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C. H. McDOWELL, ACTING DIRECTOR,
College Station, Texas

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DIGESTIBILITY OF HUMAN FOODS AND ANIMAL FEEDS AS MEASURED BY DIGESTION EXPERIMENTS WITH RATS

G. S. FRAPS

Division of Chemistry

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
GIBB GILCHRIST, President

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As part of the comprehensive investigation of the energy values of animal feeds and human foods, digestion experiments were made with white rats. Results of 508 tests of the digestibility of foods and feeds by rats are summarized. The rats digested slightly less protein than chickens from the animal feeds but slightly more than the chickens from the human foods. The rats digested less fat but more crude fiber and more nitrogen-free extract than chickens. Digestibility of protein and of nitrogen-free extract averaged practically the same for both rats and humans, but the digestibility of fats averaged a little lower by rats than by humans. Digestion experiments of foods with rats can give a good idea of digestibility with humans.

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G. S. Fraps

Collaborating Chemist, Division of Chemistry

This publication is part of a comprehensive investigation of the energy values of animal feeds and human foods. Previous work has shown that the differences in energy values of food and feeds as measured by experiments with chickens are due to a large extent to differences in digestibility and to a much less extent to differences in the energy values of the digested nutrients (3). It was thought that digestion experiments with white rats would add to the information as to the energy values of animal feeds and human foods. For this reason, digestion experiments with rats were conducted in conjunction with the other work on the productive energy of feeds and foods (3, 4). White rats are used extensively for experimental work on metabolism, vitamins, and for other types of work relative to nutrition.

The digestibilities of various foods and feeds, secured by means of rats, were compared with those for chickens and for humans. Rats may have nearly the same digestive powers as humans; therefore the data secured by digestion experiments with rats may be applied to human foods.

Previous Work

Data from some of the previous work on the digestibility of proteins, fats and oils by rats are tabulated in Table 1. Experiments with rats in which the digestibility of the protein, fat, crude fiber and nitrogen-free extract is reported, such as have been made with chickens, sheep and other animals, have not been found in the literature. The work tabulated gives the apparent digestibility of protein, in which corrections were not made for metabolized products. Experiments in which rats were used to ascertain the biological value of proteins are not included, because in these experiments the digestibility of the protein was corrected for the metabolized protein in the excrement.

Methods

Digestion experiments were made on simple mixtures containing 18% protein, or on more complicated rations used in the productive energy work with chickens (3, 6) and with rats (4). When simple mixtures were used, they were made to contain as much as possible of the feed to be tested, with the addition of 1% salt, 1% dicalcium phosphate, 0.2% fortified cod liver oil, and casein if the food was low in protein, or starch if it was high in protein. If the rats would not eat sufficient quantities of any mixture, another mixture

Table 1. Digestibility of protein and fat by rats (compiled)

Food used in ration	Protein apparent digestibility %	Fat %	Reference Number
Beef protein (10% protein ration)	88	.....	10
Butter, Standard, low protein ration	.....	89	1
Butter, Standard, high protein ration	.....	96	1
Butter spread, special, low protein ration	.....	92	1
Butter spread, special, high protein ration	.....	96	1
Casein (15% protein ration)	83	.....	10
Corn (10% protein ration)	81	.....	10
Cottonseed meal (high protein ration)	72	.....	7
Cottonseed meal, autoclaved	64	.....	7
Cottonseed meal, extracted	81	.....	7
Cottonseed oil, 15%	.....	97	9
Cottonseed oil, hydrogenated, 5%	.....	88	9
Lard, leaf (5% in ration)	.....	93	9
Lard, refined (5% in ration)	.....	98	9
Lard, hydrogenated (5%)	.....	89	9
Lard, neutral, 5%	.....	95	9
Lard, steam, low protein ration	.....	98	1
Lard, steam, high protein ration	.....	98	1
Lard special, low protein ration	.....	92	1
Lard special, high protein ration	.....	95	1
Milk (10% protein ration)	83	.....	10
Milk, fresh whole	92	99	11
Milk, powdered whole	87	99	11
Milk, evaporated	88	91	11
Oleo oil, 5%	.....	97	9
Peanut oil, 5%	.....	96	9
Potato (10% protein ration)	79	.....	10
Soybean protein (15% protein ration)	77	.....	10
Soybeans, raw	79	.....	8
Soybeans, heated	83	.....	8
Wheat protein (10% protein ration)	79	.....	10
Yeast (10% protein ration)	79	.....	10

was fed containing a smaller quantity of the test feed. The more complicated rations usually contained 50% of the feed to be tested, except in case of oils, and feeds very high in protein (3, 4, 6).

Details for the digestion experiments were as follows: Select rats which do not shed much hair. Mix up enough of the ration to be tested for the experiment and for analysis. Place six rats in the rectangular cage made for the purpose with 3/8-inch mesh bottom. Place a wire-screen platform at an angle of about 45°, directly beneath the metabolism cage. The size mesh of this inclined platform should be small enough—about 1/4-inch mesh,—to prevent feces from passing through. It should permit passage of wasted feed and urine. A tray covered with clean smooth absorbing paper should be placed beneath the platform to collect urine and waste feed. The inclined platform should be hung with wire and its lower edge should be about two inches from the bottom tray. A wire screen should be placed in front of the cage,—resting on the tray,—in order to prevent loss of feces.

