The Chemical Composition of Wheat and Rye and of Flours derived therefrom

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Considering the outstanding importance of wheat to man, curiously few comprehensive studies of its chemistry have been made. It is, however, well known that variety, soil and climate all affect the chemical composition of wheat. Our knowledge of the subject was summarized in broad fashion by Booth, Carter, Jones & Moran (1941 *a*, *b*), whilst a detailed survey of the literature has since been published by Bailey (1944). Both these publications indicate the lack of precise information on the general chemistry of flours of different extraction prepared from the same wheat grist. This is clearly a problem of great importance, particularly in war time, when the rate of extraction must be fixed at that level which guarantees, in the diet as a whole, adequate amounts of those nutrients which are supplied by bread. Accordingly, a study of the changes in the composition of flour with change in extraction was undertaken jointly by the Research Association of British Flour-Millers (now the Cereals Research Station of the Ministry of Food), St Albans, and the Department of Medicine, Cambridge.

WHEAT MIXTURES USED

The following wheat mixtures have been milled and analyzed.

(1) A typical all-Manitoba grist. The system of wheat marketing in Canada makes it comparatively easy to obtain a sample which may be taken as representative of Manitoba wheat. In order to do so, samples were obtained from 24 different shiploads of wheat reaching this country during the months of June, July and August 1943. These originated from five different ports on the Atlantic coast and two ports on the Pacific Coast. There were 12 samples of No. 1 Northern Manitoba and 12 samples of No. 2 Northern Manitoba. One sample of each grade came from the Pacific coast. West coast shipments, therefore, made up a little more than 8% of the whole. Equal weights of the 24 samples were incorporated into the grist. (2) A typical all-English grist. It is much more difficult to obtain a grist truly representative of English wheat, for there is no system of grading and no adequate information on the relative amounts of the main varieties which are produced. In addition, many farmers grow unnamed varieties of wheat. For the present purpose, samples of as many of the known varieties as possible were obtained. Additional samples of popular varieties were then collected and added to the grist to weight the mixture in their favour. Thus there were, in all, four samples of Squareheads Master, three of Little Joss and Holdfast, two each of Yeoman, Hybrid 27, Juliana, Bersee, Victor and Als, and one sample of each of 10 other varieties. In all, therefore, there were 19 varieties and 32 different samples. The wheats were all grown in Wiltshire, Cheshire, Bedfordshire, Hertfordshire or Cambridgeshire in 1943, and the same weight of each sample was taken for making up the grist. (3), (4) and (5) Grists containing 70% Manitoba and 30% English. (6) A grist of 85% Manitoba and 15% English. (7) A grist of 80% Manitoba, 10% English and 10% Argentinian (Plate). (8) A grist of 80% Manitoba, 7·5% Plate and 12·5% English.

Grists 1 and 2 were milled in an experimental laboratory mill to the following percentage extractions: 100, 85, 80, 75, 70, and 42–46 (patent flour). Grists 3–8 were milled to 100, 85, and 75% extractions in commercial mills in the first half of 1942. It must be pointed out, however, that 'percentage extraction' is not a rigid standard, since different mills produce flours of slightly different composition, even from the same grist and at the same nominal extraction. The differences are greatest at extractions above 75%, and the reason has become clear during the past 2 or 3 years. It is now known, for instance, that the scutellum fraction of the germ contains some 60% of the total aneurin in the wheat berry (Hinton, 1944), that the bran is particularly rich in iron and nicotinic acid, and that the outer endosperm, adjoining the bran, is rich in protein, iron, phosphorus and nicotinic acid (Moran, 1945). At extractions above 75% varying amounts of scutellum, bran and outer endosperm may be milled into the flour, and since they are such rich deposits of certain nutrients the composition of the final flour will depend largely upon how much of each of them is included. With these reservations in mind (Kent, Simpson, Jones & Moran, 1944; Moran & Drummond, 1945), we believe, nevertheless, that the results of the present investigation do give a general idea of the behaviour of wheat on milling, and this information does not appear hitherto to have been available.

To widen the scope of the investigation a grist of mixed English rye has also been milled in the laboratory to 100, 85, 75, and 60% extractions, and these four flours have been analyzed.

