54. The Nutritive Value of Yeast Protein: Comparison of the Supplementary Values of Yeast Protein and Casein for Maize Protein in the Nutrition of the Pig

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Since Osborne & Mendel [1919] found that rats thrived when given a diet containing brewer's yeast as sole source of protein, many investigators have further studied the nutritive value of yeast protein. Plimmer, Rosedale, Raymond & Lowndes [1934], in experiments on chickens, and Mitchell [1924*a*] in experiments on rats, found that yeast protein, when it is the sole source of nitrogen in the diet, is intermediate in nutritive value between the high value animal proteins and the poorer vegetable proteins; Thomas [1909; 1910], from some experiments carried out on himself, had earlier come to a similar conclusion. Of particular interest are the experiments of Kon & Markuze [1931]; they showed that yeast protein supplements white bread protein in the nutrition of the rat.

Trials of the value of yeast as a protein concentrate for the feeding of stock animals have all shown it to possess high nutritive value. For milk production dried brewer's yeast is as good as linseed cake [Barton, Ness & Crampton, 1926], or ground nut cake [Kieferle & Dusch, 1932] or soya-bean meal [Bünger, 1934]. In experiments summarized by Bünger [1939] dried cultured yeast (*Torula utilis*) was found to be but little inferior to fish meal for fattening pigs, when fed with some cereal and potatoes or other root crop. Many other workers have found brewer's yeast to be a good protein concentrate for pigs. The available information on the value of yeast for egg production and chicken rearing is less accurate but dried yeast appears to be about equal in value to dried skimmed milk.

The present experiments were designed to find the value of yeast protein as a supplement for cereal protein. The pig was the experimental animal chosen and maize the cereal. Comparison was made with the value of casein as a supplement for the proteins of whole maize.

METHODS

The 24 pigs used were of the Large White breed from the pedigree herd of the Agricultural Research Council Field Station, Compton. From the time of weaning until the young pigs attained about 20 kg. body weight they were given a commercial pig feed. They were then divided into eight groups of three pigs each, according to the diets they were to receive. For practical reasons it was not found possible to put all the animals on experiment at the same time; 15 animals were first procured and divided to make up groups 1, 2, 4, 6 and 7; later six pigs were received and these comprised groups 5 and 8; finally, three additional pigs were allocated to group 3. The sex, age at the beginning of the experiment and litter number of all the pigs are included in Table 3.

Each group was housed separately in a large loose box which opened into a large uncovered yard. Both box and yard had sloping floors, and, as it was considered unwise to use bedding which the animals might eat, wooden boards were provided on which the animals could lie. The pigs had access to fresh water. The individual method of feeding was employed, the animals being fed to the extent of their appetites morning and evening. To prevent scattering, the diet was mixed to a creamy consistency with water; any food

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not consumed at the morning feed was mixed with the evening ration. As far as possible the amounts fed in the evening were so adjusted that the pigs left clean troughs but were satisfied. The weight of any small amount of food unconsumed after the evening meal was estimated and in the calculation of the food consumption this amount was subtracted from the total fed. The troughs were washed daily after the evening meal and at the same time the faeces and urine were washed from the box and yard. The animals were weighed once weekly. Early in the experiment, to reduce worm infestation, the pigs were given in their food a single dose of the anthelmintic, phenothiazine (0.2 g./kg. body weight). The experiments were carried out during the summer months (May to September 1940).

Materials and diets

Maize. The ground, whole yellow maize was taken from a single batch.

Casein. The brand fed was 'Ashless G.L.', described by the manufacturers (Glaxo Laboratories, Ltd.) as a 'self-soured' type, well washed with dilute acetic acid. This contained 12.56% N (78.5% protein).

Yeast. This was kindly supplied by Dr A. C. Thaysen of the Chemical Research Laboratory (D.S.I.R.), Teddington and was pure *Torula utilis*, cultivated in a molasses medium, carefully washed and then roller-dried.

About one-fifth of the nitrogen contained in yeast is non-protein in character and consists of purines and other simple nitrogenous compounds; in the present experiments, as in all previous experiments on the nutritive value of yeast protein, no attempt has been made to investigate the true protein. The expression 'yeast protein', or more correctly 'crude protein' usually includes all the nitrogen-containing compounds present in yeast and is determined by multiplication of the nitrogen content by 6.25. In the present experiments calculations have not been based on 'protein' but on nitrogen values, which appears to be a more reasonable procedure.

The dried yeast used contained 7.87% N, hence 49% 'crude protein'.

Yeast extract. In order to avoid autolysis, brewer's yeast, kindly supplied by Messrs Greene, King and Sons, was obtained immediately after it had been filtered from the beer and was then added to twice its weight of boiling water. The mixture was boiled vigorously for 10 min. and then allowed to stand under sterile conditions for 2 days, after which the greater part of the extract was obtained by siphoning off the clear supernatant fluid. The remainder of the extract was separated from the yeast residue by a filtration process. The extract was adjusted to pH 3 with HCl and stored in sterile drums at 0°. This extract contained somewhat less than one-fifth of the nitrogen present in the yeast from which it was prepared.

Cod liver oil. This was of the type used in veterinary practice and was of guaranteed vitamin potency.

Salt mixture. Commercial materials were used in the mixture which contained bone ash 3 parts, calcium carbonate 1 part, sodium chloride 1 part and ferric oxide 0.08 part.

The composition of the various diets is given in Table 1. These were mixed at least once weekly. The yeast extract which was given to the pigs of groups 1, 6, 7 and 8 was

Table 1. *Percentage composition of the diets*

The pigs of groups 1, 6, 7 and 8 each received yeast extract equivalent to 30-45 g. dry yeast daily.

Group	Ground yellow maize	Casein (ashless G.L.)	Dried yeast (<i>Torula utilis</i>)	Cod-liver oil	Salt mixture	Group	Ground yellow maize	Casein (ashless G.L.)	Dried yeast (<i>Torula utilis</i>)	Cod-liver oil	Salt mixture
1	94.5	—	—	3	2.5	5	74.5	—	20	3	2.5
2	89.5	—	5	3	2.5	6	92.5	2	—	3	2.5
3	84.5	—	10	3	2.5	7	88.5	6	—	3	2.5
4	79.5	—	15	3	2.5	8	86.5	8	—	3	2.5

