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The essentials of the flour-milling process

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Technology

Fundamentally, two main divisions of the flour-milling process must be recognized: breaking and reduction. With wheat, the relative toughness of the bran and friability of the endosperm facilitate the separation of these materials by processes of crushing followed by sifting. On the other hand, the grain is awkwardly shaped and the endosperm is relatively firmly attached to its envelope. The grain must therefore be opened up initially and the contents spilled or released. They may then be separated from the unfurled bran coats, by means of sieves (known as scalpers), for subsequent crushing. The opening-up operation (termed 'breaking') requires a combination of pressure and shear, but shattering of the bran must be minimized since the extent to which bran fragments may be separated from endosperm after breaking varies inversely with the particle size of the mixture: for the same reason, the endosperm is desirably released mainly in the form of large particles.

Breaking process. The most effective means yet found for meeting the above requirements is a number of successive graduated treatments of the grain between pairs of spirally fluted chilled-iron rolls driven at different speeds. The rolls are progressively set closer together and more finely fluted throughout the four or five breaks usual in this country.

The scalping sieve through which the release is separated from the bran coats (or, better, break tails) becomes finer as the breaks proceed, ranging from a 1 mm aperture at the first break to 0·5–0·6 mm at the last. Basically the material passing over (overtailing) the last sieve is bran but it is perhaps better described as 'last break tails' because, to meet market requirements, it is generally sifted before sale.

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Only the material overtailing a sieve with apertures of about 1·3 mm forms commercial bran (or coarse wheatfeed); the throughs of this sieve form one of the contributions to fine wheatfeed.

The total release from the breaks, expressed as a percentage of the wheat, varies from about 81% in white-flour milling to about 93% in the milling of flour of 85% extraction. In the former it is made up roughly as follows (the actual figures may vary greatly with different types of wheat):

Stock	Particle size (mm)	Percentage of wheat
Semolina	*c.* 0·25–1·0	53
Middlings	*c.* 0·13–0·25	13
Flour (break flour)	Under 0·13	15

Successful reduction (the further processing of the semolina and middlings) requires that the material fed to the reduction rolls should be as nearly as possible homogeneous in particle size and in constitution. Hence, in preparation, semolinas and middlings are closely graded by sieving. Following this, a process, known as purification, removes free bran pieces from them easily by means of air drag (the air passes through a layer of material travelling along a sieve); these pieces pass directly, as 'purifier tails', to wheatfeed. Bran pieces with varying amounts of endosperm adhering (loaded bran) present more difficulty. Some, together with pieces of germ (embryo), remain in the 'choicest' stock ('throughs of head sheets') which passes, according to particle size, to one or other of the head (i.e. the high-quality) reduction rolls. On the principle of ensuring maximum homogeneity in roll feeds the intermediate separations from the purifiers pass to lower-quality reduction rolls. These separations contain loaded bran and pieces of scutellum in addition to endosperm. The throughs of the tail sheets are treated with finely fluted (scratch) rolls in what in one sense is an extension of the break system.

Reduction process. The difference in fragility of endosperm and envelope does not preclude overlap during reduction, which is carried out on rolls resembling the break rolls except that they have no flutings and are driven at nearly equal speeds. The bran mainly flattens but some disintegrates finely; endosperm particles are mainly reduced in size but some merely flatten. Skilful wheat selection and conditioning help but the degree of overlap may in general be reduced through regulation of grinding intensity. With coarser endosperm particles the tendency to flake is greater; the roll pressure is therefore appropriately restricted, so that most of the material is converted into particles, intermediate in size between semolina and flour, known as dunst. This operation occurs particularly on A rolls which receive the coarse semolina and to some extent on B rolls which receive the fine semolina. The grinds from these rolls are sifted on two successive grades of bolting silk with apertures of about 0·13 and 0·25 mm respectively. The finer silk separates the A and B roll flours. These belong to the patent-flour group and amount, respectively, to 20–30% and 50% of the feeds to the rolls, and, together, to about 20% of the wheat.

