TEXAS AGRICULTURAL EXPERIMENT STATION

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College Station, Texas

BULLETIN NO. 663 NOVEMBER, 1944

DIGESTIBILITY OF FEEDS AND HUMAN FOODS BY CHICKENS

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E28-1144-3M-L180

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A knowledge of the digestibility of feeds and foods is necessary in order to ascertain their feeding values. As part of a comprehensive investigation of the feeding values of various feeds and foods, a number of digestion experiments were made. This Bulletin presents a summary of 718 digestion experiments made with chickens. The feeds tested include chicken feeds, some human foods and some representatives of the nutrients contained in foods, such as albumen and casein to represent proteins, starch to represent carbohydrates and cottonseed oil to represent fats. Average coefficients of digestibility are given, and also the standard deviations when 4 or more experiments were available for the same feed. The standard deviation gives information as to the variability of the digestion coefficients. The digestibility of the nutrients of an entire ration is less variable than the digestibility of the nutrients of corn meal when fed as 50 per cent of the ration. Some work on the determination of uric acid is reported.

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DIGESTIBILITY OF FEEDS AND HUMAN FOODS BY CHICKENS

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The work here presented is a part of a comprehensive investigation of the values of the energy of different kinds of feeds. The nutritive values of feeds and foods depend to a great extent upon their digestibility. Only the nutrients which are digested can be utilized. The utilization of the digested nutrients for the production of fat and flesh by growing chickens and by rats has been discussed in other publications (6, 7, 8). A number of digestion experiments were made for the purpose of the work referred to above, and additional experiments were also made. The work on the utilization of energy showed that differences in the productive energy of various feeds are due to a greater extent to differences in their content of digestible nutrients than to differences in the energy values per unit of the digested nutrients. This makes a knowledge of the digestibility of feeds of high importance.

A summary of 39 foreign experiments and 112 American experiments on the digestibility of poultry feeds was given in Texas Bulletin 372, in 1928 (4). The Bulletin here presented contains a summary of the results of an additional 718 digestion experiments made at this Experiment Station. A summary of 178 experiments made elsewhere with poultry not included in Bulletin 372, is given in addition. As previously shown (5) chickens have high digestive powers for sugars and starch, and low digestive powers for proteins and for nitrogen-free extract remaining when sugar and starch have been deducted.

The feeds tested include chicken feeds, some human foods, and some representatives of the nutrients contained in foods, such as albumen and casein to represent proteins, starch, sugar to represent carbohydrates or nitrogen-free extract, and cottonseed oil to represent fats.

Procedure

A few of the experiments were made on single feeds fed alone, but most of them were made on feeds in balanced mixtures and in rations used for productive energy experiments, from which the digestibility of the chief feed was later calculated. The constituents of the rations used in the productive energy experiments have already been published (6, 7, 8). Balanced mixtures were prepared, to contain 2.5% calcium carbonate, 1.5% tricalcium phosphate, 1.0% salt and 0.2% cod liver oil concentrate. The balanced mixtures were made to about 18% protein with casein in the case of low protein feeds, and diluted to the same protein content with corn

meal when high protein feeds were tested. A series of digestion experiments were made on mixtures of casein and corn meal so as to obtain their digestion coefficients which were used in calculating the digestion coefficients of the other feeds with which they were used in balanced mixtures.

The baby chicks used in many of the experiments were kept in electrically heated brooders at 92-94° F until they were about 4 weeks old. Older chickens were also used and were kept at room temperature. The chickens over 8 weeks of age were fed in wire metabolism cages, 24 by 24 by 18 inches made of ¾ inch mesh chicken wire on a galvanized iron frame, supported on legs over a galvanized iron pan. The floor of the cage was of ¾ inch mesh chicken wire which was reinforced by heavy 3/16 inch wire running diagonally from corner to corner of the frame. The younger chicks were fed in groups of four to eight in each cage and the older chicks in groups of two or three.

During a preliminary period of 3 days, the chickens were fed only such amounts of food as they would either eat completely or leave only a small amount. At the end of the preliminary period, the wire cage and excrement pans were well cleaned by scraping and washing.. The chickens were then fed slightly smaller amounts of feed for a period of 4 days, during which the excrement was collected for analysis. The feed was made up in sufficient quantity to last through the entire experiment and at the start of the collection period, was weighed into a glass fruit jar. The quantity of feed to be fed was weighed out daily. At the end of the collection period, the jar and its contents was again weighed and the weight of the feed removed from the jar checked against the total of the daily weighings. Any waste feed was carefully separated from the excrement each day and weighed. It was then put into a weighed jar which was again weighed at the end of the collection period to check against the total of the daily weights. The excrement was collected twice daily to avoid decomposition. It was dried at 90° C in an oven equipped with a ventilating fan. The morning and afternoon collections of excrement when dried were weighed separately and put into a weighed jar. At the end of the experiment the wire screen and excrement pans were thoroughly cleaned by scraping and brushing and the excrement collected. The dried excrement in the jar was weighed as a check against the total of the daily weights. All the feed mixtures and excrements were analyzed.

Protein (N x 6.25), crude fiber, fat and ash were determined by the A. O. A. C. methods. Fat was determined by extraction with ether. Ammonia was determined in the excrement by distillation with magnesium oxide, and uric acid by the method given below.

Chickens excrete the undigested residues, the solid metabolic products and the urinary products all together. A few investigators have used birds whose urinary and fecal outlets were separated, by surgical operation, but in most of the work which has been reported, the uric acid has been determined in the excrement, and correction made for its presence. The method used for determining the uric acid may affect the results for the

digestibility of the protein. In the work here presented the analyses of the excrement were corrected for the uric acid and ammonia present. This does not correct for metabolic products other than uric acid and ammonia. The figures obtained, as is usually the case, are for apparent digestibility.