METHODS

The Cereals Research Station obtained the wheats and rye and were responsible for their milling. Some of the analyses were made at St Albans and some at Cambridge. A number were made independently in both places and the results compared. If these did not agree the reasons for the differences were investigated. The following methods have been used: *Total* N: the Kjeldahl-Gunning-Arnold method (Association of Official Agricultural Chemists, 1940, p. 26). The results were converted to 'protein' by multiplying by the factor 5·7. *Purine* N: von Fellenberg's method (1918) (see McCance & Shipp, 1933). *Moisture*: a weighed sample of about 5 g. was heated overnight in an electric oven at 100°. The loss of weight was determined and taken to represent the amount of moisture initially present. Work on a few samples indicates that somewhat higher figures for moisture would have been obtained by drying the flours in a high vacuum at a very low temperature. *Fat*: von Lieberman & Szekely's (1898) method has been used. It has been compared with the standard Soxhlet technique, which, as might have been expected, gave much lower results (McCance & Widdowson, 1942) and with a slight modification of one of the American 'official' methods (Association of Official Agricultural Chemists, 1940, p. 213), which gave somewhat higher results. This seemed to be due to the following causes. In von Lieberman's method the fatty acids are extracted with light petroleum after complete saponification, and subsequently titrated or weighed. In the 'official' method mixed solvents are used and the extracted material is weighed. These mixed solvents can easily be shown to extract more colouring matter and ponderable material than is extracted by light petroleum from a cereal which has been thoroughly saponified and then acidified, but they do not remove more fatty acids. Hence von Lieberman's method seemed to be preferable. *Available carbohydrate* (hereafter referred to simply as carbohydrate): samples were hydrolyzed by boiling with 1% (v/v) H_2SO_4 under a reflux condenser for 4 hr. and the resulting glucose determined by Lane & Eynon's (1923) copper reduction method. This technique had previously been checked against the methods for available carbohydrate given by Widdowson & McCance (1935). *Fibre*: a modification of the method described in the *Fertilisers and Feeding Stuffs Regulations* (1932) was used. The final filtration was carried out by suction through weighed papers (diam. 5·5 cm.). This avoided the transference of the fibre from one paper to another, as laid down in the 'official' method. The papers were treated with boiling alkali and subsequently washed in accordance with all the detail used in the actual estimation before they were dried and weighed. *Calories*: these have been determined by a variety of methods, and a special section is devoted to them. *Total ash*: the method used was substantially the same as that given in the Wheat (Examinations and Analyses) Byelaws (1939). 5 g. were incinerated overnight in a silica vessel at 580–600°, and the resulting ash weighed. *Potassium*: McCance, Widdowson & Shackleton (1936). *Calcium*: two methods were used, Greer, Mounfield & Pringle (1942) and McCance & Shipp (1933). Agreement was satisfactory. *Magnesium*: McCance & Shipp (1933). *Iron*: two methods were used, McCance *et al.* (1936) and a modification of the method given by Cowling & Benne (1942). In the latter, the colour of the ferrous *o*-phenanthroline complex was measured with a 'Spekker' absorptiometer, using Ilford No. 604 filters. *Phytate phosphorus*: two methods were used, McCance & Widdowson (1935) and Pringle & Moran (1942). Agreement was good. *Total phosphorus*: Briggs's (1922) method has been used (*a*) after wet combustion as described by McCance *et al.* (1936), (*b*) after dry ashing. A small amount of the ashed extracts containing about 1 mg. P was heated for 1 hr. in a water-bath after the addition of 4 drops conc. H_2SO_4. This made it certain that all phosphate was finally present in the *ortho* form. The solutions were then washed out into flasks graduated at 100 ml. and a sample of the 100 ml. taken for analysis. Table 1 shows that the two methods gave similar results. *Aneurin*: Nicholls, Booth, Kent-Jones, Amos & Ward (1942) and Booth (1942). *Riboflavin*: Barton-Wright & Booth (1943). *Nicotinic acid*: Barton-Wright (1944).

Table 1. *Total phosphorus in wheat, determined after a wet digestion or a dry ashing technique*

Type of flour	Total P (mg./100 g.) determined after: Wet digestion	Dry ashing
100% extraction	369	365
	348	352
	324	330
	336	336
75% extraction	112	110
	115	114
	108	108
	114	116

RESULTS

WHEAT

Chemical composition of wheats and flours from wheat

The composition of the Manitoba and English wheats and of the meals and flours made from them are given in Table 2. All the figures are related to a uniform moisture content of 15%, but in studying the figures, particularly for the unmilled wheats, it must always be remembered that English wheat in its natural state generally contains about 16% of moisture, Manitoba only some 12%. This difference has been masked by calculating all the results to a moisture basis of 15%. Comparing first the composition of the whole grains, it will be seen that the English wheat contained 8·89% and the Manitoba 13·62% of protein. Many determinations of the N in English and Manitoba wheats are available for comparison, and the figures obtained indicate that the composite samples collected for this investigation were representative of the two types of wheat.

The purine N was considerably higher in the Manitoba than in the English wheat. The additional protein in the former was evidently accompanied by additional nuclear material and was not merely storage protein. It is to be noted, however, that much more of the purine than of the total N was

Table 2. *Composition of Manitoba and English wheats*

(Results calculated on a 15% moisture basis.)

