XXXV. ON THE DIGESTIBILITY OF COCOA BUTTER. PART I.

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THERE is a considerable literature dealing with the value of cocoa as a food, and a number of observers describe experiments, carried out both on man and animals, to test the physiological utilisation of the fats and proteins contained in it. In spite of the fact that the fat is of high melting point, and is stated to be resistant to enzyme action *in vitro*, it appears, when cocoa itself is eaten, to be well absorbed and utilised. The proteins are on the whole less available, but in the majority of the experiments recorded they show a fairly satisfactory utilisation.

H. Cohn [1895] in experiments carried out upon himself found that over 95 % of the fat was absorbed, but only about half the protein. R. O. Newmann [1906] in prolonged experiments got favourable results, and found that, when moderate quantities were used, the utilisation of the fat was about 90 %. Similar results were obtained by V. Gerlach [1907]. L. Pincussohn [1907], who added 35 g. of cocoa per day to the diet of a number of subjects, found that the fat absorption was very good, in some cases as high as 98 %. The protein absorption was, however, variable, ranging from 60 to 90 %, but was best in preparations containing a low percentage of fat. N. Zuntz [1890] in the case of chocolate found that 95 % of the fat was utilised. None of these observers noticed any ill-effects upon health as the result of taking for considerable periods quantities in excess of what would be consumed in ordinary life.

Until recently there were comparatively few experiments recorded on the feeding of the actual fat contained in cocoa-beans, namely cocoa butter. Zuntz in the above-mentioned paper, in a very extensive series of observations, found that dogs fed with cocoa butter absorbed about 90 %, a utilisation very nearly as good as in the case of bacon fat. Langworthy and Holmes [1917] published a paper on the digestibility of some vegetable fats, and amongst these fats cocoa butter was included. These experiments were conducted by similar methods to those that were employed in a previous investigation [1913] on animal fats. A basal ration, supplying a minimum of fat, composed of wheat biscuits, oranges, sugar and tea, or coffee if desired, was supplemented by a blancmange or corn-starch pudding, in which was incorporated the vegetable fat under consideration. This diet was fed to normal young men, in

good health and moderately active, for periods of *three* days. Weighings were made of nett amounts of food eaten and faeces excreted, and samples of both food and faeces were analysed to determine the percentages of protein, fat and carbohydrate which were actually digested.

The digestibilities of olive oil, cotton seed oil, pea nut oil, coconut oil, sesame oil and cocoa butter were in this way compared. In 11 experiments using different amounts of cocoa butter, the average percentage utilisation was 89.6. The figures however were rather variable, running from 79.1 % to 95.5 %.

The fat-carrying blancmange was *not relished in the cocoa butter experiments* as it was in the case of the other fats, for the amount eaten was only enough to supply 51 g. of cocoa fat per man per day during the first eight experiments. This quantity did not cause any decided digestive disturbance so far as was noted. The subjects reported a "loss of appetite," but in all other respects considered that their physical condition had been normal. In later tests the subjects were urged to eat more of the blancmange containing the cocoa butter. As a result of eating the larger quantities, an average of 109 g. per day, undesirable physiological derangements were experienced. The effects were so pronounced that one subject discontinued the diet at the end of the seventh meal. "Loss of appetite," "headache," "loss of ambition," "nausea" and "sleeplessness" were conditions reported, which, the authors consider, indicate that cocoa butter in quantity had an effect not noted in the case of the other vegetable fats studied. Though the exact limit of tolerance was not determined, to judge by the experiments made in the laboratory, the maximum amount of cocoa butter that can be consumed daily without decidedly unpleasant effects lies between 51 and 109 g.

The digestibility of the carbohydrate and protein did not seem to be influenced by the digestibility of the fat. In the experiments in which large quantities of the fat were fed, the faeces contained comparatively large quantities of fat—in one experiment as much as 37 % of the dry weight. In this case they state that an odour suggesting that of cocoa butter could be clearly detected.

This latter observation is however misleading, as a smell of cocoa is in our experience a normal constituent of the smell of all faeces. Dry faeces, after extraction with ether, retain this component of the smell in a marked degree, and it has nothing to do with the nature of the diet.

Messrs Langworthy and Holmes give the following figures for the coefficients of digestibility of the oils examined. In arriving at these numbers an allowance for metabolic products is introduced.

Olive oil	97.8
Cotton seed oil	97.8
Pea nut oil	98.3
Coconut oil	97.9
Sesame oil	98.0
Cocoa butter	94.9

With regard to cocoa butter they conclude that in view of the unsatisfactory utilisation of this fat and the accompanying physiological disturbances, the advisability of the continued daily use of cocoa butter in large amounts would appear questionable.