Methods for Determining Uric Acid

The work here reported extended over a number of years and the method at first used for determination of uric acid was that of Bartlett (4), which is similar to that described below, but the uric acid in Bartlett's method was dissolved in piperidine instead of sodium hydroxide. Studies of the method were made from time to time and some modifications made in the course of years. The methods for uric acid and ammonia as finally used are described as follows:

Texas Method for Uric Acid

Weigh 1.4 grams excrement into a beaker, add 25 cc of ice-cold alcohol and allow the beaker to stand in cold water for 30 minutes. Filter off the excrement, wash twice with cold alcohol and then three times with ether. Allow to dry and return to the beaker. Add 25 cc of 0.2 N hydrochloric acid and allow to stand over night in the refrigerator so that the uric acid can crystallize out. Transfer to a 50 cc centrifuge tube with ice-cold water and centrifuge until the supernatant liquid is clear. Pour off the clear liquid. Wash the residue twice with ice water. Wash the residue into a beaker with about 20 cc of water, add 15 cc of 0.2 N sodium hydroxide and heat on the water bath with frequent stirring until the white particles of uric acid have all dissolved. This will require about an hour. Transfer to a centrifuge tube, centrifuge until clear, and pour off the clear solution to a 250 cc beaker. Wash the residue three times with hot water, pouring each washing into the baker. Evaporate the solution to about 30 cc, wash down the sides of the beaker with concentrated hydrochloric acid and evaporate to about 2 cc. Cool and put in the refrigerator on ice for 24 hours to crystallize out the uric acid. Centrifuge off the precipitate and wash it twice with ice water. Wash the precipitate into a Kjeldahl flask and determine nitrogen, distilling into 20 cc of 0.2 N hydrochloric acid. One cc of 0.2 N acid equals 0.2% nitrogen.

Ammonia Nitrogen in Chicken Feces

Weigh 1.4 gram into a Kjeldahl flask, add 200 cc water, two or three pieces of sharp glass, one drop of lubricating oil and about 2 grams magnesium oxide. Distill immediately into 10 cc 0.2 N acid, titrate and report the ammonia as nitrogen.

Studies of Other Methods for Correction for Uric Acid

Two other methods recommended for the correction for uric acid were compared with the Texas method as described above, which for purposes of discussion is called the Texas method.

The method of Daikow (3), instead of determining the uric acid directly, supposedly gives the undigested nitrogen from which the undigested protein was calculated by multiplying by 6.25.

Weigh 1.4 grams of excrement into a 600 cc beaker. Add 500 cc boiling water and neutralize with 0.10 N sodium hydroxide using phenolphthalein as an indicator. Boil for one minute with constant stirring and filter. Wash the residue back into the flask with as much hot water as previously added and filter. Transfer the residue and filter paper to a Kjeldahl flask and determine the nitrogen.

The method of Shirley and Van Landingham, (15) determines the uric acid by difference and was slightly modified by adding dilute acid to the dry excrement to decompose any salts of uric acid which might be present.

Weigh two samples of 1.4 gram each into two beakers. Add 14 cc dilute hydrochloric acid, (5 cc concentrated acid to 95 cc water) and allow to stand in the refrigerator over night. Transfer quantitatively to a 50 cc centrifuge tube and centrifuge until clear. Pour off the supernatant liquid and wash once with 25 cc cold water. To one of the portions add 15 cc water, a few wrops of phenolphthalein and about twice as much 10% diethanolamine as is necessary to make the solution alkaline, usually 6 to 8 cc, and dilute to 25 cc. To the other portion of the sample add 25 cc of normal hydrochloric acid. Digest in a water bath at 60° C, with frequent stirring, for 10 minutes. Remove and allow to cool to room temperature. Mix well with a glass rod, rinse down the sides of the tubes with a little water and centrifuge for 5 minutes at 1500 revolutions. Pour off the supernatant liquid and allow the tubes to drain for a few minutes. The sample extracted with diethanolamine is washed three times with 50 cc cold water or until the wash water is not longer alkaline to phenolphthalein. The acid extracted sample is washed only once with cold water. The residues are transferred to Kjeldahl flasks and total nitrogen determined. The differences in nitrogen between the portion extracted with hydrochloric acid and the portion extracted with diethylanolamine are considered to represent the nitrogen present as uric acid.

Results of Comparisons

The undigested nitrogen as secured by the Daikow method is given in Table 1. The results are very much lower than those secured by the Texas method, which were obtained by subtracting the sum of the uric acid nitrogen and ammonia nitrogen from the total nitrogen. It is evident that the boiling water used in the Daikow method dissolves other nitrogenous compounds in addition to the uric acid and the ammonia nitrogen; this accounts for the incorrect values for the undigested nitrogen. The low results for undigested nitrogen in the excrement give high values for digestibility of protein. This is shown by Table 2, calculated from the results in Table 1. The two digestion experiments on the same feed check equally

Table 1. Undigested nitrogen in experiments as determined by the Daikow or the Texas method

Sample number	Undigested nitrogen Daikow method per cent	Undigested nitrogen Texas method per cent
56086	1.01	3.03
56087	0.97	3.07
56088	0.79	2.87
56089	1.22	3.26
56315	0.95	2.83
56316	1.93	4.14
56317	1.74	3.67
56318	1.18	2.74
56424	0.83	3.09
56425	1.79	4.04
56426	1.49	3.72
56427	0.95	3.02

Table 2. Digestible protein calculated from analyses by two methods for uric acid