Table 2. *Analyses of diets (nitrogen)*

Group	Amount of N supplied by various constituents of the diet* (% of diet)										Percentage of N supplied by various constituents of diet					Total quantities		
	N contributed by					Digestible N† contributed by					Total N					Total digestible		
	Maize	Yeast	Casein	Yeast extract	Yeast	Maize	Yeast	Casein	Yeast extract	Maize	Yeast	Casein	Yeast extract	Maize	Yeast	N in diet %	N in diet %	Nutritive ratio‡
1	1.421	—	—	0.108	—	1.123	—	—	0.108	93.0	—	—	—	91.3	—	1.529	1.231	1: 10.4
2	1.347	0.394	—	—	0.353	1.064	0.353	—	—	77.3	22.6	—	—	75.2	24.7	1.741	1.417	1: 8.8
3	1.272	0.787	—	—	0.706	1.007	0.706	—	—	61.9	38.1	—	—	58.8	41.2	2.059	1.713	1: 7.2
4	1.196	1.181	—	—	1.059	0.945	1.059	—	—	50.3	49.7	—	—	47.2	52.8	2.377	2.004	1: 6.0
5	1.121	1.574	—	—	1.412	0.885	1.412	—	—	41.6	58.4	—	—	38.6	61.4	2.695	2.297	1: 5.1
6	1.396	—	0.251	0.041	—	1.104	—	0.251	0.041	82.6	—	14.9	2.4	79.2	—	1.688	1.396	1: 9.0
7	1.332	—	0.754	0.042	—	1.053	—	0.754	0.042	62.6	—	35.4	2.0	57.0	—	2.128	1.849	1: 6.5
8	1.302	—	1.005	0.049	—	1.030	—	1.005	0.049	55.3	—	42.7	2.1	49.4	—	2.356	2.084	1: 5.7

* Maize 1.506% N; dried yeast 7.87% N; casein (ashless G.L.) 12.56% N.

† The nitrogen in the casein and yeast extract is taken as being completely digestible.

‡ The nutritive ratio of the diet is the ratio of the energy value of the digestible protein to that of the digestible non-protein constituents. The values for the digestible non-protein constituents of maize and yeast are taken from Morrison [1936]. The amounts of non-protein energy present in casein and yeast extract are disregarded. The values used for the digestible nitrogen of maize and yeast were those found in the present experiments.

added to the diet in the troughs before feeding. Each pig received daily an amount of yeast extract equivalent to 30 g. dry yeast until it reached 35 kg. body weight, when the amount was increased to that equivalent to 45 g. dry yeast. The pigs in the negative control group (group 1) received the larger amount of yeast extract from the ninth week of the experiment although they had not reached 35 kg. body weight. Table 2 gives the analyses of the diets.

RESULTS

Group 1. Maize diet with yeast extract but no added source of protein (Tables 3, 5; Figs. 1, 2)

The three pigs (nos. 2008, 2006 and 2070) of this group did not thrive. During the 16 weeks in which they received the experimental maize diet and the watery extract of yeast, their average weight increased from 18.7 kg. to only 27.8 kg. Nevertheless, the pigs remained healthy and were always eager for their food though they consumed little when it was offered. As the experiment progressed the pigs lost their sleek appearance; their hair appeared rough and scanty. Because of lack of flesh and subcutaneous fat; the skin, although healthy, became wrinkled and the skeletal structure was very apparent; their heads were disproportionately large. Details of the amount of food consumed, weight gained and other information concerning the individual pigs are given in Table 3, and in Table 5 the average values for the group are given.

After 16 weeks on the diet containing maize only as source of protein, pigs nos. 2008 and 2070 were given 6% casein in addition (i.e. they received the diet fed to the pigs of group 7). The food intake increased immediately and the animals gained weight rapidly. During the 4 weeks before adding the casein pigs 2008 and 2070 gained 1.4 and 2.5 kg., and during the subsequent 3½ weeks they increased in body weight by 20.6 and 15.8 kg. respectively. Within about 1 week of the casein addition the animals cast their scanty coarse hair and on first sight appeared quite bald, but closer inspection revealed the presence of a fine new coat, which after 3–4 weeks had grown to a normal length, giving the pigs a fine, sleek appearance. There was a rapid deposition of subcutaneous fat, the wrinkles in the skin disappeared and in about 4 weeks the general appearance of the pigs was normal. The total food consumption of the two pigs for the 3½ weeks period was 72.3 kg. and this yielded a total live weight gain of 36.4 kg. One unit of live-weight gain was therefore produced by only 1.99 units of diet, an abnormally high productivity. It may be concluded that the pigs of group 1 did not thrive on the unsupplemented maize diet because of the inadequacy of the maize proteins.

At the same time as its group mates were given the supplement of casein, pig no. 2006 had 7.5% gelatin added to its diet. It was calculated that this amount of gelatin would supply approximately the same amount of lysine as the 6% casein. In contrast to the pigs receiving casein, however, this animal showed no improvement in its condition after 2 weeks, during which the total gain in body weight was only 0.6 kg. The diet was then further supplemented by the addition of 0.12% tryptophan (making the tryptophan content of the diet about equal to that of the 6% casein diet). After 11 days the pig had increased by only 0.2 kg. and its condition was quite unaltered. A commercial pig feed was now given; after 1 week a marked improvement in the condition of the animal was observed, and after 4 weeks the pig appeared quite normal, having cast its hair and grown a sleek new coat. During the 2½ weeks after giving the commercial feed a body-weight increase of 6.9 kg. resulted. From this observation and the following ones, it would appear that in addition to lysine and tryptophan, yeast and casein contain at least one other constituent required to supplement the proteins of maize for the pig.

Groups 2–5. Maize diets with addition of 5, 10, 15 and 20% dried yeast, respectively (Tables 3, 4, 5; Figs. 1, 2)

In contrast to the pigs of group 1 which received the maize diet supplemented with yeast extract, the animals of groups 2–5 receiving dried yeast developed satisfactorily,