Forgetting for the moment, the middle of the sandwich (the dunst), we find that most of the bran and germ particles have flattened during the rolling sufficiently to

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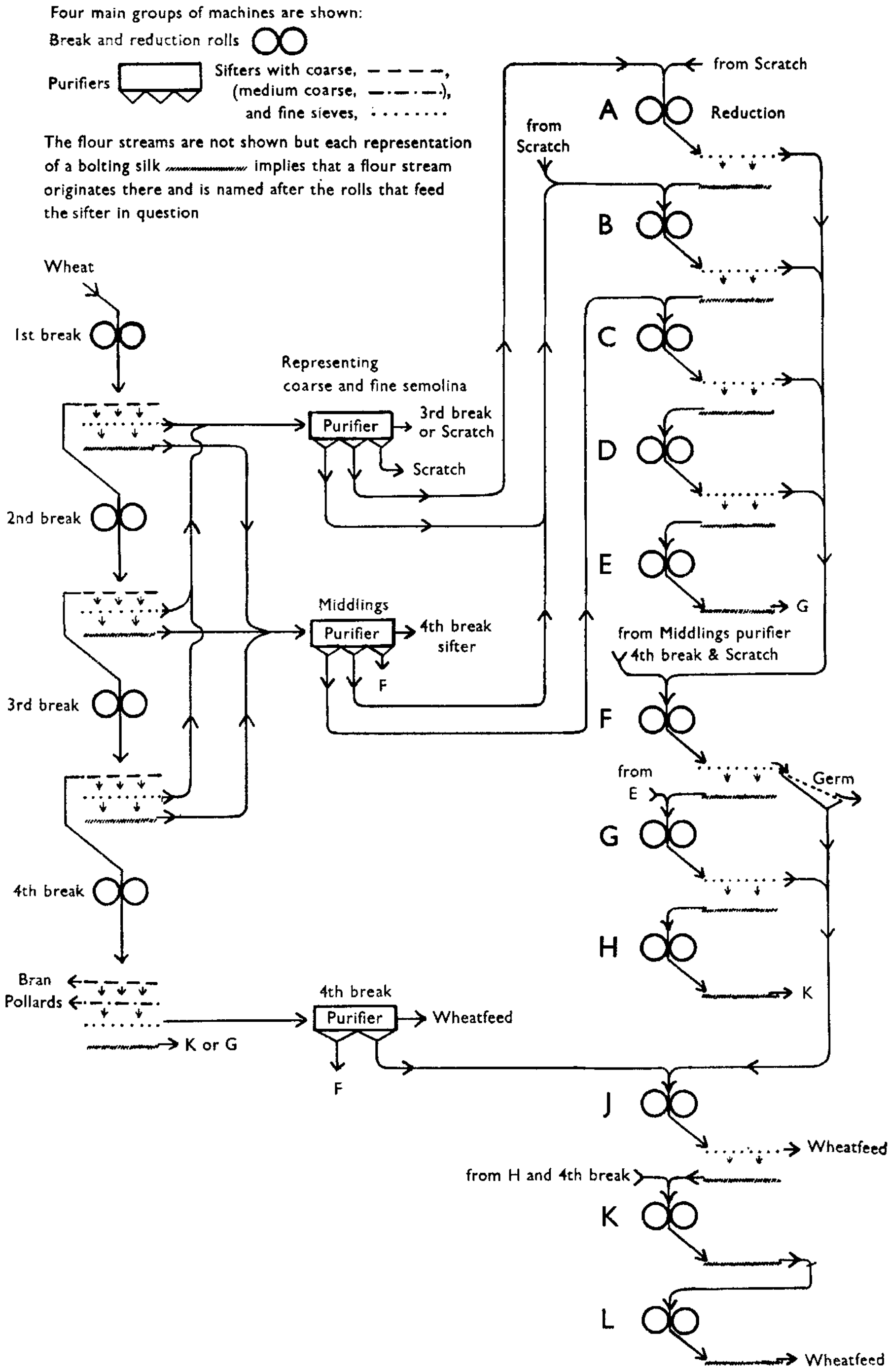

Fig. 1. A simplified diagram of the flour-milling process. The reduction roll nomenclature (as far as shown) is common to medium-sized and large British mills, but in small mills the system might end for example at G, and E might become the (only) low-grade coarse roll.