Feed number	D. E. number	Digestible protein Daikow method per cent	Digestible protein Texas method per cent
56078	470	93.49	80.60
	476	94.38	79.07
56079	471	81.77	60.87
	477	84.59	65.22
56080	472	88.21	58.65
	478	84.43	61.13
56081	473	88.11	72.42
	479	90.56	69.98

Table 3. Nitrogen in uric acid determined by two metnods

Excrement Number	Shirley and Van Landingham method per cent	Texas method per cent
52673	4.37	3.63
52674	3.30	2.70
52675	2.22	2.26
52676	2.00	1.90
52677	2.12	1.88
52678	2.23	1.93
53420	4.73	4.05
53421	2.73	2.93
53422	3.17	2.81
52163	2.16	2.13
52164	2.56	2.27
52165	2.61	2.14
52166	1.98	1.98
Average (13)	2.78	2.51

as well with both methods but by the method of Daikow the digestibility of protein is from 15 to 20% higher than when the uric acid and ammonia were determined directly.

The results secured by the method of Shirley and Van Landingham are given in Table 3. As a rule the Shirley and Van Landingham method gave results that are slightly higher than those by the Texas method. The method required a larger number of determinations to secure two results which were sufficiently close together than did the Texas method. As there are two nitrogen determinations to be made instead of one, both nitrogen determinations had to agree in order to obtain a satisfactory result on the uric acid nitrogen. The analyses are always repeated and if the two are not sufficiently close together, continued until satisfactory agreement is secured. For the 13 analyses reported above, the Texas method required only 37 determinations to obtain satisfactory agreement, while the other method required 54 runs or 108 nitrogen determinations. Ammonia was not determined in the Shirley and Van Landingham method.

In another experiment, pure uric acid was dissolved in a solution of sodium hydroxide and precipitated with acid as in the Texas method. The results were slightly low, showing that the uric acid is slightly soluble in water and thus was not completely recovered. There is still need for improvement in the methods for determining uric acid.

Digestibility of the Feeds

The digestibilities of the feeds tested were calculated from the results obtained with the mixtures or the rations by use of the coefficients of digestibility of the other feeds in the mixture, given in Table 4. The figures in Table 4 were calculated from a number of the earlier experiments and are slightly different from the average digestion coefficients finally secured for the feeds.

The average composition of the feeds used in the experiments is given in Table 5. On account of the large number of tests made, the results of

Table 4. Digestion coefficients to be used in calculation of digestibility of feeds from data secured with balanced mixtures (chickens)

	Protein	Ether extract	Crude fiber	Nitrogen-free extract
Alfalfa leaf meal	47.2	59.1	4.3	17.6
Bone meal	41.4	86.3	0	0
Buttermilk, dried	65.4	95.2	0	72.1
Casein	86.1	0	0	48.2
Cod liver oil concentrate	0	72.9	0	0
Corn meal	85.1	82.8	13.0	88.5
Cottonseed meal	74.8	98.6	11.0	26.0
Skim milk dried	65.4	95.2	0	72.1
Starch	60.0	100	0	99.0
Tankage	41.4	86.3	0	0
Wheat gray shorts	71.1	83.6	2.1	50.1
Yeast	74.8	28.4	0	52.4

Table 5. Average composition of feeds used for digestion experiments with chickens