Percentage extraction	g./100 g.											mg./100 g.									
	Total N	Protein (N ×5·7)	Fat	Carbohydrate (as starch)	Kg. cal./100 g.*	Fibre (g./100 g.)	Purine N (mg./100 g.)	Aneurin (i.u./g.)	Riboflavin (μg./g.)	Nicotinic acid (μg./g.)	Ash (g./100 g.)	Na	K	Ca	Mg	Fe	Cu	Zn	Total P	Phytate P	Cl
										Manitoba											
100	2·39	13·62	2·49	63·0	328	2·15	55	1·18	1·7	55·0	1·53	3·2	312	27·6	141·0	3·81	0·60	3·73	350	242·0	38·5
85	2·38	13·57	1·70	67·2	339	0·33	40	0·92	1·0	13·3	0·75	4·1	146	18·5	61·8	†	†	2·16	188	96·1	44·5
80	2·32	13·22	1·43	68·8	341	0·13	35	0·65	0·8	11·0	0·59	2·9	112	15·4	44·6	†	0·27	1·63	139	63·4	48·5
75	2·29	13·05	1·32	69·5	342	0·10	34	0·29	0·7	9·6	0·44	—	87	13·1	30·4	†	0·22	1·22	109	36·8	48·0
70	2·24	12·77	1·16	70·0	341	Trace	18	0·22	0·7	8·4	0·41	2·2	82	12·8	26·9	†	0·18	1·16	97	30·0	47·8
42	2·07	11·80	0·86	71·2	341	Trace	13	0·09	0·5	7·0	0·34	1·8	71	11·1	21·5	†	0·15	1·00	82	14·0	45·0
										English											
100	1·56	8·89	2·23	66·8	323	2·08	31	0·96	1·7	48·0	1·52	3·4	361	35·5	106·0	3·05	0·65	3·16	340	233·0	35·5
85	1·50	8·55	1·46	72·0	335	0·42	17	0·84	1·2	10·5	0·70	2·9	179	24·5	35·0	2·22	0·36	1·77	153	72·8	42·2
80	1·44	8·21	1·28	73·5	340	0·19	12	0·60	0·8	9·0	0·58	2·1	151	21·5	24·0	1·65	0·27	1·30	118	57·1	44·4
75	1·40	7·98	1·13	74·2	339	0·15	9	0·42	0·6	8·0	0·46	2·2	118	19·2	16·8	1·35	0·22	1·02	93	30·4	44·9
70	1·39	7·92	1·04	74·5	339	Trace	8	0·28	0·6	7·5	0·43	2·1	111	18·9	13·9	1·40	0·22	0·97	84	25·1	45·0
46	1·34	7·64	0·76	75·8	341	Trace	6	0·16	0·5	5·0	0·37	—	99	15·2	8·7	0·95	0·20	0·84	68	10·3	41·5

* Energy values of protein, fat and carbohydrate taken as 4, 9 and 4 kg. cal./g. respectively. † Contaminated during milling.

milled away from both wheats, so that purine N × 100/total N consistently fell on passing from the whole grains to the patent flours. These observations, which do not seem to have been made before, may be of some interest to those studying the physiology or the milling of the two wheats. It is evident that, whereas bread made from patent flours may rightly be regarded as almost purine-free, a diet containing much whole wheat of, say, Canadian origin would be quite the reverse (McCance & Widdowson, 1940). English wheat contained more carbohydrate to compensate for the lack of protein and fractionally less fat and fibre.

Turning now to the minerals and vitamins, for which few comparable figures are available, there is obviously a general similarity between the two wheats, but minor differences of a quantitative nature occur. Manitoba wheat contained less K, Ca and Cu, but more Mg, Zn and Fe and fractionally more P and phytic acid. There was also slightly more aneurin in the Manitoba wheat. These differences are probably real but their causes are unknown. Other samples of English and Manitoba wheats, for example, have been analyzed, and the English has always been found to contain more Ca, and Booth *et al.* (1941*a*, *b*) have also reported this. Some samples of Holdfast wheat grown in different parts of East Anglia were analyzed for Ca in an attempt to correlate the soil and the cereal chemistry, but the results were not encouraging.

Passing now to the composition of the various meals and flours, it will be seen that milling produced the effects which were, in general terms, already well known. The 85, 80, 75, 70 and patent flours contained progressively more carbohydrate than the whole wheats, but less of everything else except chlorides. Except possibly in the case of aneurin, the differences between the English and Manitoba wheats were continued into the flours milled from them. Table 2, however, gives little idea of the rate and extent to which milling removes the various substances, and to get any real picture of this, graphs must be constructed. Four illustrative ones (for protein, carbohydrate, aneurin and P) are given in Fig. 1. Fat, purines and all the minerals except chlorides give curves of the P type. The composition of flour of any desired extraction may be determined by constructing the appropriate curves and finding the answers graphically. The composition of the fractions milled away may also be calculated, if desired, from the data given in Table 2.

These figures and curves raise some rather interesting points. Since, on the one hand, the finer flours contain more Cl than the whole grain, the Cl must be concentrated in the inner rather than the outer endosperm or bran. On the other hand, elements and compounds thought to be mainly in the bran would be expected, naturally, to give curves of the

type shown in Fig. 1*d*. Such substances are K, P, phytic acid, Mg and Ca, Zn and Cu. These minerals, however, do not all mill off in exactly the same way. The percentage of Mg in the ash falls on passing from the whole grain to patent flour, whereas that of Ca rises (Teller, 1896; Sullivan & Near, 1927; Bailey, 1944). Unless special milling methods are used (Kent *et al.* 1944), the germ separates mainly with the fractions milled away between 85 and 75 %, suggest superficially that most of the fat was originally present in the bran. This, however, is not necessarily the case, for if the figures given by Booth *et al.* (1941 *a*, *b*) for the quantities of fat in the bran, germ and endosperm are accepted, and if it be assumed that the quantity of bran in any sample of wheat is six times the weight of the fibre (Moran & Pace, 1942) and that the germ amounts to 2·5 % of the whole grain (Booth *et al.* 1941 *a*, *b*), then the amount