NATURE OF THE PRESENT INVESTIGATION.

The object of the experiments detailed below was to arrive at an opinion as to whether cocoa butter could be utilised with economy as part of the fat supply of the population without detrimental results to health.

In studying the digestibility of a single food, experience has shown that it is advisable to incorporate it in a simple mixed diet, since the ordinary individual is so accustomed to a mixed diet that, no matter how palatable a simple food may be at first, it soon becomes distasteful. It is also essential that the diet in question should be palatable, and we think it desirable that no constituent of the diet should be very largely in excess of the physiological balance. This was obviously not the case in the American experiments in which large quantities of cocoa butter were fed. The diets made use of by the sub-committee of the Royal Society in their experiments on the digestibility of breads made from different kinds of flour [1918] seemed very suitable for the purpose, and in order to save time it was decided to utilise the material accumulated in these experiments as controls.

The Diets consumed.

The details of the control diets have been published in the report by the Food (War) Committee of the Royal Society on the Digestibility of Breads [1918]. Approximately the daily diet consisted of

Bread	800-1000 g.
Minced meat	50 „
Butter	50 „
Jam	100 „
Milk	600 cc.
Cheese	50 g.
Sugar	30 „
Tea	<i>ad lib.</i>

In the tables in this paper the control diets, the fat content of which has not hitherto been published, are referred to as A, B, and C. In A the bread was made from 80 % milled flour, in B from 90 % milled flour and in C from 80 % milled flour mixed with 20 % maize. Almost the same diet was used in the cocoa butter experiments, substituting 50 g. of cocoa butter for the 50 g. of butter. The bread used in these latter experiments was the ordinary bread of the shops, and the daily ration was about 850 g. It was not possible to use the special breads of the control diets, but the results of the bread experiments warrant the assumption that the use of ordinary shop bread would have little

or no influence on the results. However, to obviate this as far as possible each subject was instructed to purchase his own bread.

Probably the results are more strictly comparable with diet C, the bread of which was made from mixed cereals, since the bread supplied to the public at the time of the cocoa butter experiments was of this nature. The cocoa butter used was the ordinary fat sold under that name.

It was rather hard and brittle, pale yellow in colour and possessed when fresh a distinct flavour of cocoa, which however rapidly diminished in intensity on keeping even in a closed vessel.

It consisted almost entirely of pure fat, and the constants given below are well within the limits of variation given in the literature.

Moisture	0.17 %	Melting point	33.5 ° C.
Ash	0.059 „	Acid value	1.98
Unsap. matter	0.907 „	Sap. value	194
Sterols	0.171 „	Reichert-Meissl value	0.84
		Iodine value	37.3

Subjects used in the experiments.

An account of the eight subjects, four in Cambridge and four in London who had the control diets is given in the above-mentioned report. Out of the four subjects, previously experimented on in London, two only, viz. E. and B., were still available for the cocoa butter experiment, the others having been called to the colours. We were only able to get one additional subject—P.

Individual	Age	Wt in kilos	Occupation and state of health
E.	36	55	Laboratory assistant. Delicate health
B.	34	65	Laboratory attendant. Athlete and active worker
P.	18	64	Laboratory attendant. Active and in good health

E. and B. were therefore the only subjects who had both the control and the cocoa butter diets.

EXPERIMENTAL METHODS.

The general procedure was exactly the same as that detailed in the Royal Society Report on the Digestibility of Breads, the diet being consumed for a period of ten days, the six significant days being the 4–9th inclusive. Accurate accounts of the weights of food eaten were kept and analyses of each food were made. On the fourth, sixth and ninth days a determination of the nitrogen in the urine was also made.

As before, the collection of faeces began one day later and continued one day longer than the days of the diet.

Methods of analysis.

The coefficients of digestibility given in Langworthy and Holmes' paper referred to above were obtained in the customary way by analysing the food eaten and the faeces excreted during an experimental period. For this purpose

the total ether extract of the faeces was taken to represent the actual quantity of undigested fat—the unavailable residual of the fat eaten during the experimental period. That this assumption is far from true is apparent from a study of the composition of the faeces. It is well known that the faeces contain not only undigested food, and undigested residues of food, but also other waste materials, usually grouped under the somewhat ambiguous term metabolic products, some of which are soluble in ether. The ether extract, usually considered as fat, consists of true fat, fatty acids, and unsaponifiable matter. The unsaponifiable matter consists mainly of a variety of alcohols of the sterol group with a small proportion of fatty alcohols of lower molecular weight such as cetyl alcohol, etc. This unsaponifiable matter is partly metabolic in origin and is partly contained in the foodstuff. The ratio of true fat to fatty acids is variable, but as a rule the quantity of true fat is small and is often negligible. Faeces also contain salts of fatty acids, or soaps which are insoluble in ether.

