; but if all the N in the faeces were metabolic N, the ratio of the two faecal nitrogens should be 1. An intermediate ratio would indicate how much of the faecal N had come from the wheat and how much from the digestive glands.

METHODS

Subjects. The experiments were carried out on two men and four women. They were divided for experimental purposes into two groups, and their initials, occupation, sex, age, height and weight

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were as follows: Group 1: M.C., student dietitian, ♀, 21, 163 cm., 58·3 kg.; R.M., physician, ♂, 46, 180 cm., 60 kg.; E.W., scientist, ♀, 37, 163 cm., 63·9 kg. Group 2: C.W., research student, ♀, 21, 160 cm., 54·6 kg.; R.T., medical student, ♂, 19, 184·5 cm., 77·5 kg.; B.W., research student, ♀, 22, 155 cm., 52 kg.

Experimental arrangement. The experiment was divided into four parts. Each lasted for 11 days and consisted of (*a*) 3 preliminary days during which the experimental diet was taken but the excreta were not collected; (*b*) 7 days during which carmine was taken before the first meal and faeces were saved for analysis from the time it appeared; (*c*) an 'after' time, usually about 24 hr. in length, in which carmine was again taken with the first meal and the experimental diet was continued until it appeared. McCance & Widdowson (1942) should be consulted for further details.

Four flours were prepared from two grists. Their composition on a 15% moisture basis was as follows:

Type of wheat	% extraction	Protein (N × 5·7) (g./100 g.)	Fibre (g./100 g.)
English	80	8·15	0·17
Manitoba	80	13·05	0·24
English	90	8·32	1·15
Manitoba	90	13·51	1·15

The two 80% extractions were commercially milled samples without any 'additions' or 'improvers'. The two 90% flours were reconstituted for this experiment by members of the Cereals Research Station at St Albans. The experimental 'lay-out' was as follows:

Subject group	Flour consumed			
	Part 1	Part 2	Part 3	Part 4
1	90% Manitoba	90% English	80% Manitoba	80% English
2	80% English	80% Manitoba	90% English	90% Manitoba

In this way the effects of seasons, habit and other things were minimized and the two groups were never eating the same shade of bread. The last helped to avoid confusion, since the bread was all baked by one baker and the six people were messing together at one table.

Diet. This consisted largely of the bread under investigation. This was baked for us by Mr and Mrs Wilkin, Barrington, Cambs. Some of the flour was made into pastries and cakes. A little butter, some fat rendered out of bacon and small quantities of bramble and marmalade jelly were allowed. The only drinks permitted were water and weak tea without milk. Each person, if he remembered, took 50 mg. ascorbic acid daily. Thus for all practical purposes the flour constituted the sole source of N and furnished 77–93% of the total calories (Table 1).

The faeces were collected in tared glass bowls under dilute HCl. By applying a small pad of cotton-wool or toilet paper to the urethral orifice the women prevented any possible contamination of the faeces with urine. The faeces were prepared for sampling as described by McCance & Widdowson (1942), and duplicate portions of 100 g. dried at 95° C. till the loss of weight in 24 hr. was less than 0·1 g. They were then ground up and stored for analysis in tightly stoppered tubes. Portions of the faeces passed while eating the 80% flours were subsequently dried to constant weight.

Analytical technique. The N in the flour, bread, and faeces was determined by the Kjeldahl method (McCance & Shipp, 1933), using Cu selenide as catalyst and heating for many hours after the digests had first cleared. The calorific value of the breads, flours and faeces were determined by bomb calorimeter, and by calculation also in the case of some of the faeces (Table 3). The calorific value of the fats, sugars and jellies were arrived at by calculation, using the factors given by McCance & Widdowson (1945).