Table 3. *Experimental data (whole experiment)*

Group	Pig		Litter no.	Age at beginning of exp. weeks	Body wt. of pig, kg.			Duration of exp. weeks	Av. weekly increase wt. kg.	Total food intake kg.	Wt. increase per unit N intake kg.	Wt. increase per unit digestible N intake kg.	Food intake per unit wt. gained kg.
	No.	Sex			At beginning	At end	Increase						
1 (no added protein)	2008	Hog	9-3	17	21.6	38.4	16.8	16.3	1.03	104.9	10.5	13.0	6.25
	2006	Gilt	4-3	18	18.3	23.8	5.5	16.3	0.34	72.1	4.96	6.2	13.1
	2070	Hog	9-8	13	16.2	21.2	5.0	16.3	0.31	50.0	6.5	8.1	10.0
2 (5% yeast)	2034	Hog	12-7	14	20.7	75.2	54.5	20.3	2.68	185.5	16.85	20.8	3.41
	2035	Hog	12-7	14	18.0	83.0	65.0	19.3	3.37	209.3	17.83	21.9	3.22
	2071	Hog	9-8	13	19.0	83.3	64.3	16.3	3.94	205.7	17.95	22.1	3.20
3 (10% yeast)	2168	Hog	14-11 (2)	16	26.1	77.8	51.7	10.3	5.02	134.2	18.7	22.4	2.60
	2167	Hog	14-11 (2)	16	30.1	85.9	55.8	9.3	6.0	158.6	17.1	20.5	2.84
	2170	Hog	14-11 (2)	16	26.2	83.4	57.2	10.3	5.56	163.6	17.0	20.4	2.86
4 (15% yeast)	2080	Hog	14-11	13	22.0	83.6	61.6	15.3	4.03	183.5	14.15	16.8	2.97
	2002	Gilt	10-8	20	19.6	87.6	68.0	16.3	4.17	180.3	15.9	18.8	2.65
	2037	Hog	12-7	14	18.0	85.7	67.7	18.3	3.7	187.3	15.2	18.0	2.77
5 (20% yeast)	2129	Hog	10-9	12	12.2	83.7	71.5	17.3	4.13	197.4	13.45	15.8	2.76
	2097	Hog	10-7	14	15.2	81.3	66.1	15.3	4.33	180.2	13.6	16.0	2.73
	2118	Hog	12-18	13	18.4	81.5	63.1	17.3	3.64	191.8	12.2	14.3	3.04
6 (2% casein)	2007	Hog	9-3	17	23.7	93.3	69.6	16.3	4.27	220.6	18.75	22.7	3.17
	1999	Hog	10-8	20	20.4	86.3	65.9	16.3	4.04	202.8	19.25	23.3	3.07
	2092	Hog	9-7	12	21.4	88.9	67.5	15.3	4.41	201.0	19.9	24.1	2.98
7 (6% casein)	2009	Gilt	9-3	17	30.9	89.6	58.7	11.0	5.34	162.3	17.1	19.7	2.77
	2036	Hog	12-7	14	18.4	85.6	67.2	16.3	4.13	180.4	17.5	20.1	2.68
	2069	Hog	9-8	13	17.7	91.6	73.9	16.3	4.53	187.9	18.5	21.3	2.54
8 (8% casein)	2128	Hog	10-9	12	13.4	61.2	47.8	16.3	2.93	131.1	15.4	17.4	2.74
	2098	Hog	10-7	14	22.0	83.7	61.7	16.3	3.78	187.0	14.05	15.9	3.03
	2120	Hog	12-10	13	16.8	81.1	64.3	17.3	3.72	200.6	13.65	15.5	3.12

Table 4. *Experimental data for individual pigs during various periods*

		Pig no.	Period 24-47 kg. body wt.				Period 47-70 kg. body wt.				Period 70-85 kg. body wt.			
			Av. weekly increase wt. kg.	Wt. increase per unit N intake kg.	Wt. increase per unit digestible N intake kg.	Food intake per unit wt. gained kg.	Av. weekly increase wt. kg.	Wt. increase per unit N intake kg.	Wt. increase per unit digestible N intake kg.	Food intake per unit wt. gained kg.	Av. weekly increase wt. kg.	Wt. increase per unit N intake kg.	Wt. increase per unit digestible N intake kg.	Food intake per unit wt. gained kg.
2 (5% yeast)		2034	2.72	19.78	24.3	2.89	3.42	16.7	20.5	3.44	3.06	18.0	22.1	3.18
		2035	2.87	18.7	23.0	3.06	4.37	16.8	20.7	3.41	3.45	17.7	21.8	3.24
		2071	3.55	19.98	24.6	2.86	5.28	18.7	23.0	3.06	4.33	19.2	23.6	2.97
		2168	4.20	18.45	22.1	2.63	5.66	19.2	23.1	2.51	4.77	18.9	22.7	2.57
3 (10% yeast)		2167	5.52	20.3	24.4	2.39	6.50	15.1	18.1	3.22	5.95	17.4	20.9	2.80
		2170	4.80	17.65	21.2	2.75	7.15	16.6	22.3	2.62	5.74	18.1	21.7	2.68
		2080	3.74	16.65	19.7	2.53	4.85	15.8	18.7	2.67	4.23	16.2	19.2	2.60
4 (15% yeast)		2002	3.32	17.8	21.1	2.36	5.90	15.7	18.6	2.69	4.18	16.7	19.8	2.52
		2037	2.98	16.8	19.9	2.50	5.20	15.75	18.7	3.68	3.72	16.3	19.3	2.59
		2129	4.25	16.4	19.3	2.26	5.52	12.1	14.2	3.07	4.70	14.0	16.4	2.67
5 (20% yeast)		2097	5.10	16.6	19.5	2.24	4.70	11.85	13.9	3.13	4.90	13.9	16.3	2.67
		2118	3.48	14.85	17.4	2.50	4.66	12.6	14.8	2.94	4.00	13.6	16.0	2.73
		2007	3.49	19.9	24.1	2.97	4.88	19.1	23.1	3.09	4.07	19.45	23.5	3.04
6 (2% casein)		1999	2.82	18.4	22.3	3.22	5.36	19.9	24.1	2.97	3.80	19.2	23.2	3.08
		2092	3.58	19.9	24.1	2.97	5.50	20.3	24.6	2.91	4.28	20.1	24.3	2.94
		2009	4.56	19.7	22.7	2.39	5.98	17.2	19.8	2.76	5.26	18.2	21.0	2.60
7 (6% casein)		2036	4.17	20.95	24.1	2.23	5.82	17.6	20.3	2.65	4.83	19.2	22.1	2.44
		2069	3.78	20.7	23.8	2.27	5.63	18.35	21.1	2.54	4.52	19.6	22.5	2.41
		2128	3.56	16.85	19.0	2.50	5.30	14.8	16.7	2.96	3.99	15.95	18.0	2.66
8 (8% casein)		2098	3.54	17.15	19.4	2.47	3.65	12.85	14.5	3.27	3.59	14.85	16.8	2.85
		2120	3.50	15.5	17.5	2.74	5.10	14.4	16.3	2.96	4.08	14.95	16.9	2.84

the average weekly weight increases for the whole experimental period being 3.3, 5.5, 3.96 and 4.02 kg. per pig, respectively. The pigs of group 5 (20 % yeast) and more particularly those of group 3 (10 % yeast), which were somewhat heavier at the beginning of the experiment, thrived well throughout the experimental period. The rate of body-weight gain of the pigs of groups 2 (5 % yeast) and 4 (15 % yeast) was not high until a weight of about 30 kg. was attained, when the rate of weight gain improved (see Fig. 1).

Fig. 1. Average growth curves of the pigs in various groups. From the point marked $\uparrow$ two of the pigs of the group which had previously received the unsupplemented diet were given 6% casein and the third pig was given 7.5% gelatin, a source of lysine, and later 7.5% gelatin plus 0.12% tryptophan.

Fig. 2. Effect of the addition of yeast and casein on the productivity of the total nitrogen. The amount and nature of the source of protein added to the diet of the various groups of pigs is indicated beside the experimental points.