Number averaged		Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Water %	Ash %
7	Alfalfa leaf meal	21.9	2.8	15.6	39.4	8.1	12.2
4	Barley, whole	10.9	1.6	5.1	69.7	10.1	2.6
1	Barley, without hulls	13.7	1.0	1.0	73.0	9.9	1.4
4	Beans, lima, raw	21.1	1.2	5.2	60.0	8.1	4.4
5	Beans, navy, raw	22.7	1.4	5.0	58.4	8.5	4.0
1	Beans, pinto, raw	21.6	1.0	3.7	56.6	12.3	4.8
1	Beef, dried chipped	61.1	9.7	0.0	1.2	3.1	24.9
3	Beet pulp, dried	7.9	0.2	18.4	59.6	9.9	4.0
2	Broom corn seed	9.2	3.7	5.2	69.0	10.3	2.6
1	Buckwheat flour	16.1	3.7	2.1	64.9	10.5	2.7
3	Buttermilk, dried	35.3	7.4	0.2	39.5	7.1	10.5
1	Cane seed, red top	7.8	4.3	2.5	72.2	11.6	1.6
11	Casein	82.5	0.4	0.2	4.0	9.0	3.9
3	Citrus pulp, dried	5.5	2.7	11.3	63.6	9.7	7.2
3	Cocoanut oil meal	20.8	7.8	10.6	46.4	7.9	6.5
1	Collards, dried	2.9	0.4	1.5	5.5	87.7	2.0
5	Corn bran	9.1	7.2	12.3	61.4	7.7	2.3
6	Corn gluten feed	24.7	1.5	8.5	50.2	9.7	5.4
3	Corn gluten meal	44.7	1.6	5.0	36.1	8.7	3.9
62	Corn meal	10.8	3.8	1.4	71.7	10.7	1.6
1	Corn meal	11.1	3.4	1.2	72.5	10.5	1.3
3	Cottonseed flour	57.0	7.2	2.1	21.6	5.6	6.5
1	Cottonseed hulls	3.0	0.3	40.7	43.8	9.5	2.7
10	Cottonseed meal	42.8	6.5	9.9	27.7	6.8	6.3
3	Fish meal	66.3	3.6	0.3	6.7	7.3	15.8
1	Flour, clear	16.3	1.3	0.3	64.9	16.6	0.6
2	Flour, graham	12.4	1.8	1.8	70.3	12.3	1.4
2	Flour, low grade	16.9	2.0	0.5	67.6	12.1	0.9
6	Flour, patent	13.4	0.9	0.3	72.5	12.4	0.5
1	Gelatine	94.0*	0.1	0.0	0.0	14.3	1.9
1	Hegari seed	10.3	2.7	1.9	73.6	10.2	1.4
3	Kafir	12.0	3.5	2.3	70.8	9.6	1.6
1	Lactose	0.2	0.0	0.0	98.8	1.0	0.4
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	2.3	9.2	5.5
1	Macaroni	14.3	0.9	0.4	74.9	8.9	0.7
2	Meat meal	47.6	8.3	1.6	3.4	6.5	32.6
2	Meat and bone meal	51.0	9.1	2.0	0.9	5.8	31.2
6	Milk, dried, skim	35.0	1.1	0.2	49.8	6.3	7.6
2	Millet seed	10.9	3.8	9.8	62.0	9.9	3.6
4	Milo	11.2	2.8	2.3	71.6	10.4	1.7
5	Oat hulls	4.6	1.3	29.3	50.3	7.7	6.8
3	Oat meal	15.8	5.9	1.5	65.5	9.5	1.8
1	Oats, red	10.5	5.9	11.9	57.4	10.4	3.9
6	Peas, cow, raw	23.0	1.1	3.8	59.0	9.4	3.7
5	Peanut meal	43.9	7.4	9.9	25.6	6.6	6.6
2	Rice	7.8	0.3	0.4	78.3	12.2	1.0
4	Rice bran	12.5	12.4	11.4	41.5	9.1	13.1
1	Rice hulls, ground	2.3	0.8	40.4	26.9	9.3	20.3
4	Rice polish	13.3	14.5	2.5	49.8	10.0	9.9
1	Rye flour	12.6	1.9	2.2	69.7	11.8	1.8
3	Rye seed	13.5	1.6	2.7	69.9	10.5	1.8
3	Shrimp meal	46.8	2.8	11.0	1.3	9.7	28.4
1	Seed, cane	9.3	3.2	2.0	73.7	10.6	1.2
3	Solvent process soybean oil meal	47.0	0.5	5.7	32.2	3.7	5.9
1	Soybean oil meal	46.0	4.7	5.4	29.3	9.2	5.5
8	Starch	0.6	0.1	0.2	87.9	11.3	0.1
1	Sugar	0.1	0.0	0.1	99.7	0.1	0.0
2	Sunflower seed	19.1	28.0	31.5	12.4	5.9	3.1
5	Sweet potato	3.4	0.8	2.9	68.2	20.8	3.9
6	Tankage	59.6	8.8	1.7	1.0	6.8	22.1
2	Wheat	15.3	1.8	2.6	68.7	9.7	1.9
2	Wheat bran (human food)	12.9	2.0	9.1	61.9	6.4	7.9
6	Wheat bran	18.6	3.9	9.5	51.6	10.0	6.4
9	Wheat gray shorts	19.1	4.2	5.9	55.4	10.8	4.4
5	Yeast	51.8	0.8	3.2	29.3	6.4	8.5

*NX 6.25. The factor 6.25 is too high for gelatine.

Table 6. Digestion coefficients and standard deviations, chickens

Number averaged	Name	Digestion coefficients				Standard deviations		
		Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Protein	Ether extract	Nitrogen-free extract
2	Albumen, blood	74.0						
2	Albumen, egg, not cooked	48.1						
20	Alfalfa leaf meal	56.3	58.6	6.6	36.6	8.2	14.8	11.0
1	Barley, no hulls	73.7	77.5	24.8	80.3			
8	Barley, whole	73.4	75.3	11.6	79.6	13.8	16.4	3.2
4	Beans, lima, raw	34.5	92.3	13.7	68.5	10.1	15.5	16.9
2	Beans, lima, cooked	74.0	74.2	12.6	75.1			
6	Beans, navy, raw	41.9	63.7	16.0	40.8	9.1	49.3	17.6
3	Beans, navy, cooked	59.8	71.9	7.2	66.0			
3	Beans, pinto, raw	43.4	96.8	28.3	38.7			
3	Beef, dried	85.9	96.6	0	100.0			
11	Beet pulp	27.2	54.1	3.6	23.0	28.6	42.9	10.1
5	Broom corn seed	46.3	90.7	13.2	82.2	11.4	3.5	2.9
1	Buckwheat flour	85.8	74.4	0	88.9			
12	Buttermilk, dried	69.1	95.4	0	70.5	8.3	8.5	13.6
2	Cane seed	69.2	76.2	22.0	89.6			
37	Casein	85.1	48.2	38.5		3.4		
12	Citrus pulp	16.3	70.2	5.5	41.8	15.8	24.7	6.9
8	Cocoanut oil meal	56.4	92.1	15.4	31.5	4.8	12.6	4.0
1	Collards, dried	69.8	64.9	13.4	52.7			
16	Corn bran	53.9	89.2	6.8	33.1	13.1	7.2	7.1
11	Corn gluten feed	61.7	65.3	3.3	43.7	6.2	22.1	11.1
10	Corn gluten meal	80.5	55.1	10.8	56.5	5.4	34.9	39.0
117	Corn meal	86.1	89.5	21.6	94.1	11.6	12.2	3.7
11	Cottonseed flour	73.2	86.5	13.5	38.1	4.9	11.7	16.8
1	Cottonseed hulls	0	31.3	9.2	0			
2	Cottonseed hulls, delinted	14.3	32.5	6.0	4.7			
17	Cottonseed meal	70.0	96.7	10.4	36.2	10.8	10.1	25.1
10	Fish meal	74.8	82.7	49.8	35.1	4.6	9.3	38.8
4	Flour, clear	89.7	96.9	64.6	99.0	7.2	4.7	1.9
3	Flour, graham	74.9	98.7	44.1	90.4			
9	Flour, low grade	84.2	95.9	82.8	89.4	6.0	5.6	7.0
15	Flour, patent	85.8	96.9	81.4	95.0	6.7	7.4	4.9
4	Gelatine	74.2				3.2		
1	Hegari grain	86.0	76.9	41.9	94.9			
8	Kafir grain	79.7	79.9	12.4	93.1	12.2	7.0	2.3
2	Lactose	0	0	0	45.8			
6	Linseed oil meal	62.2	76.1	9.1	23.6	8.7	11.6	22.4