For simplicity, the scratch system is not shown, though the routes of the stocks to and from it are indicated. Like the break system it has fluted rolls (X, Y not shown on the diagram) followed by sifters and purifiers. The tails from the latter form an additional contribution to wheatfeed.

pass (as A and B tails) over the 0·25 mm sieve. They are accompanied by incompletely reduced endosperm particles and, for economy, the mixture must be treated on low-grade coarse rolls (meaning rolls that handle coarse particles). These reductions, B_2 (in larger mills, for simplicity not shown in Fig. 1) or F (shown heading the 2nd group of reductions in Fig. 1), in turn produce low-grade flour, dunst and tails. The tails, which consist largely of bran and germ (mainly embryo), may for simplicity be regarded as contributors to wheatfeed though in all but quite small mills they are sent to a further low-grade coarse reduction, J (shown heading the 3rd group of reductions in Fig. 1). The embryo has normally been flattened more than the bran during the previous smooth rollings; it may therefore be separated as a by-product by selective sieving of the tails from the coarse low-grade reductions (F, as shown in Fig. 1, or J).

The dunsts from the head reductions are relatively free from pieces of envelope. In view of this and the diminished tendency to flake consequent upon the relative smallness of the particles, these stocks are suitably rolled heavily (C reduction) so that the yield of flour on subsequent sifting is 60–70% of the grind, or about 15% of the wheat. This is the first patent flour. The dunst from this sifter passes to a further reduction (D) which also gives flour of patent grade. The dunst from it represents a substantial increase in concentration of envelope fragments; it passes to a series of further reductions, the flours from which become progressively lower in grade. The tails from all these reductions pass to the next, lower-grade, group of reductions; mainly to the coarse roll that heads the group (F and, in turn, J in Fig. 1). The dunsts from these form the main part of the feeds to the following low-grade fine rolls (G and H, and in turn K and L respectively, in Fig. 1). From all such rolls the sifted tails contribute to the fine wheatfeed; they contain bran and fine fibrous matter, pieces of germ (mainly scutellum) and flakes of endosperm.

Extraction rate and composition of flour

The term 'extraction' means, basically, the number of parts by weight of flour obtained from a hundred parts of wheat. In milling a straight-run flour, the flour streams originating from all the bolting silks (including some, e.g. X, Y, not shown in the simplified diagram of Fig. 1) are combined. They may however be regarded, individually, as falling into five principal groups, markedly differentiated in composition and properties. Table 1 shows the spread of values for contents of certain nutrients over the streams composing these groups, and also values for the bran and fine wheatfeed, at various total flour extractions. The factors underlying the marked changes in composition of flour streams of progressively lower grade at a given straight-run extraction rate (80%) have already been described (Jones & Moran, 1946).

Table 1 shows that, as the extraction rate rises, the changes in composition of the straight-run flour are accompanied by changes, mainly in the opposite sense, in the composition of the wheatfeed. The position with fibre is straightforward because this constituent originates chiefly from the bran; up to about 80% flour extraction, the fibre content of the total wheatfeed has been shown (N. L. Kent, H. V. Hart &

Table 1. *Ranges of composition* of principal groups of flour streams at various total flour extraction rates*