It was therefore considered necessary to submit both the food and faeces to a more detailed analysis than is usually the case.

The faeces were analysed in the following manner. A weighed portion of the dried faeces was subjected to a prolonged extraction (not less than a week) in a Soxhlet apparatus with ether, and the ethereal solution was made up to known volumes. Aliquot portions were then respectively titrated with standard alcoholic soda, and evaporated to dryness and weighed. In the latter estimation care must be taken not to overheat. The rest of the ethereal solution was then mixed with an alcoholic solution of sodium in considerable excess and allowed to stand 48 hours. The precipitated soaps were then filtered on the pump and thoroughly washed with ether. The ethereal filtrate and washings were then shaken with alkaline water and finally with distilled water until quite free from soap. The ethereal solution of unsaponifiable matter thus obtained was made to known volume and an aliquot portion evaporated and weighed. Estimations of the sterols, precipitable by digitonin, in the unsaponifiable residue were also made, but these values will form the subject of a separate communication. In order to estimate the fatty acids in the form of soaps, the faecal residue after extraction with ether was moistened with an alcoholic solution of hydrochloric acid, dried and again extracted with ether. In this case the acids were not estimated by evaporating the ethereal solution, as it was thought that the more soluble fatty acids being stronger than those of high molecular weight would mainly be found in these soaps. The ethereal extract was therefore exactly neutralised by a standard alcoholic soda, evaporated to dryness and weighed.

Fat in the foods was determined by extraction with ether in the usual way, and the unsaponifiable matter and sterols estimated as described. In the case of bread and meat the ether extraction was preceded by extraction with boiling alcohol, as it is well known that in such substances the extraction of fat by ether alone is imperfect, however long the extraction may be prolonged. The results are given in the following tables.

The percentage availability of the nitrogen of Diet D per day and also the nitrogen balance per day.

		E.	B.	P.	
Nitrogen	Intake in food ...	16.51	20.35	19.87	
	Excreted in urine ...	13.91	13.47	12.99	
	„ in faeces ...	2.12	2.80	2.78	
	Total ...	16.03	16.27	15.77	
	Nitrogen absorbed ...	14.39	17.55	17.09	
	Balance ...	+ 0.48	+ 4.08	+ 4.10	
	Percentage utilisation	87.14	86.2	86.0	Average 86.4

Average percentage utilisation in Diet A, 89.4; Diet B, 87.8; Diet C, 89.3.

Diet A.

		London subjects				Cambridge subjects			
		E.	C.	B.	A. C.	H. W. H.	F. J.	W. J.	A. L.
Total ether extract	Intake in food	98·93	97·28	99·41	92·79	155·28	92·53	122·08	139·93
	Excreted in faeces	3·52	3·66	4·33	3·11	4·94	1·63	2·47	2·32
	Difference	95·41	93·62	95·08	89·68	150·34	90·90	119·61	137·61
	% utilisation	96·44	96·24	95·65	96·65	96·81	98·23	97·98	98·34
		Average = 96·24				Average = 97·84			
		Average = 97·04							
True fat in food	Intake in food	96·62	94·96	97·01	90·73	150·94	89·75	119·58	137·22
Fat excreted in faeces in form of true fat, fatty acids and fatty acids in form of soap	Excreted in faeces	5·08	2·76	3·37	2·34	7·14	2·29	3·88	2·48
	Difference	91·54	92·20	93·64	88·39	143·80	87·46	115·70	134·74
	% utilisation	94·74	97·07	96·53	97·42	95·27	97·45	96·76	98·19
		Average = 96·44				Average = 96·92			
		Average = 96·68							

Diet B.