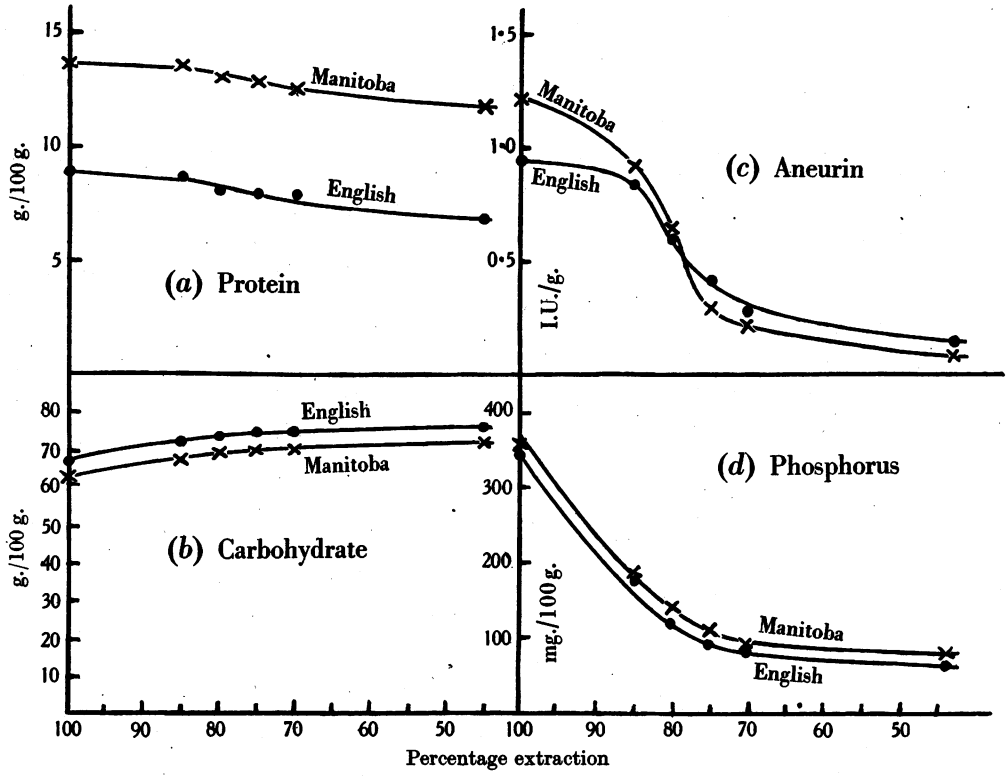

Fig. 1. The effect of milling on the composition of wheat.

and if a substance were present almost entirely in the germ—as aneurin is (Hinton, 1944)—then one would expect it to give a curve like that given by this vitamin (Fig. 1*c*).

According to Booth *et al.* (1941 *a*, *b*) typical figures for the bran, germ and endosperm are 15, 25, and 12 % of protein and 4·7, 10·8, and 1·2 % of fat respectively. Herd & Amos (1930) found the corresponding figures for fat to be 3·58, 6·72 and 0·99 %. Consequently the milling curves for protein and fat might be expected to be to some extent of the aneurin type. The protein curve may possibly so be described since the percentage of protein only begins to fall as the extraction shortens below 85 %, but the fat curve (Fig. 2) is of the type which might of fat in a whole wheat containing 2·18 % of fibre can be calculated to be 1·85 %. If further it be assumed that this wheat mills so that the 85 % flour contains 0·4 % of fibre, and practically all the germ, then the percentage of fat in the 85 % flour should be 1·56. The 75 % flour would contain about 1·2 % of fat if all the germ and the remaining fibre came away between 85 and 75 %. The curves which these figures make are shown in Fig. 2, and it is evident that had the bran and outer endosperm contained 6 instead of 4 % of fat a curve very like that of the laboratory mill would have been obtained. Thus the difference between the fat curves and the aneurin curves can be explained by the proportions of each substance present in the bran, germ and endosperm

and by the fact that the germ contributes only 2% to the weight of the whole wheat seed.

Table 3 shows the composition of the six mixed grists and of the corresponding commercial 85 and 75% flours. The composition of the whole wheats calls for no special comment, but there are some interesting points in connexion with the milled

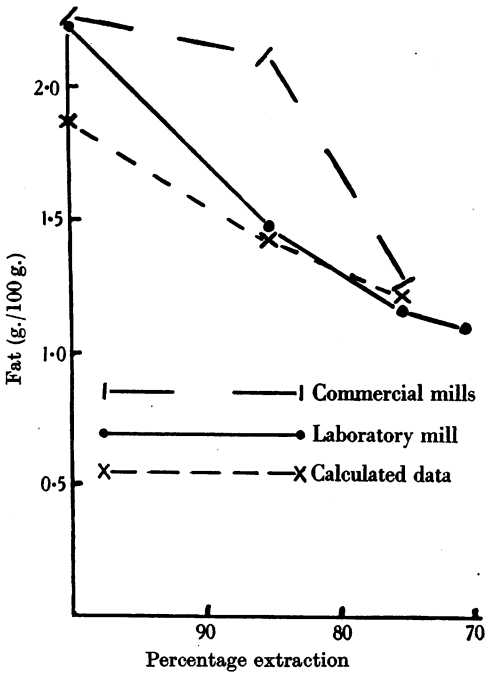

Fig. 2. The separation of fat in the milling of wheat.