Product	Yield† (%)	Protein‡ (%)	Ash§ (%)	Fibre (%)	Oil¶ (%)	Thiamine§ (µg/g)	Nicotinic acid§ (µg/g)
Wheat	100	12·4	1·5	2·0	2·0	3·87	57
85% straight-run flour	85	12·5	0·92	0·33	1·5	3·42	—
Reduction flours: head group, A-D	—	10·8–11·4	0·45–0·72	0·10–0·13	0·9–1·5	0·72– 2·25	—
first low-grade group, F-H	—	14·1–16·7	1·7 –2·7	0·38–1·1	2·7–3·9	9·9 –21·3	—
second low-grade group, J-end	—	18·5–20·1	3·8 –4·7	1·3 –4·0	5·8–6·1	13·5 –30·0	—
Break flours: I, II	—	13·3–15·4	0·71	0·20–0·24	0·9–1·2	0·93– 2·1	—
III, IV	—	19·3–19·8	1·3 –3·0	0·41–0·94	2·0–3·3	2·7 – 5·4	—
Wheatfeed: fine	10	12·6	5·1	10·6	4·7	6·0	—
coarse (bran)	5	11·1	6·1	13·5	3·7	4·6	—
80% straight-run flour	80·5	12·0	0·72	0·20	1·4	2·67	19
Reduction flours: head group, A-D	46	10·7–11·1	0·40–0·52	0·10	0·9–1·2	0·54– 1·08	9– 12
first low-grade group, F-H	7	11·9–13·2	0·67–0·95	0·15–0·33	1·7–2·5	2·4 – 4·1	17– 25
second low-grade group, J-end	5	15·6–19·2	2·2 –3·7	0·90–2·4	3·6–5·9	16·2 –32·4	33–133
Break flours: I, II	7	11·6–12·4	0·57–0·63	0·18–0·19	0·9–1·3	0·54– 1·02	18
III, IV	2	16·0–16·5	0·95–1·8	0·35–0·41	1·8–2·5	0·83– 2·85	64– 84
Wheatfeed: fine	12·5	14·3	4·7	8·4	4·7	10·4	191
coarse (bran)	7	12·4	5·9	11·1	3·9	5·0	302
70% straight-run flour	70	11·4	0·44	0·1	1·2	0·7	10
Reduction flours: head group, A-D	35	10·1–10·7	0·34–0·40	—	0·9–1·3	0·25– 0·5	9– 13
first low-grade group, F-H	5–6	11·4–12·0	0·48–0·62	—	1·5–1·7	1·2 – 1·8	14– 15
second low-grade group, J-end	5	12·2–12·7	0·70–0·90	—	2·0–2·5	2·0 – 6·0	19– 28
Break flours: I, II	7	12–14	0·50–0·60	—	1·1–1·3	0·5 – 0·6	20– 23
III, IV	2	14–17	0·70–1·0	—	1·9–2·7	0·8 – 1·8	16– 29
Wheatfeed: fine	20	15·4	3·5	5·2	4·7	14	113
coarse (bran)	10	13·0	5·1	8·9	3·5	6	232

The description of the groups is given on pp. 8–10 and in Fig. 1.

* Values are expressed on a 13% moisture basis. The values for 80% extraction are reproduced from Jones & Moran (1946). Values for the nicotinic-acid, and some for thiamine, content of flour streams at 70% extraction are from Jackson, Doherty & Malone (1943). Those for ash and oil at 70% extraction are from Kent-Jones & Amos (1947, p. 173). The remaining values including those for the 85% extraction streams are mainly from unpublished results obtained at the Cereals Research Station, St Albans. The 85% milling was done at the beginning of May 1946 by the same mill that had previously supplied the 80% samples.

† Expressed as a percentage of the wheat represented.

‡ N × 5·7.

§ These samples contained no calcium carbonate or other added nutrients.

¶ Light-petroleum extract.

C. R. Jones, unpublished) to be in direct inverse proportion to the yield of total wheatfeed. In other words, the increment in flour extraction from 70 to 80% depends substantially on recovery of material other than bran from the wheatfeed. Between 80% and 85%, however, the proportion of bran fragments entering the flour becomes considerable (Moran & Drummond, 1945).

Analytical considerations indicate that the percentage figures for yield of wheatfeed at 70% flour extraction could be roughly interpreted as follows:

Type of wheatfeed	Milling yield	Bran coats	Germ	Endosperm
Coarse	10	7	0·5–1	2 –2·5
Fine	20	7·5	1·5–2	10·5–11
Total	30	14·5	2·5	13

At 80% flour extraction the yield of coarse wheatfeed (Table 1) was in fact 7%, which, however, must not be regarded as substantiating the value for potential yield of bran coats shown in the upper row above. In the actual weight of coarse wheatfeed obtained, residual endosperm is balanced by a loss of bran through fragmentation arising from the severer break-work necessary at the higher extraction. The fragmentation, which is greatly increased at 85%, mainly results ultimately in a transference of bran from coarse to fine wheatfeed but, on the way, the bran (accompanied by germ) passes with endosperm through various stages of the reduction process, and, in due course, forms an increased proportion of the feeds to the lower-grade reductions, particularly F and later reductions (Fig. 1). Thus though the relative placing of the groups of flour streams shown in Table 1 is unaffected by rising extraction, flours from later rollings change in composition to a much greater extent than do those from the earlier stages of milling. In general the changes reflect the increased entry of fragments of bran and of germ, including scutellum, and, to some extent, of detached fragments of the aleurone layer, into the lower-grade flour streams.