Put the feed in a McCullum feed cup with a piece of 1/4-inch hardware cloth cut slightly smaller than the diameter of the cup and resting on the feed. This prevents the rats from scratching out the feed. The feed cup is put in a flat 8-inch evaporating dish held in place by a piece of 1/4-in mesh hardware cloth with a hole cut in the center to allow the feed cup to project. The hardware cloth is turned down the sides of the dish so as to hold it firmly in place. Feed so as to leave little or no residue.

If the rats eat only 75 grams of a particular feed, only 75 grams should be fed the next time. Feed three days for a preliminary period. Then weigh the feed to 0.1 gm., put it in a weighed jar and feed the rats 7 days if sufficient feces is obtained, if not, feed longer. Enough feed should be fed and the feeding period should be long enough to give feces weighing 30 gms. or more.

Collect the feces daily (except Sunday) for 7 days, putting in clean paper frequently. The feces should be freed of all feed residues and hair by careful brushing. Dry the feces daily in an electric drying oven for about two hours, but do not over-dry. Save all feed residues, dry if necessary, and weigh. Weigh the dried feces at the end of the experiment. Also weigh residual feed and the jar as a check to eliminate errors in weighing.

In calculating the digestibility of the feeds tested from the digestibility of the mixture and rations, the coefficients of digestibility given in Table 2 were used. These were derived from some preliminary experiments.

Table 2. Digestion coefficients of feeds for rats used in calculations

Name of feed	Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %
Alfalfa leaf meal	60.0	46.2	30.0	74.7
Casein	94.0	89.0	0	98.7
Corn meal	84.5	89.2	51.6	96.0
Cottonseed oil	.....	96.7	.....	.....
Skim milk, dried	88.6	99.2	0	98.4
Starch	80.0	90.0	0	99.0
Cod liver oil	.....	96.7	.....	.....
Wheat gray shorts	77.2	75.6	23.4	76.2
Yeast	81.3	45.9	93.1	89.7

Coefficients of Digestibility

On account of the large number of experiments, the results are not reported individually. The average compositions of the feeds tested are given in Table 3. The average digestion coefficients for 508 tests are given in Table 4. Where there were 4 or more tests, the standard deviations are given. The standard deviations are discussed below.

Digestibility of the protein was over 90 percent only in wheat flour, casein, macaroni and powdered whole milk. Meat (muscle tissues) was not included in the tests. Digestibility of the protein was 80 to 90 percent in asparagus, corn gluten meal, cottonseed flour, fish by-products, graham flour, grain sorghum seeds, white bread, buckwheat flour, ground careless weed seeds, kafir, linseed oil meal, millet seeds, oatmeal, peanuts, green peas, rice, rye, dried skim milk, soy bean oil meal, and yeast. The protein in beans was much more highly digestible when cooked than when raw, but there was little difference between the cooked and raw black-eye peas. Careless weed seed are very small. Some of them probably escape digestion unless ground, as is seen by comparing the digestibility of the ground and the unground seed.

Ether extract (fat) was digested more than 90% in bone meal, white bread, cocoanut oil meal, cod liver oil, cottonseed cake or meal, cottonseed flour,

Table 3. Average composition of food as used in digestion experiments

Number of samples	Food or feeds	Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Water %	Ash %
9	Alfalfa leaf meal	22.3	2.8	14.3	40.1	7.9	12.6
1	Alfalfa meal, poor quality	13.3	1.2	34.0	36.2	7.3	8.0
1	Apples, dried	1.1	.6	3.7	61.5	30.2	2.9
1	Artichoke tubers, dried	10.0	.4	4.3	78.3	2.1	4.9
2	Asparagus, dried	42.9	2.9	11.6	27.6	4.3	10.7
2	Barley, whole	11.7	1.6	5.7	68.4	10.0	2.6
2	Beans, string, dried	20.0	1.6	13.8	52.7	3.8	8.1
2	Beans, kidney red, raw	25.8	1.2	4.0	55.1	9.7	4.2
1	Beans, kidney, cooked and dried	25.1	1.2	5.1	58.0	7.7	2.9
3	Beans, lima, raw	21.0	1.0	4.3	56.9	12.3	4.5
2	Beans, lima, cooked and dried	22.8	1.2	5.4	58.7	7.9	4.0
5	Beans, navy	23.2	1.4	4.8	59.1	7.3	4.2
1	Beans, navy, cooked and dried	22.9	1.4	5.3	58.6	6.3	5.5
1	Beans, pinto, raw	22.4	1.1	2.8	57.6	12.5	3.6
4	Beet (fine roots, top of stem removed)	12.7	.5	7.7	66.6	3.4	9.1
2	Beet pulp, dried	7.4	.3	16.9	60.3	10.6	4.5
2	Bone meal	26.3	2.3	.5	3.6	6.7	60.6
1	Bran (human food)	12.7	2.1	9.1	63.0	5.2	7.9
3	Bread, white	14.6	4.8	.4	71.6	5.8	2.8
1	Broccoli, dried	21.3	2.2	15.1	43.9	5.5	12.0
1	Broom corn seed	9.1	3.7	5.0	69.3	10.4	4.5
1	Buckwheat flour	16.1	3.7	2.1	64.9	10.5	2.7
4	Cabbage, dried	20.8	1.5	11.6	51.0	4.9	10.2
1	Careless weed seed	16.2	6.1	14.8	48.8	9.0	5.1
4	Carrots, dried	8.6	1.3	9.2	68.5	4.5	7.9
15	Casein	82.5	.8	.2	3.3	9.2	4.0
2	Celery, dried	16.1	1.4	13.7	45.2	4.2	19.4
3	Chard, dried, Swiss	29.6	3.4	10.3	32.8	4.1	19.8
3	Citrus pulp, dried	5.5	2.7	11.3	63.6	9.7	7.2
2	Coconut oil meal	21.0	8.4	10.5	46.0	7.5	6.6
2	Collards, dried	23.2	3.2	11.9	41.0	6.1	14.6
2	Corn, white	9.6	4.2	2.4	72.5	9.9	1.4
6	Corn bran	9.6	7.6	11.3	61.1	8.0	2.4
3	Corn gluten feed	25.2	1.6	8.1	49.0	9.8	6.3
3	Corn gluten meal	44.7	1.6	5.0	36.1	8.7	3.9
45	Corn meal	10.3	3.5	1.3	72.9	10.7	1.3
3	Cottonseed cake	45.3	8.6	7.8	26.2	6.3	5.8
3	Cottonseed flour	57.0	7.2	2.1	21.6	5.6	6.5
1	Cottonseed hulls	3.0	.3	40.7	43.8	9.5	2.7
12	Cottonseed meal	44.6	7.0	10.0	26.2	6.5	5.7