3	Liver meal	64.6	91.2	28.5	45.2	.....	.....	.....
1	Macaroni	77.6	85.1	57.4	97.2	.....	.....	.....
16	Meat meal, meat scraps, meat and bone meal	60.6	90.4	63.0	60.0	6.4	14.7	.....
12	Milk, dried skim	74.9	57.0	.....	65.6	7.9	43.1	16.7
6	Millet seed	70.3	94.5	11.2	90.5	6.5	3.4	6.5
8	Milo, grain	87.9	84.2	23.2	96.5	15.5	14.0	3.6
17	Oat hulls	20.5	73.5	9.6	20.4	27.6	33.7	8.8
5	Oat meal	85.1	93.4	26.9	92.3	14.5	4.2	2.0
1	Oats, red whole	56.0	91.7	0	66.1	.....	.....	.....
3	Oil, corn	.....	87.5	.....	.....	.....	.....	.....
35	Oil, cottonseed	.....	89.4	.....	.....	.....	4.5	.....
2	Oil, medium hydrogenated	.....	91.3	.....	.....	.....	.....	.....
3	Oil, high hydrogenated	.....	45.2	.....	.....	.....	.....	.....
4	Oil, peanut	.....	86.8	.....	.....	.....	10.6	.....
5	Oil, cod liver	.....	63.7	.....	.....	.....	9.9	.....
4	Oil, soy bean	.....	89.7	.....	.....	.....	6.1	.....
2	Peas, canned	71.7	39.9	7.1	70.1	.....	.....	.....
1	Peas, blackeye, cooked	72.6	95.1	6.9	83.2	.....	.....	.....
5	Peas, blackeye, raw	72.9	90.2	13.1	76.4	2.3	17.5	7.2
15	Peanut meal	73.7	90.9	6.5	50.6	3.7	4.8	10.0
2	Rice, polished	100.0	100.0	50.0	95.4	.....	.....	.....
9	Rice bran	58.9	91.6	4.8	66.8	7.9	4.8	12.7
4	Rice hulls	0	40.5	3.0	17.1	.....	49.3	2.3
11	Rice polish	76.7	90.7	13.7	86.9	12.1	4.2	8.1
8	Rye seed	66.1	52.0	16.8	76.4	10.2	11.3	3.0
3	Rye flour	64.9	61.0	22.6	79.5	.....	.....	.....
9	Shrimp meal	58.6	86.6	17.7	55.6	6.6	14.9	52.7
3	Sorghum seed	65.6	88.1	11.5	89.7	.....	.....	.....
6	Soybean oil meal, average fat and quality	74.2	78.8	1.3	34.2	8.8	6.3	17.5
6	Solvent process soybean oil meal, low fat	75.2	37.7	0.1	30.0	5.1	30.6	11.4
3	Soybean oil meal, cooked at low temperature	53.5	40.5	5.6	25.7	.....	.....	.....
23	Starch	.....	.....	.....	97.0	.....	.....	2.9
1	Sugar, cane	.....	.....	.....	67.4	.....	.....	.....
5	Sunflower seed	65.5	95.0	11.7	15.5	5.4	1.8	15.8
18	Sweet potato	38.3	73.8	19.6	88.2	34.6	28.3	4.8
21	Tankage	55.4	88.1	29.6	89.6	13.7	10.7	23.6
3	Wheat, ground whole	93.3	95.6	35.7	95.3	.....	.....	.....
13	Wheat bran	58.6	86.4	6.4	37.3	7.8	16.9	9.3
4	Wheat bran (human food)	57.0	75.7	14.9	62.6	9.2	28.6	3.9
17	Wheat gray shorts	68.0	85.5	7.4	63.2	6.8	10.9	11.1
11	Yeast	68.7	47.6	8.2	53.7	7.4	31.9	12.7
718	Total							

each individual digestion experiment are not given. Table 6 contains average coefficients of digestibility and also the standard deviations if there were 4 or more tests on the same feeds. The standard deviations are not given for the crude fiber.

For comparative purposes, the average coefficients of digestibility from Bulletin 372 (4) are given in Table 7. Average coefficients compiled from a number of results, published since Bulletin 372 was prepared, are given in Table 8. These include foreign experiments, in which some of the feeds used are not often found in this country.

The standard deviation shows the variability of the data. The average of all of the standard deviations for the experiments in Table 6 were 9.8 for protein, 14.8 for ether extract, and 11.3 for nitrogen-free extract. The standard deviation is considered low if less than 5, medium if between 5 and 10, and high if over 10. A high standard deviation was sometimes due to the results of only one or two tests being widely out of line with