All the animals receiving yeast remained healthy, their coats were always sleek and they grew to be fine pigs. Pig 2034 (5 % yeast), pig 2168 (10 % yeast) and pig 2080 (15 % yeast) were each observed to vomit on one occasion shortly after feeding, while pig 2167 (10 % yeast) vomited on two occasions. These animals may have vomited at other times. All the pigs having the yeast-containing diets consumed their meals with relish and the occasional vomiting was attributed to the animals taking their food too greedily. Pig 2097 (20 % yeast) became lame towards the end of the experimental period. The joints

Table 5. *Average values for the various groups of pigs*

Group	Av. weekly wt. increase kg.	Wt. gained per unit N intake kg.	Wt. gained per unit digestible N intake kg.	Food intake per unit wt. gained kg.	Av. weekly wt. increase kg.	Wt. gained per unit N intake kg.	Wt. gained per unit digestible N intake kg.	Food intake per unit wt. gained kg.
	Whole experimental period (approx. 20-85 kg.)				Period 24-47 kg. body wt.			
1 (no added protein)	0.56	7.32	9.1	9.78	—	—	—	—
2 (5% yeast)	3.3	17.6	21.65	3.27	3.0	19.5	24.0	2.94
3 (10% yeast)	5.5	17.5	21.0	2.77	4.73	18.7	22.4	2.59
4 (15% yeast)	3.96	15.1	17.9	2.79	3.30	17.1	20.25	2.47
5 (20% yeast)	4.02	13.05	15.3	2.83	4.22	16.0	18.8	2.32
6 (2% casein)	4.24	19.3	23.3	3.07	3.28	19.45	23.5	3.06
7 (6% casein)	4.58	17.75	20.4	2.68	4.12	20.55	23.6	2.28
8 (8% casein)	3.48	14.2	16.0	2.98	3.53	16.5	18.6	2.57
	Period 47-70 kg. body wt.				Period 24-70 kg. body wt.			
1 (no added protein)	—	—	—	—	—	—	—	—
2 (5% yeast)	4.36	17.4	21.4	3.30	3.61	18.3	22.5	3.12
3 (10% yeast)	6.359	17.5	21.0	2.77	5.45	18.1	21.7	2.68
4 (15% yeast)	5.27	15.75	18.7	2.68	4.04	16.45	19.5	2.56
5 (20% yeast)	4.92	12.2	14.35	3.05	4.56	13.85	16.3	2.68
6 (2% casein)	5.23	19.75	23.9	2.99	4.04	19.6	23.7	3.02
7 (6% casein)	5.81	17.7	20.4	2.65	4.84	19.0	21.85	2.47
8 (8% casein)	4.43	13.8	15.6	3.09	3.86	15.2	17.2	2.79

of the forelimbs appeared to be sore but examination after slaughtering revealed no lesions. The forelimbs of pig 2118 (20% yeast) were somewhat stiff during a few weeks towards the end of the experimental period, but the animal later recovered.

As regards the weight of food consumed per unit of live-weight gain and the live-weight gain per unit of N consumed, there was good agreement amongst the individual pigs in groups 2-5 (Tables 3, 4). On the diet containing 5% yeast there was a smaller live-weight gain per unit of food consumed than on the diets containing the higher proportions of yeast; reckoned over the whole experimental period, the average unit live-weight gain in the groups receiving 5, 10, 15 and 20% yeast corresponded to 3.27, 2.77, 2.79 and 2.83 food units of the respective diets. The gains in live weight per unit of digestible N consumed were similar in the groups receiving 5 and 10% yeast, but when the amount of yeast was increased to 15 and 20% the gains per unit of N consumed decreased; the average gains per unit of digestible N consumed by the groups receiving 5, 10, 15 and 20% yeast were 21.65, 21.0, 17.9 and 15.3 respectively.

Groups 6-8. *Diets with yeast extract and 2, 6 and 8% casein respectively* (Tables 3, 4, 5; Figs. 1, 2)

The animals of these three groups thrived well, the average weekly weight increase over the experimental period being 4.24, 4.58 and 3.48 kg. for the groups receiving 2, 6 and 8% casein respectively. The rate of weight increase of the pigs receiving the 2% casein diet was particularly good, considering that the diet contained only 8.7% digestible protein and had a nutrient ratio of 1:9.0. The growth rate of the pigs of group 8 (8% casein) was somewhat inferior to those of the pigs of the other groups; this was probably because the animals were less healthy. Pig 2128 (group 8) refused his food on occasion and developed stiffness of the joints of the forelimbs (see below). On examination after slaughtering, the walls of the thoracic cavity were observed to have many watery blisters which may have been due to a pulmonary infection. Pigs nos. 2036 and 2069 of group 7 and nos. 2128 and 2098 of group 8 became lame after about 10 weeks on the experimental

diets. The condition of these pigs was similar to that of pigs 2097 and 2118 of group 5 (see above), but was much more severe. The knee joints of the forelegs appeared to be stiff and tender. The animals preferred to lie down and were always loath to put their weights on their forefeet; the pigs were sometimes observed to walk on their knees. There appeared to be slight swelling round the affected joints. Neither the addition of 2% CaCO_3 to the diets of pigs nos. 2036 and 2128 for a period of 2 weeks nor the addition of 2% NaH_2PO_4 to the diets of pigs nos. 2069 and 2098 for the same period improved the condition of these animals. Towards the end of the experimental period the tenderness of the joints showed improvement but some stiffness persisted. No gross changes were apparent on post-slaughter examination of the joints. The cause of the above condition was not determined, but it seems probable that it was not rachitic in character. The diets contained about 0.8% Ca and 0.7% P, of which about 0.5% was non-phytin P; neither the addition of extra CaCO_3 nor of NaH_2PO_4 improved the conditions. The 3% cod-liver oil in the diet must have supplied an abundance of vitamin D and the animals also spent most of the summer days in the open air. The diets of the affected pigs all contained the larger amounts of protein; the pigs of group 6 (2.0% casein) and those of groups 2, 3 and 4 (5, 10 and 15% yeast respectively) remained active throughout the experimental period.

The productivities of the various casein-containing diets were similar to those of the corresponding yeast-containing diets. Reckoned over the whole experimental period the average amounts of the diets containing 2, 6 and 8% casein which corresponded to unit increase in live weight, were 3.07, 2.68 and 2.98 respectively. The gain in weight per unit of digestible N was highest in the group having the diet containing 2% casein and decreased as the percentage of casein in the diet was increased to 6% and to 8%, the average values for the three diets being 23.3, 20.4 and 16.0 respectively.

Comparison of the supplementary values of yeast protein and casein for maize protein
(Tables 3, 4, 5; Figs. 1, 2)

In their method for comparison of the nutritive value of different proteins, Osborne, Mendel & Ferry [1919] determined the gain in weight of rats per unit of protein ingested from diets containing varying proportions of protein. The value of this expression increased with increase of protein level in the diet to a maximum and then decreased. Both the percentage of protein in the diet giving the maximum weight increase per unit of protein ingested and the value of the maximum increase were taken into account in estimating the nutritive value of the protein.

In calculating the results of the present experiments, a technique resembling that of Osborne *et al.* [1919] has been used. However, since much of the N in yeast is non-protein in character and the digestibilities of the N of maize, yeast and casein are quite different in degree, all comparisons in this section have been made with the digestible N values rather than the ingested protein values. As anticipated, the average weight gain per unit of digestible N consumed decreased as the body weight of the pigs increased, particularly in the groups receiving the larger amounts of yeast or casein (see Table 5); all comparisons are therefore made over the same ranges of body weight increase.