products. It is evident that at that time the commercial mills were not getting the 85% flour so clear of fibre (bran) as the laboratory mill one year later, and most of the 85% flour milled commercially in 1943 and 1944 probably contained less than 0·5% of fibre (see Ministry of Food, Scientific Adviser's Division, 1942 *a*, *b*, 1943, 1944 *a*, *b*). The figures for fat indicate that very little separated with the bran in the commercial mills during the preparing of the 85% flour. Most came away with the fraction separating off between 85 and 75% (see Fig. 2). Thus fat separated mainly between 100 and 85% on the laboratory mill and between 85 and 75% on the commercial mill. As already stated, the behaviour of fat on the laboratory mill is in keeping with what is known of the composition of wheat, and unless the wheats which were being milled commercially in 1942 had a very unusual composition, it is difficult to explain how the commercial mills managed to pass so much of the fat in the whole wheat into the 85% flour. One possible explanation is that the commercial 85% extraction flours contained more of the outer endosperm than the corresponding

Table 3. *The composition of meals and flours milled commercially from various mixed grists*

(Results calculated on a 15% moisture basis.)

Wheat mixture	Percentage extraction	g./100 g. Total N	Protein (N ×5·7)	Fat	Carbohydrate (as starch)	Kg. cal./100 g.*	Fibre (g./100 g.)	Aneurin (i.u./g.)	Riboflavin (μg./g.)	Ash (g./100 g.)	mg./100 g. K	Ca	Mg	Fe	Total P	Phytate P
1	100	2·31	13·2	2·39	63·0	326	1·95	1·2	1·9	1·55	346	32·0	154	4·0	365	255
2	100	2·32	13·2	2·52	63·0	328	1·80	1·2	1·9	1·38	327	30·1	136	4·2	330	240
3	100	2·33	13·3	2·16	62·5	322	2·05	1·2	1·9	1·48	348	30·7	140	4·3	336	248
4	100	2·16	12·3	2·24	63·5	323	2·15	1·2	2·2	1·43	365	30·5	130	4·4	343	252
5	100	2·22	12·7	2·17	62·0	319	2·10	1·2	1·8	1·38	305	31·4	126	3·7	322	240
6	100	2·23	12·7	2·00	62·0	317	2·05	1·2	1·9	1·50	320	33·3	128	3·8	332	243
1	85	2·32	13·2	2·40	66·9	342	0·50	1·1	1·7	0·81	191	19·9	65	2·4	202	116
2	85	2·33	13·3	2·26	68·9	348	0·60	1·0	1·7	0·80	168	22·5	64	2·1	186	105
3	85	2·32	13·2	2·03	68·0	343	0·50	0·95	1·7	0·77	155	18·4	62	2·6	187	104
4	85	2·14	12·2	2·00	68·0	339	0·35	1·0	1·7	0·80	174	21·1	56	2·8	190	108
5	85	2·21	12·6	2·12	66·5	335	0·35	1·05	1·2	0·85	168	21·0	64	2·4	197	118
6	85	2·16	12·3	1·84	68·0	338	0·65	1·05	1·7	0·89	182	23·0	68	2·3	200	118
1	75	2·22	12·7	1·14	69·5	339	Trace	0·5	1·0	0·44	110	14·3	33	1·0	110	44
2	75	2·20	12·5	1·41	71·0	347	0·15	0·3	0·7	0·47	103	15·1	32	1·1	108	43
3	75	2·23	12·7	1·25	70·0	342	Trace	0·45	0·7	0·48	105	14·6	36	1·5	116	48
4	75	2·06	11·7	1·20	70·5	340	Trace	0·5	0·7	0·55	120	16·7	34	1·8	124	54
5	75	2·09	11·9	1·22	71·0	343	0·20	0·5	0·7	0·51	108	17·3	34	1·4	118	54
6	75	2·08	11·9	1·14	73·0	349	Trace	0·6	0·6	0·55	123	16·7	33	1·5	120	52

* Energy values of protein, fat and carbohydrate taken as 4, 9 and 4 kg. cal./g. respectively.

laboratory milled flours. Preliminary experiments have shown that this part of the endosperm is relatively rich in fat; with one sample of Manitoba wheat a figure of 6·3 % was obtained. In any case it raises an interesting problem in milling technology.

The minerals separated on the commercial mills in very much the same way as they separated on the laboratory mill, but riboflavin did not do so. As in the case of fat, the laboratory plant milled off most of the riboflavin with the fraction which separated in the preparation of the 85 % flour, the commercial plants with the fraction separating between 85 and 75 % (Tables 2, 3). No explanation of this difference can be given until more experimental results have been obtained.

If all the solids which have been measured are added to the conventional 15 % of moisture it will be found in all the fine flours that the sum is very near 100. The average for the commercial 75 % flours was 99·84. In the original grists, however, the sum was less and averaged 95·86 for the commercial wheat mixtures. The figures for the Manitoba and English wheats were of the same order. The undetermined fractions of the whole wheats are made up of pentosans and other carbohydrates which neither hydrolyze with the starch nor separate with the fibre. They are not available as carbohydrate to man (McCance & Lawrence, 1929).

The assessment of calories in wheat and wheat flours

The calorific value of wheat is one of its most important assets in nutrition, and its determination correspondingly desirable. It is a difficult matter to decide upon the best approximation to the physiological value, but so important is it that more experiments have been carried out on wheat than upon any other foodstuff.