Table 7. Coefficients of digestibility, chickens, average from Bulletin 372

Number averaged		Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %
2	Alfalfa leaf meal	100	0	4	0
2	Alfalfa meal	63	22	1	34
21	Barley	72	58	10	82
6	Blood meal	91	46	18	48
12	Buckwheat	61	86	10	84
5	Buttermilk, dried	82	79	.....	81
43	Corn and corn meal, bolted and unbolted	74	87	13	90
8	Cottonseed meal, Texas	76	86	12	86
8	Cowpea meal	48	88	11	86
6	Darso	36	86	38	89
10	Feterita	88	81	33	91
11	Fish meal	91	96	.....	15
3	India wheat	75	84	21	83
17	Kafir (dwarf)	67	78	18	92
6	Kafir, average for Texas only	84	80	19	93
7	Bone meal	87	93	24	34
2	Millet	76	78	17	87
12	Milo	83	78	31	92
11	Oat groats	77	89	14	91
21	Oats, whole	74	82	7	69
5	Peanut meats	80	78	4	84
3	Peas	88	81	9	87
7	Potatoes, white	47	0	6	85
3	Potatoes, sweet	0	25	4	77
9	Rice bran	58	87	3	52
2	Rice, brown	84	88	7	98
4	Rice polish	81	95	4	89
10	Rice, rough	74	72	5	84
8	Rye	65	31	12	86
3	Shallu	78	85	39	94
7	Sorghum	16	84	15	88
2	Soybean	70	93	53	76
5	Soybean oil meal	83	81	2	83
8	Soybean oil cake	83	82	0	80
4	Tankage, digester	85	96	4	44
9	Wheat middlings, 6.25% fiber	50	53	9	50
4	Wheat gray shorts	69	85	13	71
11	Wheat bran	60	50	8	54
34	Wheat	74	47	9	89
9	Wheat middlings, 8.5% fiber	76	53	8	60

Table 8. Coefficients of digestibility—chickens—compiled

Number averaged		Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Reference number
7	Alfalfa	65	55	44	61	1, 3
1	Alfalfa silage	60	55	.....	53	1
1	Artichoke, Jerusalem	67	.....	29	94	3
3	Barley	77	80	12	86	1, 3
1	Barley malt	75	70	.....	74	1
1	Barley bran	85	86	20	86	3
2	Beans	86	75	32	86	1, 3
2	Beets	69	74	.....	87	1
1	Blood meal	88	90	.....	75	1
1	Bone meal	90	90	.....	85	1
1	Brewers' grains	80	60	.....	78	1
1	Buckwheat bran	60	67	25	61	3
3	Buttermilk	93	92	.....	94	1
1	Cabbage	72	57	71	80	3
2	Carrots	68	64	54	93	1, 3
9	Clover	63	61	52	65	1, 3
2	Cocoanut meal	73	82	.....	85	1
11	Corn	80	86	13	9	1, 3, 10, 11
1	Corn feed meal	85	82	5	82	1
2	Corn, flaked	88	78	.....	95	11
3	Cottonseed cake	76	73	55	73	1
3	Cod fish meal	90	90	.....	65	1
1	Flax seed	90	93	6	60	1
4	Grass	63	55	41	65	1, 3
1	Grass silage	60	60	.....	58	1
1	Hemp seed	75	90	.....	65	1
1	Lentils	86	63	53	93	3
2	Linseed cake	82	83	.....	80	1
2	Lupine meal	82	69	.....	80	1
1	Meat meal	90	90	.....	85	1
1	Millet	90	73	5	88	12
2	Milk, skim	93	92	.....	94	1
1	Milk, whole	95	92	.....	94	1
6	Oats	71	81	21	73	1, 11, 12
2	Oat meal	85	75	9	91	1
2	Palm kernel	70	77	.....	77	1
1	Peanut cake, 0.1 to 5.0% crude fiber	83	81	7	82	1
1	Peanut cake, 5.1 to 10% crude fiber	76	74	4	75	1
1	Peanut cake, 10.5 to 15.0% crude fiber	70	68	.....	67	1
1	Peanut meal, extracted	82	80	7	81	1
14	Peas	75	75	14	79	1, 3, 10
3	Potatoes, Irish	63	41	13	88	1, 3
3	Rape seed	80	86	.....	79	1, 3
1	Rice feed meal	67	88	.....	58	3
1	Rice, ground	72	85	4	68	1
1	Rice, polished	87	50	47	97	3
2	Rutabagas	75	75	69	90	1, 3
2	Rye bran	73	66	33	67	1, 3
3	Rye, grain	70	59	5	85	1, 3
1	Soybeans	92	90	37	69	3
7	Soybean meal	78	72	9	81	1, 3
1	Speltz bran	78	88	25	40	3
3	Sugar beet	70	78	33	91	1, 3
1	Sugar beet leaves	74	25	75	89	3
3	Sunflower seed cake	77	82	3	86	1
3	Sunflower seed meal extracted	72	75	0	80	1
1	Tapioca meal	86	85	8	87	1
3	Turnip	68	74	35	91	1, 3
1	Vetch	84	75	6	80	1
18	Wheat	88	49	10	88	1, 11
6	Wheat bran	62	53	9	46	1, 13
8	Wheat, coarse middlings	76	86	5	88	13
1	Wheat malt sprouts	76	70	.....	75	1
1	Whale meal	85	90	.....	60	1
1	Yeast, dried	90	70	.....	88	1

the others for the same feed. It might have been more accurate to exclude such tests from the calculations on the assumption that these differences were due to errors and not to actual differences in digestibility.

High standard deviations occurred when the feed had a low content of the nutrient being studied, such as ether extract in dried beet pulp, in citrus pulp, in dried skim milk, or in oat hulls, or protein in beet pulp or oat hulls. Low standard deviations are found in feeds with a high content of the nutrient studied, such as protein in casein, in coconut oil meal, in corn gluten meal, or peanut meal, and nitrogen-free extract in barley, broom corn seed, corn meal, and flour. The data show that variations in digestibility are much greater with some kinds of feeds than with others. The actual variations may not be as great as they appear from the table, because the digestibility of the different feeds were determined with mixtures and rations and part of the variations are no doubt due to differences in the digestibility of the other feeds in the mixture, while all the variation is assigned to the feed being studied. This is shown below.