		London subjects				Cambridge subjects			
		E.	C.	B.	A. C.	H. W. H.	F. J.	W. J.	A. L.
Total ether extract	Intake in food	101·83	94·50	107·40	105·40	155·59	113·69	107·71	144·70
	Excreted in faeces	2·77	—	1·74	2·13	3·38	3·71	2·63	4·97
	Difference	99·06	—	105·66	103·27	152·21	109·98	105·08	139·73
	% utilisation	97·28	—	98·38	97·98	97·83	96·74	97·56	96·57
		Average = 97·88				Average = 97·18			
		Average = 97·48							
True fat in food Fat excreted in faeces as fat, fatty acids and fatty acids in form of soap	Intake in food	99·16	92·23	104·47	102·70	151·06	110·31	105·05	140·55
	Excreted in faeces	4·41	—	2·52	3·78	5·38	5·77	3·53	6·69
	Difference	94·75	—	101·95	98·92	145·68	104·54	101·52	133·86
	% utilisation	95·55	—	97·59	96·32	96·44	94·77	96·64	95·24
		Average = 96·49				Average = 95·77			
		Average = 96·08							

Table IV.

Diet C.

		London subjects				Cambridge subjects			
		E.	C.	B.	A. C.	H. W. H.	F. J.	W. J.	A. L.
Total ether extract	Intake in food	98.23	97.75	99.01	91.03	167.30	109.50	109.70	163.50
	Excreted in faeces	3.73	4.17	3.49	3.57	4.06	2.50	2.41	4.12
	Difference	94.50	93.58	95.52	87.46	163.24	107.00	107.29	159.38
	% utilisation	96.20	95.73	96.48	96.08	97.57	97.72	97.79	97.48
		Average = 96.12				Average = 97.64			
		Average = 96.88							
True fat in food	Intake in food	96.85	95.44	97.46	89.76	163.30	106.10	107.24	159.53
Fat excreted in faeces in form of true fat, fatty acids and fatty acids in form of soap	Excreted in faeces	4.36	6.54	3.72	3.59	4.06	2.50	4.12	2.41
	Difference	92.49	88.90	93.74	86.17	159.24	103.60	103.12	157.12
	% utilisation	95.50	93.15	96.18	96.00	97.51	97.64	96.16	98.49
		Average = 95.20				Average = 97.45			
		Average = 96.32							

Table V.

Diet D.

				London subjects			
				E.	B.	P.	
Total ether extract	...	...	Intake in food	...	109.00	105.73	105.53
			Excreted in faeces	...	5.41	6.66	6.66
			Difference	...	103.59	99.07	98.87
			Percentage utilisation		95.04	93.70	93.68
				Average = 94.14			
True fat in food	...	...	Intake in food	...	107.77	104.40	104.25
Fat excreted in faeces in form of true fat, fatty acids and fatty acids in form of soap	...	...	Excreted in faeces	...	6.27	7.56	7.62
			Difference	...	101.50	96.84	96.63
			Percentage utilisation		94.18	92.76	92.69
				Average = 93.21			

Table VI.

Comparative table showing average percentage fat utilisation in different diets.

				Diets			
				A	B	C	D
Total ether extract	...	...	...	97.04	97.48	96.88	94.14
True fat in food, and excreted in faeces as neutral fat, fatty acids and fatty acids in form of soap	...	...	...	96.68	96.08	96.32	93.21

HEALTH OF THE SUBJECTS.

All the subjects found the cocoa butter palatable, and were quite content with the diet. They suffered no appreciable change in weight during the experimental period. Their excreta were normal in appearance, and no apparent digestive trouble was noted. Their health was normal throughout.

DISCUSSION OF RESULTS.

Assuming that the bread sold to the public at the date of the experiments (1918) is comparable with that used in the diets A, B and C, it will be seen from Table I that in the case of the cocoa butter diet D there is a small but definite decrease in the utilisation of nitrogen, a result in agreement with observations recorded by various observers in experiments with cocoa.

The average percentage utilisation of fat in the cocoa butter diet D, whether judged by the total ether extract or by the true fat, is lower than the average values in the butter diets A, B and C, but the difference is not very marked, and the figures come within the limits of variation of A and C. The utilisation from this point of view must be regarded as satisfactory.

It will be noticed that the figure we obtained for the percentage utilisation of ether extract in diet D (94.14) is considerably higher than the figure 89.6 given by the American observers, though it comes within their limits of variation 79.1 to 95.5. It must be remembered however that diet D contained in addition to the cocoa butter a considerable amount of ordinary fat present in the meat, milk and cheese. That this slightly lower average utilisation is real and not merely the result of the smaller number of subjects eating diet D, and indicates that the cocoa butter is less digestible than ordinary butter, is shown by a consideration of the composition of the fatty matter of the faeces.