There are two common ways of finding out the calorific value of a foodstuff. The direct method involves the use of a bomb calorimeter, and the results so obtained, on the series of wheats whose chemical composition has just been described, are given in the first column of Table 4. The second or indirect method consists of analyzing the foodstuff for protein, fat and carbohydrate and multiplying the results by factors which are based upon the accepted heats of combustion of these substances. With the figures 5·65, 9·45 and 4·2 for protein, fat and starch respectively (Sherman, 1937), the necessary analysis and arithmetic produced the figures shown in column 2. It will be seen that the indirect method has given the more irregular results of the two, and that they are on average considerably lower for the 100 % wheats, practically the same for the 85 % extraction and slightly higher at 75 % extraction. Two reasons may be given for these differences. First, *all* the indirect figures are a little high because some of the nitrogen must be there in the form of purines and other bodies with lower heats of combustion than the proteins, and also because a little of the carbohydrate is present as maltose which should have a heat of combustion of about 3·96. Secondly, the indirect figures are rightly lower than the direct ones for the 100 % wheat, and they are slightly lower for the 85 % meal because protein, fat and starch did not account for the whole of the organic matter. In every 100 g. of whole wheat there are at least 4 g. of fibre, pentosans and other undetermined but chemically combustible material. Assuming that these will have heats of combustion of 4·2 cal./g., and deducting $4 \times 4{\cdot}2 = 16{\cdot}8$ cal. from the average total energy value of the 100 % wheat (as determined by the bomb calorimeter), a figure of 360 is arrived at, and this is very close to the indirect figure of 358. By and large, therefore, the agreement between the two methods is really excellent. The figures so far considered, however, are largely theoretical so far as human nutrition is concerned. No person would be able to derive as many calories from these samples of wheat as are set out in columns 1 and 2 because both the urine and the faeces always contain combustible materials. Two deductions, therefore, have to be made from these purely physical data to obtain an estimate of the physiological or available calories.

The loss by the bowel may be found by subjecting the faeces of a person living on bread to combustion in the bomb calorimeter. Macrae, Hutchinson, Irwin, Bacon & McDougall (1942) carried out such experiments when they were subsisting very largely upon 100 and 73 % flours, and similar tests have been made by others. The data are summarized in Fig. 3. The earlier workers tended to employ very short metabolic periods, and the estimates of Macrae *et al.* (1942), the Royal Society, Food (War) Committee (1918), Newman, Robinson, Halnan & Neville (1912) and of Krebs & Mellanby (1942) are probably the most reliable. Krebs & Mellanby, however, used dry weights to make their computations and not the results of calorimetry. If the figures 96, 94·5 and 87 % are taken for the digestibility coefficients of 75, 85 and 100 % flours respectively, the data in column 1 may be corrected for the losses in the faeces and the results are shown in column 3.

There is no doubt that the digestibility of wheat flour is largely a matter of the quantity of bran it contains, and the wheats used by Macrae *et al.* (1942) and others for their digestibility trials were not the same as those which have recently been analyzed. To meet such a difficulty, Moran & Pace (1942) devised a method of using the quantity of fibre in any sample of wheat to assess its digestibility. If this method of correcting the figures in column 1 is used, the figures given in column 4 are obtained.

Table 4. *The assessment of calories in wheat*

(Results calculated on a 15% moisture basis.)

Grists	Total energy kg. cal./100 g.		Available energy (kg. cal./100 g.)					
	Determined by bomb calorimeter	Calculated by use of factors 5·65, 9·45 and 4·2 kg. cal. for protein, fat and carbohydrate respectively	Bomb data after first correction (for digestibility) based on		Second correction (for urinary nitrogen)	Bomb data after second correction based on		By use of factors 4, 9 and 4 kg. cal./g. for protein, fat and carbohydrate respectively
			Digestibility experiments	Method of Moran & Pace (1942)		Digestibility experiments	Method of Moran & Pace (1942)	
			(1) Whole wheats					
All Manitoba	383	367	332	327	15	317	312	328
All English	372	351	324	318	9	315	309	323
Mixed 1	376	362	327	325	14	313	311	326
„ 2	375	363	326	327	14	312	313	328
„ 3	377	357	328	323	14	314	309	322
„ 4	375	358	326	319	13	313	306	323
„ 5	377	352	328	322	14	314	308	319
„ 6	375	351	326	322	14	312	308	317
Average	377	358	327	323	13	314	310	324
			(2) 85% extractions					
All Manitoba	379	374	358	360	16	342	344	339
All English	371	364	350	351	10	340	341	335
Mixed 1	375	378	354	353	15	339	338	342
„ 2	374	385	353	350	15	338	335	348
„ 3	375	380	354	353	15	339	338	343
„ 4	373	374	352	354	14	338	340	339
„ 5	373	371	352	354	15	337	339	335
„ 6	373	373	352	348	14	338	334	338
Average	374	372	353	353	14	339	339	340
			(3) 75% extractions					
All Manitoba	371	378	356	360	15	341	345	342
All English	366	368	351	352	9	342	343	339
Mixed 1	371	374	356	358	15	341	343	339
„ 2	371	381	356	358	15	341	343	347
„ 3	373	378	358	360	15	343	345	342
„ 4	378	373	358	359	14	344	345	340
„ 5	371	377	356	358	14	341	344	343
„ 6	372	384	358	359	14	343	345	349
Average	372	376	356	358	14	342	344	342