Effect of Percentage of Protein on Digestibility

The digestibility of corn meal was calculated from experiments on 3 series of rations containing 17, 24 and 31 per cent protein and differing only in the percentages of casein and corn meal present. The ration fed in series 17 consisted of 60% corn meal, 16.3% wheat gray shorts, 10% dried skim milk, 4% alfalfa leaf meal, 6% yeast, 1.5% oyster shell, 1% tricalcium phosphate, 1% salt, and 0.2% cod liver oil concentrate, and contained approximately 17% protein. The ration fed in series 24 contained 10% casein in place of 10% corn meal, and contained 24% protein while series 30 contained 20% casein in place of 20% corn meal, with 31 per cent protein.

The average digestion coefficients of the rations and those of the corn meal fed in the rations were calculated from the data from the rations and are given in Table 9. The differences in protein content of the rations had practically no effect upon the digestibility of the protein or the nitrogen-free extract of the corn meal. The digestibility of the ether extract decreased as the protein content of the rations increased. When the digestibility of the constituents of the corn meal was calculated from the results with these rations (Table 9), the digestibility of the ether extract was lower in the ration containing 31 per cent protein than in the other two, and the difference was found by statistical analysis to be significant. Barnes, Primrose, and Burr, 1944, (2) comparing the results obtained from rats on diets containing 12 or 28% casein, and 14 or 30% protein, concluded that the lower protein intake is associated with a lower digestibility of fat. The results here reported are exactly the opposite, since the lower protein intake is associated with a higher digestibility of fat, though they relate to the natural fat in the feeds and not to butter fat or lard, and to chickens and not rats, as was the case with the work of Barnes, et al.

Table 9. Digestion coefficients of rations and of corn meal in rations.

Number averaged	Name	Digestion coefficients				Standard deviations		
		Protein	Ether extract	Crude fiber	Nitrogen-free extract	Protein	Ether extract	Nitrogen-free extract
26	Corn meal ration about 17% protein	75.1	88.2	7.7	81.0	2.3	2.1	1.9
20	Corn meal ration about 21% protein	79.2	87.3	4.9	78.3	2.2	2.0	2.1
24	Corn meal ration about 31% protein	80.8	83.3	5.5	79.1	1.8	3.1	2.3
26	Corn meal in ration 17% protein	83.9	93.3	20.6	94.5	7.8	7.7	5.3
20	Corn meal in ration 24% protein	85.3	88.1	17.9	94.3	10.1	9.5	4.5
24	Corn meal in ration 31% protein	86.5	79.4*	22.7	95.3	18.5	15.8	5.5

*Difference from 93.3 statistically significant

Variations of Digestibility of Rations Compared with Digestibility Of the Chief Feed in the Rations

The standard deviations of the coefficient of digestibility of the protein in the series of rations discussed above (Table 9) in which casein replaced corn meal were 2.3, 2.2, and 1.8 compared with standard deviations of 7.8, 10.1 and 18.5 for the coefficients of digestibility of the protein of the corn meal, as calculated from the data of the same rations. The standard deviations of the digestion coefficients for the ether extract in the rations were 2.1, 2.0 and 3.1 compared with 7.7, 9.5 and 15.8 for that of the corn meal calculated from the same rations. For nitrogen-free extract the standard deviations were 1.9, 2.1 and 2.3 for the rations compared with 5.3, 4.5 and 5.5 for the corn meal. This shows that the variability of the digestion coefficients calculated for a feed fed in a ration may be much greater than that of the entire ration. Comparatively small deviations in the digestion coefficients of a mixture may result in much larger deviations in the digestion coefficients of a feed which is a part of the mixture. Part, at least, of the variations of the digestibility of a feed fed in a mixture is due, not to variations in the digestibility of the feed, but to variations in the ration, or to small errors which are magnified when the digestibility of the feed is calculated from the digestibility of the ration in which it was fed. For example, in experiment 433, the ration eaten (363.5 grams) contained 111.74 grams of protein, of which 11.25 grams was from the corn meal. An error of 0.5 gm. in the protein digested would affect the digestibility of the protein in the entire ration less than 0.5 per cent, but it would effect the digestibility of the protein in the corn meal 4.5 per cent. For this reason, errors which would have only a small effect on the constituents of the entire ration will have a much larger effect on a constituent of the ration.

Comparisons of Mixtures and Rations

Digestion experiments were made (a) on the unmixed feeds, (b) in mixtures containing a large percentage of the food to be tested, balanced with starch if the food was a protein food or casein, if it was a carbohydrate food and (c) complete rations in which the food to be tested was 50 per cent or less of the ration. The complete rations were used in determining the productive energy of the feeds, and are described elsewhere (6, 7, 8).

There were sufficient numbers of experiments for some comparisons to be made of the digestion coefficients secured from the feed fed in rations with those secured when it was fed in the balanced mixtures. These comparisons are given in Table 10. The coefficient of digestibility of the protein in dried buttermilk was significantly lower in the ration than in the balanced mixture, that of cottonseed meal was significantly lower when fed alone than when fed in a ration. The digestibility of the ether extract was significantly lower when fed in a ration containing 31 per cent protein, due to casein, than in a ration containing 17 per cent. The coefficient

Table 10. Digestion coefficients of chicken feed in rations (R) as compared with balanced mixtures (M) or alone (A)