3	Egg plant fruit, dried	17.3	2.1	12.8	53.6	7.0	7.2
3	Fish meal	66.3	3.6	.4	6.6	7.3	15.8
4	Flour, graham	12.6	1.9	2.0	70.4	11.5	1.6
2	Flour, low grade	17.0	2.0	.5	67.5	12.1	.9
1	Flour, clear	16.3	1.3	.3	64.9	16.6	.6
3	Flour, patent	13.6	.9	.3	72.0	12.7	.5
2	Hominy feed	11.7	7.2	4.9	65.2	8.6	2.4
4	Kafir	11.8	3.4	2.2	71.6	9.5	1.5
1	Lactose	.2	.0	.2	98.6	1.0	.0
1	Lettuce, dried	21.3	3.9	9.4	49.4	4.0	12.0
2	Linseed oil meal	37.3	6.5	7.8	33.5	9.0	5.9
1	Liver meal	64.0	17.8	1.2	2.2	9.3	5.5
2	Macaroni	15.0	1.9	.4	72.5	9.3	.9
2	Meat and bone meal	51.0	9.1	2.0	.9	5.8	31.2
1	Meat scraps	48.5	9.6	1.5	2.9	5.9	31.6
2	Milk, buttermilk, dried	39.5	7.0	.2	39.1	6.4	7.8
4	Milk, skim, dried	35.1	1.1	.2	49.8	6.0	7.8
2	Milk, whole, powdered	26.1	26.3	.4	37.6	4.1	5.5
2	Millet seed	10.9	3.8	9.7	62.0	10.0	3.6
2	Milo, dwarf yellow	11.6	2.8	1.9	73.0	8.9	1.8
1	Mistletoe, dried	20.6	5.2	18.5	44.0	6.2	5.5
2	Mustard greens, dried	27.2	2.7	11.5	28.9	5.0	24.7
4	Oat hulls, ground	4.2	1.2	29.5	50.6	7.6	6.9
5	Oat meal	16.3	5.1	1.5	66.5	8.7	1.9
3	Okra pods and seed, dried	14.6	1.3	10.5	59.4	6.3	7.9
1	Parsley, dried	21.6	3.6	11.0	45.7	4.9	13.2
2	Peanuts, raw	30.8	46.8	3.0	11.9	5.4	2.1
4	Peanut meal	43.1	7.6	9.6	26.7	5.9	7.1
3	Peas, black eye, cooked and dried	25.8	1.6	3.6	59.3	6.0	3.7
4	Peas, black eye, raw	23.5	1.1	3.0	57.9	10.9	3.6
2	Peas, cowpeas, raw	23.2	1.1	4.9	56.8	10.3	3.7
1	Peas, green, dried	21.0	1.2	1.7	63.4	9.4	3.3
4	Peppers, green, dried	15.2	2.1	12.6	59.4	5.1	7.3
3	Potato, Irish, dried	12.0	.3	2.0	76.7	4.1	4.9
14	Potato, sweet, dried	5.7	.9	3.3	80.7	5.5	3.9
3	Pumpkin, dried	9.2	3.1	9.4	67.1	5.3	5.9
2	Rice, cooked and dried	8.7	.2	.4	85.2	4.6	.9
2	Rice, raw	7.5	.5	.4	78.9	12.1	.6
4	Rice bran	12.6	11.9	11.1	42.9	8.7	11.8
1	Rice hulls	2.3	.8	40.4	26.9	9.3	20.3
3	Rice polish	13.0	13.4	2.5	52.5	10.2	8.4
2	Rye	13.8	1.5	2.5	70.0	10.4	1.8
3	Shrimp meal	46.8	2.8	11.0	1.3	9.7	28.4
2	Sorghum seed, sumac	10.3	3.3	2.2	72.9	10.0	1.3
1	Sorghum halepense seed, Sudan grass	14.2	2.4	25.4	38.4	7.6	12.0
3	Soybean oil meal, solvent process	47.0	.5	5.7	32.2	8.7	5.9
3	Spinach, dried	26.9	2.3	9.3	28.3	6.8	26.4
2	Squash, dried	25.1	1.8	11.2	46.4	4.8	10.7
6	Starch, corn	.6	.1	.2	87.8	11.2	.1
2	Sunflower seed	19.1	28.0	31.5	12.4	5.9	3.1