RESULTS

Digestibility of calories. Table 1 gives the calorie intakes and outputs for the four parts of the experiment. The individual intakes varied from 11,665 to 31,000 in the 7 days, but each person's intake was approximately the same in all four parts. The averaged intakes varied only from 19,740 in part 1 to 20,430 in part 4, and may be considered to have been constant. There are four comparisons in digestibility to be made. (1) English flour 90% extraction, Manitoba flour 90% extraction. It will be seen that the figures for these two flours were—as it was hoped they would be—almost identical, indicating that the two flours were equally well digested and absorbed. (2) English flour 80% extraction, Manitoba flour 80% extraction. The Manitoba flour was slightly better digested and absorbed by all except B.W., whose figures may be considered identical. This result was anticipated when the experiments were being carried out, for, except in the case of B.W., the 80% English flour produced more fermentation and larger stools than the 80% Manitoba. In two of the subjects the disturbance amounted almost to diarrhoea for a short period of time. Both groups of subjects were affected, so that the upset must be attributed to something in the physico-chemical nature of the flour and not to some mild epidemic gastro-intestinal infection. This matter will be referred to again. (3) English flour 90% extraction, English flour 80% extraction. The 80% was more completely digested and absorbed, as might have been expected from all the previous work which has been carried out on the effect of raising and lowering the extraction on the digestibility. The difference would probably have been slightly larger had this particular English flour not produced some intestinal disturbance. (4) Manitoba flour 90% extraction, Manitoba flour 80% extraction. The difference expected from previous work was again obtained.

No previous workers have used quite the same extractions or grists as those employed in this investigation. Newman, Robinson, Halnan & Neville (1912) came nearest, but some of their periods were only 3 days in length and only two subjects took part in some of their experiments. They found the percentage digestibility of their total rations to be 91·4 at 92% extraction and 92·1 at 88% extraction, say 91·8 at 90% extraction, and they found also the percentage digestibility of their total rations to be 95·8 when they were eating a 'standard' flour of 80% extraction. These figures are close to the present ones.

Table 1. *Calorie digestibility*

Subject	Calories in 7 days' food	Distribution of calories: % from wheat	% from fat	% from sugars	Calories in 7 days' faeces	% digestibility of total intake
			90% English			
M.C.	19,026	78·0	11·2	10·8	1,110	94·2
R.M.	29,070	93·0	3·8	3·2	2,270	92·2
R.T.	23,288	81·4	10·1	8·5	1,470	93·7
B.W.	17,370	79·0	12·8	8·2	1,170	93·2
C.W.	17,993	80·0	10·4	9·6	1,130	93·3
E.W.	11,665	79·5	11·9	8·6	790	93·2
Average	19,740	82·0	9·8	8·2	1,322	93·3
			80% English			
M.C.	20,031	79·3	11·5	9·2	842	95·8
R.M.	31,003	93·0	3·8	3·2	1,325	95·7
R.T.	24,102	82·4	9·1	8·5	960	96·0
B.W.	17,284	77·5	12·5	10·0	615	96·6
C.W.	18,803	80·5	9·2	10·3	900	95·2
E.W.	13,751	78·8	14·7	6·5	745	94·4
Average	20,830	81·9	10·1	8·0	898	95·6
			90% Manitoba			
M.C.	18,941	77·6	11·6	11·0	1,330	93·0
R.M.	28,477	93·0	3·8	3·2	1,905	93·3
R.T.	22,479	81·1	10·3	8·6	1,340	94·0
B.W.	17,419	78·6	13·0	8·4	1,300	92·5
C.W.	17,656	79·6	9·4	11·0	1,165	93·4
E.W.	15,240	78·0	14·1	7·9	985	93·6
Average	20,040	81·3	10·4	8·3	1,334	93·3
			80% Manitoba			
M.C.	18,864	78·4	11·3	10·3	617	96·7
R.M.	29,478	92·0	4·4	3·6	1,050	96·4
R.T.	23,531	81·9	10·1	8·0	730	96·9
B.W.	17,865	77·0	13·3	9·7	575	96·8
C.W.	18,282	80·2	9·8	10·0	538	96·9
E.W.	14,572	80·0	13·5	6·5	500	96·6
Average	20,430	81·6	10·4	8·0	668	96·7

Protein digestibility. Table 2 gives the N in the food and the faeces and the apparent digestibility of the four different kinds of flour. There are again

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four comparisons in intake and digestibility to be made:

(1) English flour 90 % extraction, Manitoba flour 90 % extraction. The intakes were much lower on the English flour and averaged only 68 g. in the 7 days against 100 g. on the Canadian flour. In spite of this difference in intake the N in the faeces was very nearly the same on the two regimes, and in fact it was slightly higher on the English flour. The apparent digestibility, therefore, was not the same for the two types of flour, and averaged 80 % for the English and 87·2 % for the Manitoba. This proves that Snyder (1905) was correct in stating that the quantity of protein in the wheat affects its apparent digestibility, and all the work which has been carried out before or since on the digestibility of wheat protein must be reconsidered in this light. It is, however, difficult to do so satisfactorily, for most workers, including Snyder himself (1905), incorporated milk in their rations up to quite large amounts, and many did not use the same wheats for the two extractions which they wished to compare. It is more instructive to employ only the present data to assess the true digestibility of wheat proteins. If all the protein in the faeces had been unabsorbed wheat protein one would have expected the faecal N on the English wheat to have been 68/100 times the N on the Manitoba wheat. Since,

Table 2. *Intake and digestibility of wheat protein* (N)

Subjects	N in 7 days' food (g.)	N in 7 days' faeces (g.)	% digestibility	N in 7 days' food (g.)	N in 7 days' faeces (g.)	% digestibility
		90 % English			90 % Manitoba	
M.C.	60·3	11·3	81·5	89·8	11·0	87·7
R.M.	110·0	20·8	81·7	161·0	19·3	88·0
R.T.	79·8	15·3	81·2	113·0	12·8	88·7
B.W.	58·3	12·3	78·8	80·5	11·9	86·0
C.W.	60·8	13·7	77·5	86·1	13·1	84·8
E.W.	38·0	8·3	78·2	77·8	8·6	89·0
Average	68·0	13·6	80·0	100·0	12·8	87·2
		80 % English			80 % Manitoba	
M.C.	59·3	12·2	79·4	90·2	8·8	91·0
R.M.	110·0	17·0	84·5	166·0	15·3	90·8
R.T.	76·7	13·1	82·9	117·0	9·6	91·8
B.W.	54·9	8·2	85·0	83·7	9·0	89·3
C.W.	58·3	8·0	86·3	89·1	7·6	88·1
E.W.	43·0	8·8	79·5	68·5	5·8	91·5
Average	67·5	11·2	83·4	102·2	9·3	90·9

Table 3. *Analysis of the faeces passed on the* 80 % *flours*

Subject	Total dry wt. (g.)	N × 6·25 g.	Fat (g.)	Residue (g.)	Calories calc.	Calories bomb
			80 % English			
M.C.	165	77	8	80	839	842
R.M.	246	106	10	130	1138	1325
R.T.	173	82	12	79	904	960
B.W.	119	51	8	60	612	615
C.W.	168	50	1	117	784	900
E.W.	140	55	7	78	709	745
Average	169	70·2	7·7	90·7	831	898
			80 % Manitoba			
M.C.	120	45	6	69	600	617
R.M.	204	95	12	97	1053	1050
R.T.	145	60	10	75	746	730
B.W.	124	56	6	62	632	575
C.W.	106	48	4	54	535	538
E.W.	98	36	7	55	499	500
Average	133	56·7	7·5	68·7	678	668

however, the faeces contained almost the same quantity of N regardless of the intake, it is suggested that none of the protein originally present in the wheats was finding its way directly into the faeces and that all the N in the faeces was 'metabolic' N. If this is correct, it means that all previous workers on the subject have been measuring metabolic N, and not protein digestibility, at any rate at extraction rates up to 90 %, and this puts a very different complexion on their results.

(2) English flour 80 % extraction, Manitoba flour 80 % extraction. This comparison is not so satisfactory as the previous one because of the digestive upset previously mentioned, but if all the protein in 90 % flour is digested and absorbed, one would certainly expect the same to be true of 80 % flour. The intakes averaged 67·5 g. on the English flour and 102·2 on the Manitoba. The corresponding outputs were 11·2 and 9·3 g. and the apparent digestibility 83·4 and 90·9 %. In order to find out if possible what effect the two flours had had on the composition of the faeces, the stools passed on the two regimes were dried to constant weight and analysed for fat. The results are given in Table 3. The calories were calculated on the assumption that the residual matter in the faeces was carbohydrate in nature, and the factors used were 5·6 for protein, 9·3 for fat and 4·2 for carbohydrate. The table shows that the faeces passed while eating English flour contained no more fat but slightly more residual matter and protein. On the English wheat the calculated calories of some of the subjects, notably R.M., R.T., C.W. and E.W., were lower than the 'bomb' data, and it is suggested that this may have been due to a loss of volatile acids during the second drying—to constant weight. The agreement was very satisfactory on the Manitoba diets. The excess of carbohydrate matter was greater than that of protein, but further analysis is not very illuminating. It is clear, however, that the additional faecal matter passed while the subjects were eating the English flour was not entirely wheat protein and was probably made up of fermentation and bacterial residues, mucous and other metabolic products. In spite of the slight uncertainty introduced into the quantitative aspects of the data at this extraction, there is nothing in them contradictory to the conclusions already reached as to the true digestibility of wheat protein and as to the effects of the amount of protein in the flours on the apparent digestibility.