Values quoted in Table 1 suggest that the proportions of germ present in the lowest-grade flours reach a ceiling at 80% extraction. At 85%, the thiamine content of the flours of the second low-grade group has risen little, but the same level is approached also by flours from the first low-grade group. This effect results, not basically from changes of route in the flow represented by Fig. 1, but from adjustments at particular points (Horder, Dodds & Moran, 1954, p. 75). Essentially these adjustments increase the amount of scutellum (and bran) passing to the early part of the reduction system and they increase the turn-out of flour from this part of the system. In consequence, the feeds to the intermediate reductions contain more germ and bran than they do at lower extraction rates. This effect also underlies the greatly increased spread in composition in the head group, A–D.

The possibility will be appreciated that, with conditions set for a relatively low straight-run flour extraction, a suitable combination of lower-grade flour streams may be chosen which will resemble in overall nutrient content a straight-run flour of higher extraction. The reason will also be understood why the proportion of the total flour represented by such a combination, say with a nutrient content equal to that of straight-run 80% flour from the same wheat, will increase rapidly as the overall extraction rate is raised in the range 70–80%. This principle was applied in manufacturing simultaneously both white flour and flour equivalent to National flour (see Horder *et al.* 1954, p. 51).

Influence of wheat type on flour composition

Although the relationships shown in Table 1 between different extraction rates are broadly typical, strictly they apply only to the milling of similar grists. Wheats of different types, or wheats of the same type but of different harvests, may differ markedly in yielding power, which depends not only on endosperm content of the grain but on degree of ease of separation of endosperm from bran.

With a mill adjusted for high-extraction milling, the inclusion in the grist of an easier-yielding wheat causes little change in the composition of the flours from the early parts of the system but markedly affects the flours from the later reductions. The feeds to these reductions release flour more freely so that unless the adjustment of the rolls is lightened the prescribed extraction rate will be exceeded. The lightening of the adjustment, however, diminishes the proportion of scutellum and bran fragments entering the flour. This effect was conspicuous after the good English harvest in 1945. The inclusion of the new English wheat, at 80% extraction milling, caused the thiamine in the second low-grade group of flours to fall by about one-third from the levels shown in Table 1, so the thiamine content of the straight-run flour tended to be in the range 1·8–2·1, instead of 2·4–2·7 μg/g. To reach the latter figures under these circumstances would have required the use of increased pressures on the later reductions with a consequent increase in total flour extraction of 2–3%. To meet at the same time a prescription of 80% extraction it would have been necessary in effect to accommodate the additional low-grade flour by diverting to wheatfeed a corresponding proportion of flour, with lower thiamine content but better baking quality, originating from earlier in the mill. Partly similar considerations applied, after decontrol of the industry in 1953, in respect of the requirement that National flour should be of 80% extraction. It happened that the available Manitoba and English wheat supplies both showed marked improvement in milling quality, with the result that the National flour improved in colour and fell in thiamine content.

Under such circumstances clearly extraction rate is unrealistic as a measure of nutrient content in flour. The principle is further illustrated in Table 2 which shows analytical results on two pairs of flours both milled in the St Albans laboratories from the same wheat mixture (65% Manitoba and 35% English). At both 70% and 80% extraction, the upper row of results relates to flours milled, on normal lines, with the aim of producing good colour. In the tests represented by the lower rows, additional flour, produced by severer breaking or by severer reduction of germ-rich stocks, replaced a corresponding proportion of higher-grade flour (which accordingly was allocated to wheatfeed). In each pair, although the nominal extraction rates were similar, the flours differed considerably in composition.