Over the period in which the body weight of the pigs increased from 24 to 70 kg. (approx. 50–150 lb.) the average weight gains per unit of digestible N consumed by the pigs in groups 2, 3, 4 and 5, receiving diets containing 5, 10, 15 and 20% yeast, were 22.5, 21.7, 19.5 and 16.3 respectively; the amounts of digestible N in these diets were 1.42, 1.71, 2.00 and 2.30, and the proportions of the total digestible N supplied by the yeast were 24.7, 41.2, 52.8 and 61.4% respectively. The average weight gains over the same range of body-weight increase per unit of digestible N consumed by the pigs of groups 6, 7 and 8, receiving 2, 6 and 8% casein were 23.7, 21.85 and 17.2 units respectively; these three diets contained respectively 1.40, 1.85 and 2.08% digestible N and, of the total digestible N, 18.0, 40.7 and 48.2% respectively, was supplied by the

casein in the diets. Similar calculations made over the whole experimental period of approximate weight increase from 20 to 85 kg. and over the ranges 24–47 kg. and 47–70 kg. gave values which in general were similar to those for the range 24–70 kg. (see Tables 3, 4, 5).

Since the highest weight increase per unit of digestible N consumed occurred in the pigs receiving the diets with the smallest amounts of yeast or casein (5 and 2% respectively) the proteins present in these amounts were evidently sufficient to supplement completely the proteins of the maize. The supplementary values of yeast protein or casein for maize protein are thus shown to be very great. Taken over the whole experimental period, the average weight gain per unit of digestible N consumed by the pigs receiving the unsupplemented maize diet was 9.1, the addition of 5% yeast, i.e. about 2.5% crude yeast protein, which supplied 24.7% of the total digestible N of the diet, increased the above value to 21.7 while the addition of 2% casein, which supplied 18% of the total digestible N of the diet increased it to 23.3.

The extra protein laid down in the tissues of the pigs as a result of supplementation of the maize diet with small amounts of casein or yeast was considerably more than the amounts contained in the casein or yeast added. Eight weight units of the digestible maize N as consumed from the unsupplemented diet (group 1) yielded a body-weight increase of about 70 units, while 8 units of digestible maize N, together with 2 units of digestible casein or yeast N yielded about 230 units of body weight increase; thus the additional 2 units of N yielded about 160 units extra body weight increase. If the proportion of protein in the pig's body is assumed to be 15% of the live weight,* it is calculated that the addition of the 2 units of digestible N from casein or yeast caused about 3.5 units of extra N to be laid down in the tissues of the pigs.

It is possible to make a very rough estimate of the proportion of the digestible N, not used for maintenance, which was retained in the tissues of the pigs of the different groups. Calculations have been made for the pigs of group 1 for the whole experimental period and for those of group 2 (5% yeast) and group 6 (2% casein) for the period during which their body weights increased from 24 to 47 kg. In doing so it has been assumed: (1) that the pigs required 2 g. each, daily, of digestible N for maintenance, since pigs of this weight, when fed on a N-free diet, excrete about 2 g. N daily [see Mitchell, 1924*b*]; (2) that for all the groups of pigs the amount of protein laid down was 15% of the body weight increase. Thereby it has been estimated that only about 35% of the total N available for body building was retained in the tissues of the pigs of group 1 (no protein supplement), while 70–75% was used for tissue building by the pigs of both group 2 (5% yeast) and group 6 (2% casein).

The maximum body-weight increase per unit of digested N, as observed in our experiments, was about 24 units. In unpublished experiments with pigs by Sir Charles Martin, in which yeast and casein were the sources of protein in the diet, a similar value was obtained. Woodman & Evans [1940], in their experiments on 'low-protein' diets for pigs, obtained about 22 units body weight increase per unit digestible N fed. It would appear, therefore, that 24 units weight increase per unit digestible N consumed is about the maximum value for the pig. This value was given in our experiments by the maize diets containing 2% casein or 5% yeast (groups 6 and 2 respectively), so that the combined proteins of these diets, made up of 4 parts digestible maize protein and 1 part of casein or digestible yeast protein, must have approached the ideal protein mixture for the pig.

Examination of the carcass quality of the pigs by Dr E. H. Callow (see Addendum 1) showed that there was no significant difference between the proportion of fat to muscle in the animals which received yeast and those receiving casein; presumably, therefore, approximately the same amount of protein was laid down by the animals.

* Dr E. H. Callow, personal communication.

Statistical examination of the experimental data by Dr J. O. Irwin and Mr J. C. D. Hutchinson (see Addendum 2) revealed no significant difference in the weight gain per unit of N consumed by the pigs in the groups which received casein and the corresponding groups which received equivalent amounts of yeast protein; there was, however, a significant difference amongst the groups of animals receiving the different levels of protein.

Consideration of the above results and of the additional data fully set out in Tables 3-5 shows that, as a supplement for maize protein, the digestible N of yeast is about equal in nutritive value to that of casein; both are excellent supplements.

Determination of the digestibility coefficients of the N of maize and yeast

Since the pigs were given no bedding and the stools of the pigs in all the eight groups were well formed, it was possible to obtain a fairly accurate estimate of the dry weight of the faeces passed. Every day during a period of 2 weeks, when the weights of the animals averaged about 40 kg., the faeces from each group were collected and the total weights determined by mincing, mixing carefully and estimating the percentage dry weight in aliquot portions.

Although the concreted floors of the pens sloped into a drain, urinary contamination of the faeces was unavoidable; this had little effect on the dry weight of the faeces but a considerable effect on their N content. To determine the amount of N in the faeces, samples from each of the pigs were obtained, free from urine, immediately they were passed, dried and their N determined. From the average N content of the dried faeces from the three pigs of a group and the total weight of dry faeces excreted by the animals during the 2 weeks period, the total amount of faecal N excreted by the group during that period could be calculated.

In the determination of the coefficient of 'apparent' digestibility of maize N (Table 6), from the data given by the groups of pigs receiving casein, it was assumed that the N of the casein and yeast extract was completely digestible. In the case of the casein, at least, this was justifiable, since increasing the casein content of the diet from 2% (group 6) to 8% (group 8) did not increase the faecal N to any considerable extent. From results of groups 6-8, receiving 2, 6 and 8% casein, the digestibility coefficients obtained for maize protein were 80.2, 77.0 and 79.4 respectively, while the value calculated from the total intake and faecal output of the three groups taken together was 79.1; this value was used in making all calculations. The pigs of group 1 (no extra protein supplement) gave a digestibility coefficient for maize protein of only 71.4. The animals of this group consumed little food and therefore little N, so that the amount of endogenous N excreted in the faeces must have been larger in proportion to the N intake than in the other groups of pigs which consumed much more N; even in these groups much of the N present in the faeces must have been endogenous in origin, and therefore the difference between the ingested and faecal N indicates not the 'true' digestibility, but only the 'apparent' digestibility of the former.