Table 3. Average composition of foods as used in digestion experiments—continued

Number of samples	Food or feeds	Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Water %	Ash %
3	Tankage	58.8	9.4	1.9	1.4	6.4	22.1
1	Tomatoes, dried	13.3	2.9	8.6	55.5	11.4	8.3
2	Turnip bulbs, dried	10.8	1.0	12.3	62.9	4.0	9.0
2	Turnip greens, dried	20.0	2.7	12.4	40.5	4.3	20.2
3	Wheat	14.0	1.7	2.7	69.9	9.9	1.8
5	Wheat bran	18.5	4.0	9.9	50.9	10.4	6.3
1	Wheat bran with screenings	15.0	3.8	11.4	53.7	9.7	6.4
12	Wheat gray shorts	18.6	3.9	6.0	57.0	10.1	4.4
7	Yeast, dried brewers	49.7	1.0	4.3	30.8	5.5	8.7

Table 4. Diegestion coefficients and standard deviations—rat experiments

Number of Tests	Food or feed	Protein	Ether extract	Crude fiber	Nitrogen-free extract	Standard deviations		
						Protein	Ether extract	Nitrogen-free extract
		%	%	%	%			
16	Alfalfa leaf meal	54.1	23.7	28.8	66.8	19.7	20.5	21.7
1	Apples, dried	0	36.3	23.1	93.5	.....	.....	.....
1	Artichoke tubers	27.1	0	33.8	89.9	.....	.....	.....
2	Asparagus, dried	83.7	65.0	81.1	87.1	.....	.....	.....
2	Barley, whole	68.8	44.3	25.4	88.9	.....	.....	.....
2	Beans, dried string	53.3	21.4	74.5	89.0	.....	.....	.....
2	Beans, kidney, raw	46.3	12.0	63.9	90.2	.....	.....	.....
1	Beans, kidney, cooked	72.6	72.0	56.5	91.5	.....	.....	.....
3	Beans, lima, raw	36.4	66.5	44.2	90.1	.....	.....	.....
2	Beans, lima, cooked	71.4	56.3	53.2	92.7	.....	.....	.....
5	Beans, navy, raw	54.0	47.3	60.3	91.7	4.5	10.7	1.7
4	Beans, navy, cooked	73.4	60.8	57.6	91.8	2.9	3.7	3.1
1	Beans, pinto, raw	20.0	0	28.4	87.0	.....	.....	.....

5	Beets, roots	47.5	24.9	68.3	92.3	13.4	38.6	1.6
5	Beet pulp	25.7	0	67.9	81.7	11.9	.....	2.3
3	Bone meal	29.2	91.5	0	85.7	.....	.....	.....
5	Bran, breakfast food (contains added sugar)	63.6	44.1	27.1	73.6	2.7	12.2	3.2
4	Bread, white	85.0	91.0	70.7	98.5	4.0	1.7	1.1
1	Broccoli	53.6	36.2	59.4	81.4	.....	.....	.....
2	Broom corn seed	20.7	82.2	29.6	82.0	.....	.....	.....
2	Buckwheat flour	83.3	86.4	24.2	95.2	.....	.....	.....
7	Buttermilk	77.3	80.4	0	96.7	6.2	10.5	2.6
5	Cabbage, dried	57.9	67.9	68.9	85.2	5.7	18.1	6.5
1	Careless weed seed, not ground	69.8	78.2	28.9	84.6	.....	.....	.....
1	Careless weed seed, ground	85.2	91.5	47.0	96.0	.....	.....	.....
4	Carrots	26.3	79.5	64.0	90.2	11.9	15.4	5.3
23	Casein	93.8	23.2	24.7	89.6	2.0	30.3	22.1
2	Celery	63.1	66.8	55.0	85.3	.....	.....	.....
3	Chard, Swiss, dried	71.3	59.9	68.8	62.4	.....	.....	.....
8	Citrus pulp	0.4	64.6	48.1	78.7	1.5	16.9	4.0
2	Cocanut oil meal	63.8	97.4	58.0	71.6	.....	.....	.....
5	Cod liver oil	.....	95.0	.....	.....	.....	3.8	.....
2	Collards	72.5	52.4	58.4	80.5	.....	.....	.....
2	Corn	77.5	89.5	36.2	93.7	.....	.....	.....
9	Corn bran	62.3	88.7	17.6	46.5	16.7	4.2	13.2
4	Corn gluten feed	73.7	44.4	38.2	65.9	8.9	19.5	2.7
5	Corn gluten meal	88.8	35.4	44.9	72.8	2.0	27.7	6.9
1	Corn oil	0	82.0	0	0	.....	.....	.....
66	Corn meal	79.7	79.0	43.7	98.3	14.4	22.7	1.9
3	Cottonseed cake	73.9	96.2	21.1	67.1	.....	.....	.....
25	Cottonseed oil	.....	96.1	.....	.....	.....	3.4	.....
7	Cottonseed flour	83.1	90.5	78.5	86.8	2.9	11.4	7.4
2	Cottonseed hulls	0	52.8	8.9	2.8	.....	.....	.....
12	Cottonseed meal	75.8	95.6	23.1	64.3	3.2	2.6	11.8
2	Cottonseed oil, medium hydrogenated	.....	93.7	.....	.....	.....	.....	.....
2	Cottonseed oil, highly hydrogenated	.....	47.5	.....	.....	.....	.....	.....
3	Egg plant	43.7	68.5	57.6	87.6	.....	.....	.....
7	Fish, by-product meal	86.6	87.2	.....	.....	4.9	2.8	.....
6	Flour, graham	87.0	83.4	43.5	95.4	4.6	6.9	2.9
3	Flour, low grade	93.9	92.8	73.0	98.8	.....	.....	.....
1	Flour, clear	94.3	88.0	73.5	98.7	.....	.....	.....
5	Flour, patent	95.2	77.6	71.1	99.0	2.3	29.6	0.6
2	Hominy feed	72.4	88.8	24.0	80.7	.....	.....	.....
6	Kafir	82.5	79.9	48.1	96.0	6.5	5.2	2.0
1	Lactose	0	100.0	0	100.0	.....	.....	.....
1	Lettuce	60.5	64.0	64.8	83.7	.....	.....	.....
4	Linseed oil meal	81.0	88.7	36.9	77.1	1.2	4.6	2.1
1	Liver meal	73.1	92.7	100.0	2.0	.....	.....	.....
2	Macaroni	93.6	85.0	39.2	98.8	.....	.....	.....
6	Meat by-product and bone meal	70.9	92.8	.....	44.0	4.1	2.7	52.2
3	Meat by-product meal	63.0	91.7	5.6	18.5	.....	.....	.....
3	Milk, powdered whole	90.1	97.4	.....	90.0	.....	.....	.....
3	Millet seed	83.0	92.9	34.5	92.8	.....	.....	.....
2	Milo	78.0	76.1	21.5	94.3	.....	.....	.....