(3) English flour 90 % extraction, English flour 80 % extraction and (4) Manitoba flour 90 % extraction, Manitoba flour 80 % extraction. Here we have comparative data similar to those of all previous workers. Raising the extraction lowered the apparent digestibility. It has been thought hitherto that the additional N which appeared in the faeces on raising the rate of extraction was partly due to N in the indigestible pericarp, and in the aleurone layer. Rubner (1916), however, always appreciated how much bran increased the output of metabolic N, and since, moreover, the present results with man strongly suggest that all or practically all the faecal N is metabolic N, then it is evident that raising the extraction at any rate up to 90 % lowers the apparent digestibility, not so much by introducing indigestible protein matter into the food as by raising the amount of metabolic N secreted into the gut. Hutchinson & Morris (1936) reached similar conclusions with ruminants.

DISCUSSION

The results now reported should not be unexpected to anyone who has made a study of the available literature. It has been recognized for some time that the contribution made by metabolic products to the N found in the faeces must be very considerable. Hutchinson & Morris (1936) demonstrated this for goats and cows, and it is no doubt the explanation of Reifenstein's (1944) results. This author found that in man the faecal N does not approximate to 10 % of the intake as is frequently assumed but tends to be relatively constant whatever the intake. It is perhaps surprising that the protein of bran should be completely digested and absorbed, but it has been shown that the aleurone layer of the grain is well utilized by rats (Jacquot & Guillemet, 1944). The matter of wheat, however, has never been specifically investigated in man, and the present results do call for a reappraisement of much of the work which has been published in the past. The completeness, for example, with which cereal proteins appear to be digested and absorbed suggests that the efficiency of the intestine must be of a much higher order than has hitherto been supposed. It may be argued that it makes little difference to the economy of the animal whether the faecal N came from the food or the gut, but in fact this is not the case. On a mixed diet complete digestion and absorption must be beneficial. Some again may put forward the view that it is not economical to raise the extraction rate of flour, and by so doing to add a small amount of vegetable protein to the food if the result is a large increase in the output of metabolic N and of a valuable assortment of amino acids. The evidence, however, is against this view, for, first, it has often been shown that raising the extraction leads to a net gain of crude protein for human nutrition, and secondly, the protein added when the extraction is raised comes from the germ and the aleurone layer of the bran and both appear to contain a rich and valuable mixture of amino acids.

Some people who have read the manuscript of

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this paper have criticized the authors for not using a whole-meal flour. It is easy to be wise after the event. In planning these experiments the authors naturally considered using such a flour, but they did not do so, partly because they thought it would be unpleasantly laxative, but mainly because they did not expect to find the protein in the 90 % flour completely digested and absorbed. It is this finding which points to the desirability of work with a whole-meal flour.

SUMMARY

1. Two men and four women carried out digestibility experiments on English and Canadian wheats at 90 and 80 % extractions. The flour was the only source of protein and contributed 77–93 % of the total dietary calories.

2. At 90 % extraction the digestibility of the diets in terms of calories was unaffected by the source of the flour and amounted to 93·3 %. At 80 % extraction the digestibility of the diet containing English wheat amounted to 95·6 % and of those containing Manitoba wheat to 96·7 %. The difference is attributed to mild intestinal upsets on the English flour.

3. The apparent digestibility of the protein depended upon the amount of N in the wheat and fell as the extraction rose. A quantitative analysis of the results indicates that the protein in wheat flour of 90 and 80 % extraction is completely digested and absorbed, and that the N found in the faeces is entirely derived from the secretions of the gut.

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