If we knew the average molecular weight of the acids excreted in the faeces on the various diets, it would be possible from the data we obtained to calculate for each individual the ratio of the fatty acids to unsaponified neutral fat in the faeces, since estimations were made on the ether extracts of (a) total solids by evaporation, (b) unsaponifiable matter, (c) free acids by titration with standard alkali: the difference between (a) and (b + c) would give the neutral fat. We do not know the average molecular weights of the acids in question, and furthermore the values for total solids may be slightly lower than the true values owing to loss of volatile acid on evaporation of the ether. We could not therefore get an accurate quantitative relation between the fatty acids and neutral fats in the faeces, but by assuming that the fatty acids were all stearic it can be shown that there is a marked difference between the composition of the faeces A, B and C on the one hand, and D on the other. This will be clear from the following figures for the two subjects who had all four diets.

Table VII.

Weights per cent. of dry faeces.

Diet	Individual	Total ether extract	Unsaponifiable matter	Real fatty matter	Approximate amount of fatty acid reckoned as stearic acid	Neutral fat by difference
A	E.	13.13	3.95	9.18	11.71	Probably nil
	B.	14.36	3.58	10.78	10.31	0.47
B	E.	6.99	2.40	4.59	8.37	Probably nil
	B.	5.50	1.72	3.78	6.28	"
C	E.	12.07	3.30	8.77	" 15.9 "	"
	B.	13.14	3.25	9.89	10.1	"
D	E.	15.18	1.96	13.22	1.41	11.81
	B.	15.48	1.80	13.68	4.05	9.63
	P.	14.07	0.90	13.17	4.54	8.63

It will be seen that whereas in the diets A, B and C the fatty matter of the ether extracts was mainly acids with little or perhaps no neutral fat, in the case of diet D the fat of the ether extract was mainly neutral fat. This clearly indicates that some small portion of the cocoa butter passed the intestinal tract unchanged.

More light would however be thrown on this question by a knowledge of the actual components of the fats used in the various diets, especially cocoa butter which differs markedly from animal fats and the more liquid vegetable fats, and of the fatty matter in the faeces produced. Experiments are being made on the separation of the acids from these various substances by fractional distillation of their methyl esters, with a view to the determination of the molecular weights, iodine values, etc. of the different fractions. These results are nearing completion and we hope shortly to be able to publish them.

QUALITATIVE EXPERIMENTS.

In order to get some idea of the tolerance for cocoa butter, and to find whether physiological disturbances similar to these noted by the American observers were produced when it was fed in excessive quantity with ordinary diet, four workers in the laboratory volunteered to try and eat three to four ounces per day for four days or so.

The four subjects were F. W. F. a chemist, W. L. S. a physiologist, W. G. R. a cadet of the O.T.C., and G. T. W. a cadet of the O.T.C.

They report as follows:

G. T. W. When I first started eating cocoa butter I did not enjoy it at all—that was eating about four ounces per day—but after the first two days I quite liked it, and found it most palatable when eaten with bread and jam. It has had no effect on me at all. The amount eaten was 1 lb. in five days.

W. G. R. Quantity eaten per day three to four ounces. At first the cocoa butter was unpleasant, giving rise to a bilious feeling, but later, when taken slightly warm with salt, this was not noticeable.

So long as it was eaten with some strong flavouring it made a fairly good substitute for butter, but was not pleasant when eaten alone with bread.

In spite of the fact that the amount taken was far in excess of my usual butter allowance, no ill effects were experienced.

W. L. S. I could not stomach much of your cocoa butter. I managed one ounce the first day, and was troubled by eructations. It also proved distinctly laxative. On the second day I could only take $\frac{1}{2}$ ounce and since then have taken none. It did not appear to be a very good sample¹.

F. W. F. I deliberately ate even larger quantities of cocoa butter than those given by the American observers, but without experiencing any of the unpleasant physiological effects they mention. The weights taken for the five days were as follows: 56, 237, 201, 102 and 135 g. These quantities were very far in excess of my ordinary fat ration, and were naturally unpalatably large. The faeces showed the high value, for the ether extract, of 24.3 g. % of dry weight.

GENERAL CONCLUSIONS.

1. Cocoa butter is rather less digestible than butter, but the experiments recorded show satisfactory utilisation.

2. Beyond the slight laxative action observed in the case of some of the subjects who consumed large quantities of the cocoa butter, no undesirable physiological effects were noticed.

3. Our experiments show no indication whatever that cocoa butter is a "slow poison," and there can be no doubt that this substance could be used to supplement the fat need of the population with safety. This conclusion is in agreement with general experience, since large quantities of this fat must have been consumed with impunity in the various chocolate preparations on the market—which may contain as much as 20 % of fat.

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¹ The same cocoa butter was supplied to each volunteer, and its constants were normal.