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Table 2. *Composition* of flours differently milled† to two nominal extractions from the same wheat mixture*

Extraction (%)		Colour value‡ (scale units)	Protein (%)	Ash (%)	Fibre (%)	Thiamine (μg/g)	Nicotinic acid (μg/g)	Riboflavin (μg/g)	Iron (mg/100 g)
70	A	1·0	11·0	0·41	—	0·54	11·4	0·54	0·82
70	B	2·8	11·4	0·47	—	0·92	11·5	0·51	1·18
80	A	4·3	11·7	0·64	0·15	2·08	16·0	0·74	1·45
80	B	6·0	11·9	0·74	0·20	2·57	17·8	0·77	1·72
Wheat (100)		—	12·1	1·53	2·0	3·85	50·0	1·63	3·40

* All results are expressed on a 13% moisture basis.

† In test 70 A, gentle breaking was used, particularly in the last break, followed by a long, gentle, reduction process, with relatively fine dressing covers.

In test 70 B, the breaking was as severe as in 80% milling.

Test 80 A represented normal progressive milling, but in test 80 B, additional flour produced by severer reduction of germ-rich stocks replaced a corresponding proportion of higher-grade reduction flour.

‡ Determined by means of Kent-Jones and Martin Colour Grader (Kent-Jones, Amos, Martin, Scott & Elias, 1956).

Flour streams and baking quality

A brief reference to baking quality is necessary to form a balanced impression of the value of the lower-grade flour streams. The bottom row of Pl. 1 shows loaves baked from certain of the samples referred to in the middle (80%) section of Table 1. The upper row shows loaves from the same samples in which the flours have been treated with the optimum amounts of the improver, potassium bromate. The differences are still very marked.

The outer endosperm, contained largely in the last-break flours, typically shows a marked baking response to fairly heavy improver treatment. On the other hand, very low-grade reduction flour shows a smaller response even to heavy treatment. As shown in Pl. 1 the loaf baked from such flour failed to rise much in the oven; it had a dense soggy crumb with a dirty greyish-brown colour. In the straight-run flour this low-grade flour is in effect ‘carried’ by the better baking quality of flours from the head reduction group, though the latter depends on the strength of the wheat used. The weight attached to such considerations is increased by the advent of mechanized baking. It was fortunate that the conditions which necessitated the milling of high-extraction flour in this country during the decade 1940–50 also ensured that the wheat available was mainly the strongest in commerce, namely Manitoba wheat.

EXPLANATION OF PLATE

Loaves baked from some samples referred to in the middle section of Table 1. Bottom row: left, 80% straight-run flour; middle, IV Break flour; right, second low-grade reduction group of flours. The upper row shows loaves from the same flours treated with the optimum amounts of the improver, potassium bromate.

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Problems and pleasures of human experiments

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Introduction

No one, I believe, has so far made experiments on his fellow men to find out how to feed his tame rats, yet many people have worked on rats with the firm belief that their results could be applied directly to the nutrition of their fellow men. Investigations on animals have been of inestimable value in nutritional research, but Claude Bernard (1865) saw the dangers of generalizing too widely from the results obtained from them: 'Les expériences pratiquées sur le chien ou sur la grenouille ne pouvaient, dans l'application, être concluantes que pour le chien et pour la grenouille, mais jamais pour l'homme'. And we have always felt that if one's chief concern was man the crucial experiments should, if possible, be made on him.

Whatever the nature of the investigation, whether it concerns bread or anything else, experimental work on man presents problems and gives pleasures which are to be found in no other kind of work. Strangely enough, man is the only mammal for which a vivisection licence is not required. This makes things easier in some ways, more difficult in others. It makes things easier because no records have to be kept for the Home Office, and there is no necessity to get a new certificate signed by the President of the Royal Society or one of the Royal Colleges every time the experimental lay-out is changed. It makes things more difficult because the responsibility of the investigator is very much greater. He is not protected by the Home Office and, although if he is working with fellow scientists he can explain to them the nature of the experiment and get their consent, if he is working with children, for example, the whole responsibility rests with him. The parents or guardians must, of course, agree to the investigation being made, and be told in general terms the nature of the experiment, but they are unlikely to understand it fully, and they have to trust the investigator. It goes without saying that no experiment must ever be made on a human being that could within reason be expected to do him any permanent harm. This limits the nature of the experiments, and one hesitates, for example, to deprive a child for any length of time of any food or dietary constituent that is known to be beneficial to him. It also limits the criteria by which the effects of a food or a diet may be judged, so that these are restricted mainly to body measurements, clinical examinations (including special ones such as radiological and dental