In the determination of the 'true' digestibility coefficient of yeast N (Table 7) it was assumed that the 'apparent' digestibility coefficient of maize N was 79.1. The values for the digestibility coefficient of yeast N calculated from results obtained with the pigs of groups 3, 4 and 5 receiving 10, 15 and 20% yeast, agreed well with each other, being 90.6, 88.0 and 91.7 respectively. The value given by the animals of group 2 (5% yeast) was 84.0; the amount of yeast in this diet was probably too low for the accurate determination of the digestibility of the yeast protein. The value employed in the calculations throughout this paper was 89.6 and was obtained from the results on all the four groups receiving yeast.

The value 79.1 obtained for the coefficient of 'apparent' digestibility of maize N agrees well with those given by other investigators. It is probable, therefore, that the value of 89.6 found for the 'true' digestibility coefficient of the dried yeast approximates to the

Table 6. 'Apparent' digestibility of nitrogen of maize*

Group	Total food intake per group during 2 weeks kg.	Intake of maize N kg.	Weight of dry faeces kg.	% N in faeces	N output in faeces kg.	Coefficient of digestibility of maize N
1	27.15	0.385	4.37	2.51	0.110	71.4
6 (2% casein)	102.4	1.43	13.62	2.07	0.283	80.2
7 (6% casein)	62.97	0.838	8.43	2.29	0.193	77.0
8 (8% casein)	76.63	0.997	9.39	2.18	0.205	79.4
Total of groups 6-8	—	3.265	—	—	0.681	79.1

* It is assumed that the N of casein and yeast extract is completely digestible.

Table 7. 'True' digestibility of N of dried yeast (*Torula utilis*)

Assuming maize N has 'apparent' digestibility coefficient of 79.1.

Group	Food intake during 2 weeks kg.	Intake of maize N kg.	Intake of yeast N kg.	Weight of dry faeces kg.	% N in faeces	N output in faeces kg.	N in faeces from maize kg.	N in faeces from yeast kg.	Coefficient of digestibility of yeast N
2 (5% yeast)	87.06	1.175	0.343	11.28	2.64	0.300	0.248	0.055	84.0
3 (10% yeast)	83.32	1.06	0.648	10.66	2.64	0.282	0.221	0.061	90.6
4 (15% yeast)	88.63	1.06	1.045	13.68	2.54	0.347	0.221	0.126	88.0
5 (20% yeast)	92.61	1.04	1.460	12.95	2.61	0.338	0.217	0.121	91.7
Total of groups 2-5	—	—	3.496	—	—	—	—	0.363	89.6

correct value. Völtz & Baudrexel [1911 *a, b*] found that man digests 86% of the N of dried brewer's yeast, while Kuen & Püringer [1934] obtained values for the digestibility coefficients of cultured yeast protein of 86.4 and 94.4 respectively in two human subjects.

The method employed in the present work did not permit of very accurate determination of the total dry weight of the faeces, but this disadvantage was offset by the fact that the animals were living under normal conditions and not confined to metabolism cages as is usual in the determination of digestibility coefficients.

DISCUSSION

Of the proteins present in human diets it is not uncommon to find that about half of the total is contained in the cereals. In general, the poorest people consume the most cereals but when food is scarce all classes must eat much cereal. The proteins of cereals as a class are not nutritionally of the highest quality since many do not contain a sufficient proportion of certain dietetically essential amino-acids; these must be supplied by the other protein-containing foodstuffs in the diet. In assessing the nutritive value of the protein of a non-cereal foodstuff, it is probably of more practical use to determine its value when fed with cereals rather than when it is the sole source of protein in the diet.

In the experiments described above, which were designed to yield information on the supplemental value of yeast protein for cereal protein, maize was the cereal chosen. The proteins of maize include a considerable amount of zein, a particularly inferior protein, recognized to be poorer in quality than those of other cereals; therefore, any protein which supplements maize protein ought to be equally efficient in correcting the deficiencies of the proteins of other cereals.

Much experimental evidence on the value of the proteins of maize in the nutrition of the rat and the pig is available. The rat does not thrive when zein [Osborne & Mendel, 1914*a*] or maize gluten [Osborne & Mendel, 1914*b*; 1917] are fed but when whole maize is given [Hogan, 1916] or maize gluten together with whole maize [Johns, Finks & Paul, 1919], rats gain in body weight at a satisfactory rate. Lysine and tryptophan are the amino-acids deficient in maize which limit the growth of rats fed on a maize-containing diet [Osborne & Mendel, 1914*a*; 1917; Mitchell & Smuts, 1932]. In some of the earlier work on the value of maize protein in the nutrition of the pig, it is probable that nicotinic acid deficiency complicated the experiments [see Birch, Chick & Martin, 1937; Chick, Macrae, Martin & Martin, 1938*a*]. In the experiments of Chick *et al.* [1938*b*] pigs given a diet containing 69.5 % ground maize and 25 % maize gluten, supplemented with adequate amounts of B-vitamins supplied as a watery extract of yeast, did not gain in weight because of the inadequacy of the protein; the animals thrived later when the maize gluten was replaced by casein. On the other hand, Hart & McCollum [1914] and McCollum, Simmonds & Pittz [1916] did succeed in making pigs thrive on a diet in which all the protein was supplied by maize. Their diet contained 30 % 'maize gluten feed', a by-product in the manufacture of maize starch, rich in maize germ and therefore presumably containing proteins of higher quality than those in the maize gluten used by other workers, which mainly originated from the endosperm of the cereal.

In the present experiments the animals receiving the unsupplemented maize diet did not thrive because of the inadequacy of the maize protein. Since the addition of small amounts of either casein or yeast to the diet made it adequate for the pigs, it would appear that it was the quality of the maize protein rather than its quantity which was the limiting factor.

It is interesting that pig no. 2006 did not improve in any way when its maize diet was supplemented with gelatin, a good source of lysine, or with gelatin and tryptophan, whilst its group-mates improved rapidly when given casein. It would seem that casein and yeast contain undetermined amino-acids, additional to lysine and tryptophan, which are required to supplement maize protein for growing pigs. There appears therefore to be a species difference between pigs and rats as regards their amino-acid requirements, for it is well established that the addition of lysine and tryptophan to maize protein corrects it for the rat [Mitchell & Smuts, 1932; Osborne & Mendel, 1914*a*; 1917]. Species differences as regards requirements for various water-soluble vitamins is of course well established; for example, the pig requires that nicotinic acid be supplied in its diet whilst the rat appears to be independent of an extrinsic source of that substance.

The value of yeast in correcting the deficiencies of maize protein has been emphasized above (pp. 468-9). The addition of 5 % yeast (2.5 % crude protein) to the maize diet changed it from one unsuited to the rearing of pigs to one which yielded fine animals. This effect was entirely due to the proteins of the yeast, since the unsupplemented maize diet was adequately supplied with all other nutrients, including the vitamins of the B group, which were added in a watery extract of yeast. Yeast protein is probably not inferior to casein for this purpose.