Table 4. Digestion coefficients and standard deviations—rat experiments—(continued)

Number of tests	Food or feed	Protein	Ether extract	Crude fiber	Nitrogen-free extract	Standard deviations		
						Protein	Ether extract	Nitrogen-free extract
		%	%	%	%			
1	Mistletoe	16.5	0	16.4	61.1			
2	Mustard greens	69.8	66.0	48.8	69.1			
6	Oat hulls	17.7	27.2	15.3	20.7	17.7	33.3	10.9
7	Oatmeal	86.8	90.2	42.1	97.1	2.2	2.3	1.1
4	Okra (dried)	38.9	45.2	66.2	81.9	13.4	26.2	4.1
1	Parsley, dried	64.2	62.2	59.5	80.9			
2	Peanuts, raw	88.8	96.7	74.5	75.8			
1	Peanut oil	0	82.0	0	0			
6	Peanut meal	81.7	89.3	30.5	84.5	2.6	8.6	5.8
3	Peas, blackeye cooked	77.7	77.2	59.4	94.1			
4	Peas, blackeye raw	72.9	70.0	45.5	93.0	2.7	6.8	2.4
1	Peas, green	85.0	77.8	84.6	97.8			
3	Peppers, dried green	45.1	51.4	27.0	83.7			
5	Potato (Irish)	52.4	12.3	67.6	92.1	17.6	22.8	3.6
15	Potato, sweet	34.2	66.7	66.9	97.3	15.5	26.0	2.2
3	Pumpkin, dried	47.4	77.5	72.8	94.3			
2	Rice, raw	73.6	70.3	76.3	99.5			
2	Rice, cooked	84.4	70.5	76.8	99.5			
6	Rice bran	58.3	89.1	29.1	83.0	16.6	6.0	12.3
2	Rice hulls	0	39.8	3.8	26.6			
3	Rice polishings	79.2	94.4	31.3	97.3			
3	Rye	80.3	49.7	30.6	91.9			
1	Rye flour	74.6	100.0	9.1	97.4			
4	Shrimp by-product meal	78.5	75.3			1.7	9.4	
5	Skim milk	87.0	51.6	0	99.0	3.2	49.0	.9
2	Sorghum seed, sumac	45.8	83.0	36.1	88.7			
1	Soybean oil	0	80.7	0	0			
9	Soybean oil meal, solvent process	80.6	32.0	44.6	85.9	6.9	30.2	12.9
3	Spinach	71.8	29.9	64.0	72.7			
12	Starch, corn				99.0			1.2
2	Squash	44.3	49.9	69.3	75.2			
3	Sunflower seed	78.1	97.9	32.9	32.8			
9	Tankage	57.4	88.1	28.2	24.9	11.9	8.8	29.9
1	Tomatoes, dried	35.1	52.2	12.9	80.9			
1	Turnip roots	34.3	92.2	73.3	88.6			
2	Turnip greens	64.2	71.9	54.2	73.9			
3	Wheat	77.7	61.1	20.7	92.1			
10	Wheat bran	73.5	46.7	22.1	60.1	5.1	12.2	2.3
15	Wheat gray shorts	73.9	64.2	22.6	80.6	6.5	16.8	4.1
12	Yeast, dried brewers	80.4	0	75.6	95.5	2.5		4.4

cottonseed oil, medium hydrogenated cottonseed oil, low-grade flour, liver meal, meat and bone meal, powdered whole milk, millet seed, oatmeal, peanuts, rice polishings, rye flour, sunflower seed and turnip roots.