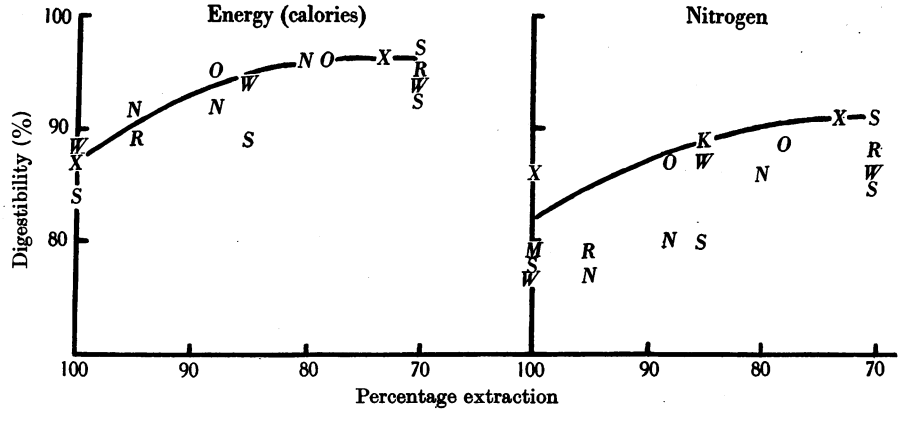

Fig. 3. The digestibility of wheat. *N*, Newman *et al.* (1912); *M*, Martin & Robison (1922); *O*, Royal Society (1918); *K*, Krebs & Mellanby (1942); *X*, Macrae *et al.* (1942); *R*, Rubner (1916); *W*, Woods & Merrill (1900); *S*, Snyder (1901, 1905).

The combustible materials in the urine are mainly products of nitrogen metabolism, which are not oxidized by the animal to the same extent as they are in the bomb calorimeter. The magnitude of the necessary correction may be assessed by multiplying each gram of protein which has been absorbed by 1·3 (Sherman, 1937), but this in turn involves an assessment of the percentage of nitrogen absorbed from the gut and excreted in the urine. A number of authors have attempted to solve this difficult problem by living on diets consisting largely of wheat, and some of their results are shown in Fig. 3. All of them are really too low because in all the experiments the diet contained foods other than bread, and some of the N in the digestive juices and faeces must be attributed to them. It is, moreover, clearly unwise to draw any line to average these scattered results, but the most satisfactory figures are probably those of Macrae *et al.* (1942), Martin & Robison (1922), the Royal Society, Food (War) Committee (1918), and Krebs & Mellanby (1942), and the digestibility of wheat N in 75, 85 and 100 % flours, has, therefore, been taken to be 91, 89 and 82 % respectively. The losses of calories in the urine, computed in this way, amount to the figures given in column 5, and when columns 3 and 4 are corrected for urinary losses by deducting the figures given in column 5 the estimates for the available calories given in columns 6 and 7 are obtained.

Yet another method of reaching a figure for the available calories is to multiply the protein, fat and carbohydrate in the wheat by factors which allow for the incomplete combustion and for the digestibility of these proximate principles. The figures 4, 9 and 4 are usually employed (Sherman, 1937). The factor 4 for protein assumes a digestibility of 92 %, but it would clearly only be correct to use this figure for the 75 % flour. The factors 3·6 and 3·9 would be more appropriate for the 100 and 85 % meals (see Fig. 3). The factor 4 for carbohydrate is based upon a figure 4·1 for the calorie value of the carbohydrate in a mixed diet and upon the assumption that 98 % of this carbohydrate is digestible. It happens to fit the conditions present in 75 % flour very well, for the starch in it has a calorie value in the bomb of 4·2 and the flour has an over-all calorie digestibility of 96 %. If, however, the factors 4 and 9 are correct for the carbohydrate and fat in 75 % flour with a digestibility of 96 % they must be too high for whole wheat with a digestibility of only 87 %. There is another way of reaching the same conclusion. Taking the average figures for whole wheat, 50 cal. are lost in the faeces for every 100 g. taken by mouth. Of these 50 cal., 8 can be assigned to protein and 17 to unavailable carbohydrate. This leaves 25 calories, i.e. about 8 % of the total calories attributable to starch and fat in every 100 g. of wheat. Factors of 8·7 for fat and 3·85 for carbohydrate would allow for these losses by the bowel.

The calorie values of these wheats obtained by using the factors 4, 9 and 4, are given in column 8. The figures are more variable than those in columns 6 and 7. The average figures in column 8, however, for the 75 and 85 % flours agree very well with the corresponding data in columns 6 and 7, but they are too high, as was only to be expected, for the 100 % meals. Had the factors 3·6, 8·7 and 3·85 been used, the calories for these meals would have averaged 309, and it is suggested that 310 be taken as a suitable figure for the available calories in whole wheats. The calorie value of 85 % meal is very close to that of 75 % flour but tends to be slightly lower—340 as against 342 cal./100 g.