Since high-quality protein and B-vitamins are probably the principal nutrients lacking in many poor diets, it would appear that yeast, which contains about 50 % of high quality protein and amounts of B-vitamins unsurpassed by any natural product, would correct the deficiencies of such diets more effectively than would any other foodstuff.

Yeast in the nutrition of the pig

It has long been recognized that yeast is a suitable foodstuff for the fattening of pigs. Halnan [1924] states that it is not advisable to feed more than 10 % yeast. Of many investigators in America who fed brewer's yeast to pigs [Smith, 1924; Culbertson & Thomas, 1933; Edwards & Brown, 1925; Weaver, 1925; Shrewsbury, Vestal & Hange,

1932; Livesay & Stillwell, 1928; Loeffel, 1937], some observed that it had a beneficial effect, but none found it economical, since the slightly increased return did not cover the extra cost of the yeast. However, all the above workers added the yeast to diets which in themselves were reasonably well balanced, since they contained cereals together with varying amounts of different protein concentrates (tankage, soya bean meal and weatings); further, the amount of yeast added was usually small, generally less than 1% of the diet and never more than 3%.

Gärtner & Gaede [1932] and Gärtner [1937] found that pigs thrived much better when given a diet consisting mainly of steamed potatoes and barley meal, together with amounts of dried brewer's yeast up to 600 g. per pig daily, than when given the same diet without the yeast. Steinbach [1937], on the other hand, considered it advisable to feed some animal protein with yeast to obtain the best results. In experiments by Bünger, Schultz & Augustin [1936], Bünger, Fissmer & Harre [1939] and Richter & Brüggemann [1936; 1939] summarized by Bünger [1939], the values were compared of fishmeal and of a cultivated yeast, of a type similar to that used by us, as supplements to diets consisting mainly of steamed or ensilaged potatoes and a cereal. Younger pigs thrived somewhat better when fishmeal was given, but for pigs of 100 lb. body weight or more, yeast and fishmeal were equally efficient supplements.

In our experiments it was found that yeast corrected the deficiencies of maize for the pig even when only small amounts were included in the diet; this particular yeast is therefore a good protein concentrate for pigs. The animals having 5% yeast in their diet (about 2.5% crude yeast protein) did not gain in weight at a satisfactory rate until a body weight of about 60 lb. was attained, but thereafter the rate of gain was good. With 10% yeast or more there were very satisfactory gains, averaging about 10 lb. weekly throughout the experimental period. The average amount of diet which yielded unit body-weight increase over the body-weight range of 50–150 lb. in the groups receiving 10, 15 or 20% yeast was only about 2.7 units. In ordinary practice the amount of diet required to give unit gain over this range is about 3.5 or more. The high productivity observed in the present experiments may have been partially due to the fact that our diets, by virtue of the maize and cod-liver oil they contained, had a higher energy value than diets commonly fed to pigs. Our experiments were carried out during the summer months when a higher productivity must be expected and, further, the pigs had no opportunity to scatter and waste their food. In practice it is probable that the most satisfactory results would be obtained by feeding 10% yeast in the diet until a body weight of about 80 lb. is reached and thereafter 5%.

Of special interest is the observation that the pigs receiving the diets containing only 2% casein and 5% yeast thrived well. These diets had nutritive ratios of 1:9.0 and 1:8.8 respectively, and therefore, according to common belief, should have been quite unsuitable for young pigs which are usually stated to require diets with a much narrower nutritive ratio of about 1:5. Woodman & Evans [1940] did find that young pigs thrived on a diet containing less protein than is usually fed, but even their diet had a nutritive ratio of about 1:7. Protein concentrates are usually rich also in B-vitamins and it seems possible that the vitamin requirements of the pig rather than its protein needs may have governed the amount of protein concentrate required. The growth of our animals, which received adequate amounts of B-vitamins either as yeast or yeast extract, as well as of other known essential nutrients, could only have been limited by the protein content of the diets.

SUMMARY AND CONCLUSIONS

1. Weanling pigs fed on a diet of maize meal supplemented by an extract rich in B-vitamins prepared by boiling fresh brewer's yeast with twice its weight of water, by cod-liver oil to furnish fat-soluble vitamins and by salts, grew poorly with an average weight

increase of 9.1 kg. (20.0 lb.) in 16 weeks. The diet contained 7.7 % digestible protein and had a nutrient ratio of 1 : 10.4.

The animals had a vigorous appetite but were easily satisfied so that their food intake was low. They were lively and healthy; their hair was scanty and rough, their skin wrinkled and their heads abnormally large compared with their bodies. There was no dermatitis.

2. Similar pigs on the same basal maize diet to which 2, 6 or 8 % casein (ashless G.L.) was added all grew well and reached about 85 kg. (190 lb.) live weight in about 16 weeks. Their diets contained 8.7, 11.6 and 13.0 % digestible protein and had nutrient ratios of 1 : 9.0, 1 : 6.5 and 1 : 5.7 respectively.

3. Similar pigs on the same basal maize diet, to which 5, 10, 15 or 20 % of pure dried yeast (*Torula utilis*, grown in a molasses medium) was added, also grew well and reached about 85 kg. (190 lb.) live weight, also in about 16 weeks. The dried yeast contained about 45 % crude protein. The diets contained 8.9, 10.7, 12.5 and 14.4 % total digestible protein and had nutritive ratios of 1 : 8.8, 1 : 7.2, 1 : 6.0 and 1 : 5.1 respectively.

4. The capacity of the proteins in the yeast to supplement the proteins of maize was of the same order as that of the casein.

5. The units of live weight pig produced per unit of digestible N fed, taken over the whole experimental period, were 23.3, 20.4 and 16.0 in the groups receiving the diets containing 2, 6 and 8 % casein respectively, 21.65, 21.0, 17.9 and 15.3 in the groups receiving 5, 10, 15 and 20 % yeast, respectively and 9.1 in the group receiving the unsupplemented maize diet. Both the proteins of yeast and casein had therefore striking supplemental values for maize protein; the addition of either yeast protein or casein in amounts equal only to about 20 % of the protein present in the maize increased the value of the total protein in the diet to more than twice that of the unsupplemented maize protein.

6. The amount of diet eaten corresponding to unit increase in live weight was 3.07, 2.68 and 2.98 units in the groups receiving 2, 6 and 8 % casein and 3.27, 2.77, 2.79 and 2.83 in the groups receiving 5, 10, 15 and 20 % yeast respectively. These productivities are greater than those usually obtained in pig husbandry which range from about 3.5 to 4.

7. The addition of yeast to a cereal diet therefore serves a dual purpose; it supplies good protein and vitamins. From the good results obtained with diets of so wide a nutritive ratio as 1 : 9.0, it is concluded that the higher proportion of protein usually found necessary for the growth of young pigs may be due to shortage of B-vitamins, even in feeds containing weatings; presumably the excess of protein concentrate provides the B-vitamins and corrects the deficiency.