Nitrogen-free extract was digested over 90% in beans, both raw and cooked, beets, white bread, buckwheat flour, clear flour, patent flour, kafir, lactose, macaroni, powdered whole milk, milo, oatmeal, green peas, potatoes Irish or sweet, pumpkin, rice, rice polishings, rye, rye flour, skim milk, starch, wheat and yeast.

Variations as Shown by Standard Deviations

Standard deviations are given in Table 4. The standard deviation is recognized as a measure of variation. The standard deviation was calculated in the usual way by adding the squares of the differences from the average, dividing the sum by the number of tests less one, and extracting the square root. A deviation greater than the standard deviation occurs about once in 3 trials, while twice the standard deviation is exceeded about once in 22 trials (2).

Variations in Digestibility

Variations in the digestibility of feeds as shown by the standard deviations are due partly to differences in the digestive process, partly to differences between different samples of the same feed, and partly to errors of manipulation and analysis in the experimental work. Experimental errors, while small when the entire ration is considered, may be large when all the errors are assigned to any one ingredient of the ration, as shown below.

Table 5 contains a comparison of the variations in coefficients of digestibility of corn meal rations and of the corn meal in the rations calculated from the results of the tests with the same rations. The standard deviations of the coefficients of digestibility for the entire ration were quite low for protein, ether extract and nitrogen-free extract, although higher for the crude fiber. Crude fiber is present only to a small extent and comparatively slight errors in the analysis of the excrement or the feed could cause large differences in the coefficients of its digestibility.

The standard deviations were much larger for the corn meal contained in the ration than for the entire ration, ranging from 1.5 to 14 times as much. The differences increased with the extent to which casein was present as shown by the percentage of protein in the rations. The standard deviations for the nitrogen-free extract were quite low: This nutrient comprised about 70% of the corn meal. Those for the protein, the ether extract, and especially the crude fiber, were much higher; these nutrients are present in much smaller percentages than the nitrogen-free extract.

It would be reasonable to think that the actual digestibility of the corn meal does not vary any more than that of the ration in which it is fed. When all the experimental and analytical errors are assigned to a portion of the ration such as the corn meal, the variations appear larger than they really are. When high standard deviations occur a small number of experiments are not sufficient for an accurate average. When the feed tested is fed as part of a

Table 5. Comparison of variations in digestibility of corn meal rations and of corn meal calculated from the digestibility of the rations

Ration or feed	No. averaged	Coefficients of digestibility				Standard deviations			
		Protein	Ether extract	Crude fiber	Nitrogen-free extract	Protein	Ether extract	Crude fiber	Nitrogen-free extract
		%	%	%	%	%	%	%	%
Corn meal ration, 16.7% protein....	4	80.7	85.7	45.9	92.9	1.4	3.7	7.3	0.4
Corn meal ration, 21% protein.....	8	85.2	86.1	31.9	91.7	1.8	1.8	13.0	0.9
Corn meal ration, 30% protein.....	10	86.2	80.4	29.7	91.6	1.4	2.8	14.2	1.2
Digestibility of corn meal calculated from above rations:									
Ration 16.7% protein.....	4	79.4	92.1	60.6	98.7	5.5	10.5	28.8	0.7
Ration 21.0% protein.....	8	78.0	90.4	29.2	99.2	10.4	9.0	18.5	1.7
Ration 30.0% protein.....	10	60.8	44.7	20.0	99.2	19.6	27.3	32.9	1.8

ration, high standard deviations do not necessarily mean that the digestibility of constituents of the feeds are as highly variable as the standard deviations would lead one to suppose. These differences are partly mathematical, rather than actual.

Comparative Digestibility by Rats and Chickens

Comparisons of the average digestion coefficients secured with rats with those for corresponding feeds with chickens (5) are given in Table 6. On an average of all the comparisons of the feeds, the rats digested slightly less protein, a little less fat, and appreciably more crude fiber and nitrogen-free extract than the chickens. The rats digested a little more protein from the human foods than the chickens, and more nitrogen-free extract, but less fat. Differences between the digestive powers of chickens and that of rats occur chiefly with feeds low in the constituents being studied. When the feed is high in protein, in fat or in nitrogen-free extract, the differences are usually small. On the average rats have slightly higher digestive powers than chickens.

Comparative Digestibility by Rats and Humans

Average digestion coefficients of feeds by humans, a compiled by us from the literature, compared with these for rats fed corresponding foods, are given in Table 7. The average of the coefficients compared is 70.0 for protein by rats and 71.3 by humans; 72.6 for fat by rats, and 82.4 for humans, and 91.5 for nitrogen-free extract by rats and 91.7 for humans. Except for fat, the average digestibility was practically the same by rats and humans. The human digestion experiments listed in which crude fiber was determined were so few (five) that a comparison is not justified.