Note. The factors 4·1, 9·3 and 4·1 which are generally used in England in preference to the factors 4, 9 and 4 allow for the incomplete combustion of the protein but not for digestibility. They give the sum total of physiological calories which a food provides and, suitably modified for carbohydrate, they are the best factors to use in the construction of tables which set out to give the composition of foods. To get over the use of the factor 4·1, which was always and at best a compromise between the correct factors for starch and monosaccharides, McCance & Widdowson (1942) expressed all the available carbohydrate in foods as glucose and multiplied the results by 3·75. The factor 4·2 would certainly be the correct one to employ for the starch in cereals and it should be noted that these factors, 4·1, 9·3 and 4·2 for protein, fat and starch respectively, would be equally correct for a patent flour or a whole meal.

Rye

Chemical composition of rye and rye flours

Table 5 gives the composition of an all-English rye grist and of three flours milled from it on the laboratory mill by a continental method using a much extended break system. The mixture was not a composite one and does not claim to be really representative of English rye. It was richer in vitamin B_1 than other samples which have been analyzed, and, although the grain contained less protein than the composite sample of English wheat, the figure 7·98 may be quite a high one for an English or a German rye (Kent-Jones, 1939). Rye grown in other parts of the world, however, may contain considerably more protein (Fox & Golberg, 1944). The methods of analysis accounted for 100·8 % of the 60 % flour and 95·24 % of the whole grain, figures very like those for wheat. The calories as determined by bomb calorimeter are shown in Table 6. No digestibility trials seem to have been carried out on rye, but the method of Moran & Pace (1942) may be used to arrive at the available calories and these data are given in the second column of Table 6. The available calories obtained by using the factors 4, 9

Table 5. *Composition of rye and its milled products*

(Results calculated on a 15% moisture basis.)

Percentage extraction	g./100 g. Protein (N × 5·7)	Fat	Carbohydrate (as starch)	Fibre	Aneurin (i.u./g.)	Riboflavin (μg./g.)	Ash (g./100 g.)	mg./100 g. K	Ca	Mg	Fe	Total P	Phytate P
100	7·98	1·98	69	1·56	1·45	2·90	1·72	412	31·5	92	2·70	359	258
85	7·30	1·64	73	0·84	0·98	2·00	1·04	203	26·1	45	1·97	193	104
75	6·67	1·33	75	0·48	0·80	1·40	0·72	172	19·5	26	1·72	129	57
60	5·64	1·01	78	0·22	—	0·85	0·51	140	15·3	16	1·32	78	24

and 4 for the protein, fat and carbohydrate respectively are given in column 3 and, as with wheat, the agreement is good for the fine flours, but the factors give higher figures for the 100% meal. It would probably be better not to use these factors for whole cereals.

Table 6. *The assessment of calories in rye flours of various extractions*

Percentage extraction	Total energy (kg. cal./100 g.) determined by bomb calorimeter	Available energy (kg. cal./100 g.) Determination based on method of Moran & Pace (1942)	Calculated from factors 4, 9 and 4 kg. cal./g. for protein, fat and carbohydrate respectively
100	367	317	326
85	365	329	336
75	363	339	339
60	361	343	346

The composition of the rye grain was, on the whole, similar to that of whole wheat, and in a general sense also milling did to the rye what it did to the wheat, but there were differences which deserve some comment. Enough protein milled away with the coarse bran to bring the amount in the 85% flour well below that in the grain, and the fall in the percentage of protein on passing from the whole meal to the finest flour was considerably greater than it was in the case of wheat. The rye contained less fibre, but this did not come away so clean, so that even the finest flour was left with 0·22% in it. Rye fat began to separate freely in the preparation of the 85% flour, and, although less of the total fat was milled away in preparing the finer rye flours the fat in rye behaved generally as did the wheat fat in the laboratory mill. The same may be said of the riboflavin.

SUMMARY

1. Representative samples of English and Manitoba wheats have been obtained and milled to 85, 80, 75, 70 and 42–46% extractions on a laboratory mill. The whole wheats and the flours have been analyzed.

2. On the assumption that each wheat had 15% of moisture in it, the Manitoba contained more protein, fat, Mg, Fe and Zn, and less carbohydrate, K, Ca and Cu than the English. The two wheats contained almost equal amounts of fibre, aneurin, riboflavin, Na, P and Cl. Similar relationships characterized the corresponding flours.

3. The flours milled from these wheats contained progressively more carbohydrate and less of almost every other nutrient. The extent of this fall and the stage of the milling process at which it took place differed from one constituent to another and was sometimes highly characteristic (Figs. 1, 2).

4. Mixed grists of Manitoba and English wheat and the corresponding 85 and 75% flours were obtained from six commercial mills. In their general relationship to each other and to the original grists these flours closely resembled those prepared on the laboratory mill, but there were consistent differences in the way in which the fat and the riboflavin separated.

5. The finest flours provide fractionally more available calories than 'National' (85% extraction) flour, and some 10% more than an equal weight of whole wheat.

6. The sample of English rye analyzed did not differ strikingly from English wheat but its constituents separated differently on milling. The finer flours contained proportionally less protein, and more carbohydrate and fibre, than the corresponding wheaten flours.

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Hypervitaminosis A

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Many forms of injury are known to occur in experimental animals when they are dosed with greatly excessive amounts of oils or concentrates containing vitamin A. Takahashi, Nakamiya, Kawakami & Kitasato (1925) tested the effect of excess of their crude concentrate 'Biosterin' when given orally to rats and mice, and observed loss of hair, emaciation and paralysis of the hind legs. After periods varying from a few days to several weeks the animals died, and at autopsy fatty degeneration of the liver,