Number averaged		Protein %	Ether extract %	Crude fiber %	Nitrogen-free extract %	Standard deviation			
						Protein	Ether extract	Nitrogen-free extract	Class
6	Alfalfa leaf meal	61.4	51.0	13.4	26.4	6.8	11.6	15.2	M
14	Alfalfa leaf meal	54.1	61.8	3.7	40.9	10.7	20.0	10.8	R
4	Buttermilk, dried	76.5*	96.8	.....	69.7	3.1	2.7	17.4	M
8	Buttermilk, dried	65.4	94.5	.....	72.2	7.6	10.4	11.0	R
9	Corn meal	70.1**	89.9	9.9	90.5	7.4	1.6	3.0	A
117	Corn meal	86.1	89.5	21.6	94.1	11.6	12.2	3.7	A11
13	Casein	84.2	.....	.....	.....	3.0	.....	.....	M
24	Casein	85.5	.....	.....	.....	3.6	.....	.....	R
6	Cottonseed meal	62.9*	93.0	12.2	55.1*	14.4	16.0	35.0	M
11	Cottonseed meal	73.9	98.7	9.4	25.9	5.9	2.8	7.9	R
6	Flour, patent	89.6	97.4	62.2	97.4	4.8	6.3	1.5	M
9	Flour, patent	83.3	96.6	94.2	93.4	6.9	8.5	5.8	R
5	Peanut meal	74.6	92.4	4.5	55.2	3.7	2.2	5.6	M
10	Peanut meal	73.2	90.2	7.6	48.4	3.8	5.8	11.1	R
5	Rice polishings	67.8*	91.2	10.3	79.3**	4.4	2.9	6.5	M
6	Rice polishings	76.5	90.4	16.5	90.3	6.3	2.5	2.5	R
6	Milk, dried skim	77.7	85.3	100.0	62.6	9.9	31.9	21.7	M
6	Milk, dried skim	72.2	28.7	19.1	68.5	5.7	34.0	10.9	R

*Difference statistically significant
**Difference highly significant

of digestibility of the nitrogen-free extract of cottonseed meal was significantly higher when fed in a balanced mixture than when fed in a ration. The other differences shown in the comparisons in Table 10 are apparently not significant. The differences were not in the same direction when significant. As a general rule, the mixtures and the rations may be considered to give the same results.

Discussion of Some Individual Feeds

The digestibility of the protein and of the nitrogen-free extract of raw beans (Table 6) was appreciably less than that of the cooked beans. Raw beans are evidently not good chicken feed. The digestibility of the black-eye peas was nearly the same raw as when cooked.

The soybean oil meal cooked at a low temperature was less digestible then that cooked at a higher temperature.

The protein of dried beef was digested 85.9 per cent, compared with 60.6 per cent for meat scraps, meat meal and meat and bone tankage and 55.4 for tankages. Dried beef consists of the muscle, while tankage and meat by-products are made from animal by-products not suitable for human food, and may contain little muscular tissue.

The constituents of wheat bran, wheat gray shorts and graham flour are almost all less digestible than those of the various grades of flour. Wheat bran and wheat gray shorts contain smaller percentage of starch than flour, and larger percentages of pentosans. The graham flour contains wheat bran and wheat gray shorts, which accounts to some extent for the constituents of the graham flour having lower digestibility than those of patent flour or low grade flour. Lactose (milk sugar) had a low digestibility. It had a laxative effect, when fed as 15 per cent of the ration, and not only had a low digestibility but the digested lactose had a low productive energy (8).

Cottonseed oil hydrogenated to a medium degree (iodine number 65) had a digestibility practically the same as unhydrogenated oil. When hydrogenated to a high degree (iodine number 10) the digestibility was only half that of the moderately hydrogenated oil. The productive energy of the digested oil when highly hydrogenated was also lower than that of the medium hydrogenated oil.

The factor for converting nitrogen to protein in gelatin should be 5.60 and not 6.25. However, to use one factor for gelatin and a different factor for the other feeds in calculating the protein in the same mixture is not correct. Nitrogen could be used for calculating the digestibility of the protein, and then the nitrogen-free extract could be calculated by difference. With use of the correct factor for protein, the nitrogen-free extract for gelatin is 0 but it is not 0 in the ration used due to the presence of other feeds. It seems simpler to use the factor 6.25 throughout and to calculate the nitrogen-free extract separately for the mixture, even though both the analysis of the mixture and the gelatin add to more than 100%. With the factor 6.25 the constituents of the gelatin add to 110 per cent.

ACKNOWLEDGEMENT

Feeding the chickens, analyses of the samples and other work was done by E. C. Carlyle, S. M. Greenberg, and other members of the staff.

SUMMARY

Average digestion coefficients are given for 718 digestion experiments with chickens. Methods for determining uric acid were studied. The digestion coefficients for the individual feeds were calculated from experiments with balanced mixtures or rations. The standard deviations of the digestion coefficients were calculated when 4 or more experiments were made on the same kind of feeds and show the variability of the digestion coefficients. The standard deviations were often high for nutrients which were present in low percentages in the feed. The standard deviations are high in some cases, and this indicates wide variability in the results. These variations are evidently due to errors in the work rather than to differences in the digestibility of the nutrient. Low standard deviations were found with many feeds, especially for nutrients present in high percentages.

With 3 groups of mixed rations which differed only in their percentages of casein and corn meal, the digestion coefficients of the protein and nitrogen-free extract were in the limits of error. The fat was digested to a smaller extent from the rations high in protein than from those low in protein. When the standard deviations were compared for the coefficients of digestibility of rations containing corn meal and for those of the corn meal contained in these rations calculated from the data secured from these experiments, the standard deviations were much higher for the corn meal than for the entire ration. This shows that small variations in the digestibility of rations may appear as much larger variations in the digestibility of individual feeds fed as part of these rations. Tables are given showing the digestion coefficients secured with the various feeds and foods used, and also tables showing the coefficients of digestibility secured in previous work at this station and also by other workers.

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