It would seem that for foods on which reliable digestion experiments with humans are not available, results of digestion experiments with rats could be used with no great error. This is the case especially with vegetables. Many human digestion experiments have been carried out with complicated diets, in which the food to be studied was only a small portion of the entire ration. When fed in this way, as pointed out in this publication and in a previous publication (5), the coefficients of digestibility of the ingredients are subject to greater error than that of the entire ration. Digestion experiments with rats may in such cases give more accurate data than the experiments with human beings.

Table 6. Digestion coefficients of rats compared with those for chickens

Food or feed		Protein		Ether extract		Crude fiber		Nitrogen-free extract	
		Rats	Chickens	Rats	Chickens	Rats	Chickens	Rats	Chickens
Alfalfa leaf meal		54.1	56.3	23.7	58.6	28.8	6.6	66.8	36.6
Barley	H	53.2	73.4	25.0	75.3	21.4	11.6	88.4	79.6
Beans, lima, raw	H	41.0	34.5	68.1	92.3	42.3	13.7	89.6	68.5
Beans, lima, cooked	H	63.6	74.0	47.1	74.2	44.7	12.6	91.0	75.1
Beans, navy, raw	H	64.8	41.9	52.9	63.7	62.1	16.0	92.2	40.8
Beans, navy, cooked	H	59.5	59.8	54.9	71.9	57.5	7.2	90.4	66.0
Beet pulp		6.0	27.2	0	54.1	65.7	3.6	85.4	23.0
Bran, breakfast food (contains added sugar)	H	63.6	57.0	44.1	75.7	27.1	14.9	73.6	62.6
Buckwheat flour	H	83.7	85.8	87.4	74.4	26.0	0	95.3	88.9
Buttermilk	H	77.3	69.1	80.4	95.4	.....	.....	96.7	70.5
Casein	H	93.8	85.1	23.2	48.2	.....	.....	.....	.....
Citrus pulp		1.1	16.3	52.7	70.2	37.2	5.9	76.1	41.8
Coconut oil meal	H	65.7	56.4	100.0	92.1	61.0	15.4	69.1	31.5
Cod liver oil		.....	.....	95.0	63.7	.....	.....	.....	.....
Collards	H	72.5	69.8	52.4	64.9	58.4	13.4	80.5	52.7
Corn meal	H	78.7	86.1	78.7	89.5	41.9	21.6	98.4	94.1
Corn bran		57.2	53.9	88.7	89.2	17.6	6.8	46.5	33.1
Corn gluten feed		71.0	61.7	37.9	65.3	36.7	3.3	66.3	43.7
Corn gluten meal		88.3	80.5	19.0	55.1	44.7	10.8	73.0	56.5
Corn oil	H	.....	.....	82.0	87.5	.....	.....	.....	.....
Cottonseed flour	H	81.6	73.2	84.9	86.5	87.1	13.5	90.2	38.1
Cottonseed hulls		0	0	52.8	31.3	8.9	9.2	2.8	0
Cottonseed meal		75.8	70.0	95.6	96.7	23.1	10.4	64.3	36.2
Cottonseed oil	H	.....	.....	95.4	89.4	.....	.....	.....	.....
Fish by-product meal	H	82.0	74.8	85.4	82.7	62.1	49.8	12.9	35.1
Flour, graham	H	87.0	74.9	83.4	98.7	43.5	44.1	95.4	90.4
Flour, low grade	H	93.9	84.2	92.8	95.9	73.0	82.8	98.8	89.4
Flour, clear	H	94.3	89.7	88.0	96.9	73.5	64.6	98.7	99.0
Flour, patent	H	95.2	85.8	77.6	96.9	71.1	81.4	99.0	95.0
Hydrogenated cottonseed oil (A)	H	.....	.....	93.7	91.3	.....	.....	.....	.....
Hydrogenated cottonseed oil (B)	H	.....	.....	47.5	45.2	.....	.....	.....	.....
Kafir	H	82.5	79.7	79.9	79.9	48.1	12.4	96.0	93.1
Lactose		.....	.....	.....	.....	.....	.....	100.0	45.8
Linseed oil meal		80.0	62.2	85.1	76.1	31.2	9.1	69.8	23.6
Macaroni	H	93.6	77.6	85.0	85.1	39.2	57.4	98.9	97.2
Meat by-product and bone meal		68.7	60.6	92.1	90.4	5.6	63.0	42.3	60.0
Milk, skim, dried	H	87.0	74.9	51.6	57.0	.....	.....	99.0	68.6
Millet seed		80.8	70.3	93.7	94.5	35.6	11.2	94.5	90.5
Milo		78.0	87.9	76.1	84.2	21.5	23.2	94.3	96.5
Oat hulls		19.0	20.5	20.1	73.5	14.1	9.6	20.7	20.4