8. Two pigs which had received the diet of maize and yeast extract for 16 weeks and had ceased to gain in weight had 6 % casein added to their diet; they immediately increased in weight and each gained about 18 kg. (40 lb.) in 3½ weeks. Clearly the growth had been limited by the inadequacy of the protein supplied by the maize.

9. One pig kept for 16 weeks on the same maize diet failed to respond to an addition of gelatin (to supply lysine) or of gelatin and tryptophan. Later this pig thrived satisfactorily when given a commercial pig feed. Therefore, lysine and tryptophan apparently are not the only constituents of casein and yeast protein required to supplement the deficiencies of maize protein.

10. The specimen of yeast fed was a pure culture of *Torula utilis* grown on a molasses medium. This was carefully washed and dried before any autolysis had taken place. A commercial preparation of dried yeast from a brewery might not have an equal supplemental value. Indeed some unpublished experiments made in 1938 by one of us (T. F. M.) in conjunction with Sir Charles Martin, Dr H. Chick and Dr A. J. P. Martin indicated this possibility, for in this instance 5 % of the commercial dried yeast used, although supplying sufficient B-vitamins, did not produce more than a moiety of the growth obtained when casein was also added.

11. In the present experiments maize N was found to have an 'apparent' digestibility coefficient of about 79 and yeast N a 'true' digestibility coefficient of about 90.

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ADDENDUM 1

Carcass data. By E. H. Callow, *Low Temperature Research Station, Cambridge*

Before examining the carcass data for this experiment it is necessary to make sure that other factors, external to the experiment, do not affect the results unduly. The effect of (a) killing pigs at too early a stage of development, and (b) of extremely slow growth due to accidental causes, has to be avoided. For the reason (a) the results from pig 2128 and for reason (b) the results from pigs 1999 and 2002 are omitted. This leaves seven pigs which received the diet containing casein and eleven pigs which received the diet containing dried yeast. The data in Table 1 show the average values for the carcasses from these two groups of animals.

Table 1. *Carcass data*

	Casein	Yeast
1. Diet		
2. Number of animals	7	11
3. Average weight of carcass (hot)	149.6 lb.	138.5 lb.
4. Average age	211.3 days	206.2 days
5. Average carcass weight/age	0.707 lb./day	0.671 lb./day
6. Average thickness of back fat, thinnest	30.6 mm.	29.1 mm.
7. Average thickness of back fat, thickest	54.8 mm.	51.1 mm.
8. Average iodine number of fat sample	80.4	83.1
9. Average length of body cavity	729.7 mm.	729.3 mm.
10. Average length of hind leg	569.5 mm.	563.4 mm.
11. Average % of fat in carcass	41.2	43.1
12. Average % of bone in carcass	10.2	10.8

Notes on data in Table 1

(a) The carcass included the head, feet, flare fat and kidneys and was weighed within 30 min. of the death of the animal.

(b) The subcutaneous fat was measured at two points (i) at the thinnest point in the loin near the last rib, (ii) at the thickest point over the shoulder. In both cases the thickness of the skin was included in this measurement.

(c) A sample of back fat was removed from the bung. The fat was extracted without solvents, filtered, dried for the determination of its refractive index. The iodine number was calculated from an equation relating iodine number of refractive index (Callow & Brimley, unpublished results).

(d) The length of body cavity was measured (on the hot carcass suspended from a gambrel) from the pubis symphysis to the point where the first rib joins the back-bone, and the length of the hind leg from the pubis symphysis to the tip of the toe.

(e) The quantity of fat in each carcass was calculated from an equation relating the thickness of the loin fat (thinnest back fat less 2 mm. for skin) with the total fat [McMeekan, 1941] and from this value the percentage value was calculated.

(f) The weight, and hence percentage of bone, was calculated from a similar equation [McMeekan, 1941] relating weight of bone to length of leg.

Discussion

The carcass data for the two groups of animals show little difference, and it has not been thought necessary to subject them to statistical analysis. The difference between them for the thickness of back fat and the iodine number of the fat can be attributed to the yeast-fed group being killed at a slightly earlier age and consequently at a lower carcass weight than the casein group. It can therefore be claimed that dried yeast is as good a food as casein for the growth and fattening of pigs.

The value of the iodine number for the fat of both groups is excessively high, which can be attributed to the large amount of cod-liver oil in both diets. On a normal diet the iodine number of the fat would not exceed 65.

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ADDENDUM 2

Statistical examination of the experimental data. By J. O. Irwin,
Medical Research Council, and J. C. D. Hutchinson, School of Agriculture,
University of Cambridge

Analyses of variance were made of the weight increase of the pigs per unit digestible N and the food intake per unit weight gain over the range of body weights from 24 to 70 kg. The figures from groups 2, 3, 4, 6, 7 and 8 were used for this examination. We have then two main treatments, representing yeast, groups 2-4, and casein, groups 6-8, and three sub-treatments (A, B and C) representing three different levels of protein supplement to the basal ration as follows:

Sub-treatments	Yeast groups		Casein groups	
	Group	% digestible N	Group	% digestible N
A	2	1.417	6	1.396
B	3	1.713	7	1.849
C	4	2.004	8	2.084

Analysis of variance of the weight increase per unit digestible N

The analysis of variance is given in Table 1.

Table 1

	Sum of squares	Degrees of freedom	Mean square	Mean square/mean square of error
Main treatments	0.43	1	0.43	0.80
Sub-treatments	72.59	2	36.30	67.22
Interaction	8.88	2	4.44	8.22
Total treatments	81.90	5	16.38	30.33
Error	6.45	12	0.54	—
Total	88.35	17	—	—

From this table it appears that the difference between the main treatments is not significant, that the difference between the sub-treatments is significant to more than 0.1 % and that interaction between sub-treatments and the main treatments is significant to more than 1 %. This means that the relative effect of the main treatments is different according to the level of protein supplement. Examination of the means of the sub-groups shows that the casein supplement was the more efficient at the higher levels. The standard deviation of the gain in weight per unit digestible N consumed is 0.735.

Analysis of variance of food intake per unit weight gain

The analysis of variance is given in Table 2.

Table 2

	Sum of squares	Degrees of freedom	Mean square	Mean square/mean square of error
Main treatments	0.0047	1	0.0047	0.45
Sub-treatments	0.8183	2	0.4091	39.34
Interaction	0.1417	2	0.0708	6.81
Total treatments	0.9647	5	0.1929	18.55
Error	0.1246	12	0.0104	—
Total	1.0893	17	—	—

The difference between the main treatments is again not significant. That between the sub-treatments is significant to more than 0.1 %. The interaction between sub-treatments and the main treatment is significant to nearly 1 %. The casein supplement was, as above, more efficient at the higher levels of protein. The standard deviation of the food intake per unit weight gain is 0.10.