Oatmeal	H	86.8	85.1	90.2	93.4	42.1	26.9	97.1	92.3
Peanut oil	H	.....	.....	82.0	86.8	.....	.....	.....	.....
Peanut meal	H	82.3	73.7	88.5	90.9	31.3	6.5	84.7	50.6
Peas, cooked blackeye	H	77.8	72.6	77.6	95.1	55.9	6.9	94.2	83.2
Potato, sweet	H	36.4	38.3	66.0	73.8	65.9	19.6	97.6	88.2
Rice	H	86.5	100.0	91.1	100.0	88.8	50.0	100.0	95.4
Rice bran	.....	55.9	58.9	90.0	91.6	30.6	4.8	82.1	66.8
Rice hulls	.....	0	0	39.8	40.5	3.8	3.0	26.6	17.1
Rice polish	.....	76.3	76.7	95.6	90.7	19.1	13.7	99.8	86.9
Rye	H	79.1	66.1	54.8	52.0	26.6	16.8	93.0	76.4
Rye flour	H	74.6	64.9	100.0	61.0	9.1	22.6	97.4	79.5
Shrimp meal	.....	79.9	58.6	64.7	86.6	46.2	17.7	100.0	55.6
Sorghum seed, sumac	.....	27.1	65.6	80.3	88.1	24.9	11.5	86.2	89.7
Soybean oil	H	.....	.....	80.7	89.7	.....	.....	.....	.....
Soybean oil meal	H	83.8	74.2	22.9	78.8	44.8	1.3	91.9	34.2
Starch	H	.....	.....	.....	.....	.....	.....	99.0	97.0
Sunflower seed	.....	79.4	65.5	97.2	95.0	31.9	11.7	34.3	15.5
Tankage	.....	55.8	55.4	87.0	88.1	26.2	29.6	19.3	89.6
Wheat	H	77.7	93.3	61.1	95.6	20.7	35.7	92.1	95.3
Wheat bran	.....	72.3	58.6	49.3	86.4	21.2	6.4	59.9	37.3
Wheat gray shorts	.....	73.9	68.0	67.7	85.5	21.9	7.4	80.1	63.2
Yeast	.....	80.9	68.7	9.2	47.6	70.7	8.2	95.8	53.7
Number (all)	.....	53	53	60	60	51	51	54	54
Average (all)	.....	67.6	68.3	66.5	78.8	39.1	20.3	77.7	63.2
Number (human foods H)	.....	30	20	36	36	27	27	30	30
Average (human foods H)	.....	76.7	72.5	71.6	81.3	49.1	26.6	90.0	74.3

Table 7. Comparative digestibility of foods by rats and by humans

Food or feed	Protein		Ether extract		Crude fiber		Nitrogen-free extract	
	Rats	Humans	Rats	Humans	Rats	Humans	Rats	Humans
Apples, dried	0	.....	36.3	.....	23.1	.....	93.5	.....
Apple sauce	.....	19	.....	98	.....	95	.....	99
Barley	53.2	69	25.0	.....	21.4	.....	88.4	97
Beans, cooked	59.5	77	54.9	60	57.5	.....	80.4	94
Beet, roots	47.5	73	24.9	100	68.3	84	92.3	97
Bread, white	85.0	87	91.0	75	70.7	53	98.5	98
Cabbage	57.9	48	67.9	40	68.9	77	85.2	82
Carrots	26.3	61	79.5	94	64.0	.....	90.2	89
Corn meal	78.7	76	78.7	68	41.9	.....	98.4	97
Corn oil	.....	.....	82.0	97	.....	.....	.....	.....
Cottonseed meal	75.8	78	95.6	100	23.1	.....	64.3	60
Cottonseed oil	.....	.....	95.4	98	.....	.....	.....	.....
Flour, graham	87.0	83	83.4	64	43.5	.....	95.4	95
Flour, low grade	93.9	91	92.8	86	73.0	.....	98.8	96
Hydrogenated cottonseed oil	.....	.....	93.7	96	.....	.....	.....	.....
Macaroni	93.6	84	85.0	56	39.2	.....	98.9	97
Milk, whole	90.1	92	97.4	97	.....	.....	90.0	89
Milk, skim, dried	87.0	95	51.6	93	.....	.....	99.0	97
Milo	78.0	37	76.1	.....	21.5	.....	94.3	97
Oat meal	86.8	84	90.2	87	42.1	.....	97.1	97
Peas, green	85.0	79	77.8	61	84.6	.....	97.8	92
Potatoes, Irish	52.4	75	12.3	80	67.6	74	92.0	99
Peanut oil	.....	.....	82.0	88	.....	.....	.....	.....
Peas, cooked, blackeye	77.8	74	77.6	63	55.9	.....	94.2	88
Rice	86.5	71	91.1	97	88.8	.....	100.0	97
Rye flour	74.6	70	100.0	93	9.1	.....	97.4	93
Soybean oil	.....	.....	80.7	98	.....	.....	.....	.....
Starch	.....	.....	.....	.....	.....	.....	99.0	100
Wheat	77.7	71	61.1	71	20.7	.....	92.1	93
Wheat bran, finely ground	72.3	45	49.3	.....	21.2	.....	59.9	57
Number totaled	23	23	28	25	21	5	24	24
Average	70.7	71.3	72.6	82.4	47.9	76.6	91.5	91.7

SUMMARY

Results of 508 tests of the digestibility of foods and feeds by rats are summarized. The rats digested slightly less protein than did the chickens from all the feeds, but digested a little more protein than did the chickens from human foods. The rats digested less fat but more crude fiber and more nitrogen-free extract than the chickens. The digestibility of protein and of nitrogen-free extract by rats and humans averaged practically the same. Rats digested smaller percentages of fats than the humans on an average.

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