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FOOD IN ITS RELATIONS

TO

VARIOUS EXIGENCIES OF THE

ANIMAL BODY.

BY

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AND

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THE appearance in the June (Supplementary) Number of the Philosophical Magazine of the interesting paper by Professors Fick and Wislicenus "On the Origin of Muscular Power," and the further interest excited in the subject by Professor Frankland's recent lecture at the Royal Institution, seem to render it opportune that the important question of the connexion between certain constituents of food and certain exigencies of the animal body should receive a little further consideration at the present time. Professor Frankland truly said that, since the appearance of Baron Liebig's masterly and highly suggestive work 'On Organic Chemistry in its applications to Physiology and Pathology' in 1842, his views of the relation of the nitrogenous and the non-nitrogenous constituents of food to certain requirements of the animal organism have been pretty generally adopted by text-book writers. It is also true that authorities on the subject of the chemistry of food have, even so recently as last year and this, either directly maintained or taken for granted the correctness of Baron Liebig's views. It is, however, not the case, as was also assumed by Professor Frankland, that those views have remained unquestioned excepting in the one or two instances of criticism to which he referred.

This question, in various aspects, has occupied a great deal of our own attention for many years past; and so long ago as 1852 we advocated substantially the views now adopted by Professors Fick, Wislicenus, and Frankland; and we have on various occasions since that date expressed them with greater definiteness, and urged them the more emphatically, as new experimental evidence either of others or ourselves seemed to lend them support or confirmation. It may be well, therefore, to state very briefly

the course of our own investigations bearing upon the subject, and also the conclusions that we have based upon them.

In Baron Liebig's work above alluded to, and also in subsequent publications, he treated of the food requirements of the animal body generally—that is, under different conditions; and starting from the fundamental assumptions, on the one hand, of the direct connexion of the nitrogenous or, as he designated them, the "*plastic*" constituents of food, not only with the formation in the animal body of the compounds containing nitrogen, but also with the development of muscular power, and, on the other, of the general relationship of the non-nitrogenous constituents of food with respiration, the development of heat, and the deposition of animal fat, he concluded that the relative value of different foods, as such, was to a great extent dependent on, and even measurable by, the proportion of nitrogenous constituents which they contained.

It was upon the assumption of the broad and fundamental classification of the constituents of food according to their various offices in the animal economy, as above stated, that numerous analyses of food were undertaken, and, founded upon the results obtained, Tables constructed professing to arrange current articles of food, both of man and other animals, according to their comparative values as such; and whether the object were the feeding of animals for the production of milk, the so-called fattening of them for the production of meat, or the support of the body for the exercise of muscular power, the proportion of nitrogenous constituents was generally taken as the measure of that value.

Omitting, for the sake of brevity, any special reference to the labours or views of others, it will suffice here to make a few such quotations from Baron Liebig's works as will best convey shortly in his own words a pretty clear indication of his own views, and at the same time pretty fairly represent those of a large proportion both of systematic writers and experimenters, on the points in question. Speaking of the nitrogenous constituents of food, he said:—

"It is found that animals require for their support less of any vegetable food in proportion as it is richer in these peculiar matters, and cannot be nourished by vegetables in which these matters are absent." (Chemical Letters, 3rd edition, p. 349.)

Again:—

"The admirable experiments of Boussingault prove, that the increase in the weight of the body in the fattening or feeding of stock (just as is the case with the supply of milk obtained from milch cows), is in proportion to the amount of plastic constituents in the daily supply of fodder." (Chemical Letters, 3rd edit. p. 369.)

In regard to the exercise of force, he said:—

"As an immediate effect of the manifestation of mechanical force, we see, that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre (just as the acid lost its chemical character by combining with zinc); and all experience proves, that this conversion of living muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed, that they are mutually proportional; that a rapid transformation of muscular fibre, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter." (Organic Chemistry in its applications to Physiology and Pathology, 1842, pp. 220 & 221.)

And again:—

"The amount of azotized food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed.

"The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time.

"The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine.

"The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera." (Ibid. p. 245.)

Our own direct experiments have had reference chiefly to the feeding of fattening animals; but the characteristic food requirements of the body, when fed with the view to the exercise of muscular power, have also been made the subjects of inquiry.

Referring to the feeding of fattening animals, the question arises, whether in the use of the currently adopted food-stuffs *the amount of food consumed by a given weight of animal within a given time,* and *the amount of increase produced* are more influenced by the amount of the nitrogenous or of the non-nitrogenous constituents which the food supplies; that is to say, whether the sum of the requirements of the animal system under these circumstances is such that, in the use of the ordinary articles of food, the *amount taken* or *increase produced* will

be more regulated, or measurable, by the supplies of the nitrogenous or "flesh-forming" constituents, or by those of the more specially respiratory and fat-forming non-nitrogenous constituents.

To acquire the data necessary for the satisfactory solution of this question, some hundreds of animals—oxen, sheep, and pigs—have been experimented upon. Comparative lots being selected, the general plan of the feeding-experiments was to give to some a fixed and limited amount of food of known composition in regard to its contents of nitrogenous and non-nitrogenous constituents, to others a fixed and limited amount of food of different composition in this respect, and to allow all to take as much as they chose to eat of some other food, also of known composition, the quantity consumed being weighed. In some cases a single description of food only, or a mixture of several descriptions in known proportions, was given *ad libitum*, but weighed; and in others, several descriptions of food were allowed, each separately, *ad libitum*, but weighed. It will be seen that in this way great variation in the amount and proportion of the nitrogenous and non-nitrogenous constituents supplied was attained, whilst the animals, according to the nature of the food within their reach, fixed for themselves the limit of their consumption. All such comparative experiments were conducted for many weeks, or even for several months, consecutively, and the weights of the animals themselves were determined at the commencement, at stated periods during the progress, and at the conclusion of the experiment*.

To determine the character and composition of the gross increase in live-weight, the weights of the individual internal organs and of other separated parts of several hundred animals of different descriptions and in different conditions as to age, maturity, and fatness were taken; whilst in some carefully-selected cases the total amounts of fat, nitrogenous substance, mineral matter, and water were determined†.

* "On the Composition of Foods in relation to Respiration and the Feeding of Animals," Report of the British Association for the Advancement of Science for 1852. "Agricultural Chemistry: Sheep-feeding and Manure," part 1, Journ. Roy. Ag. Soc. Eng. vol. x. part 1, 1849. "Reports of Experiments on the Comparative Fattening Qualities of different Breeds of Sheep," ibid. vol. xii. part 2, 1851; vol. xiii. part 1, 1852; vol. xvi. part 1, 1855. "Agricultural Chemistry: Pig Feeding," ibid. vol. xiv. part. 2, 1853. "On the Equivalency of Starch and Sugar in Food," Rep. Brit. Assoc. for 1854.

† "Experimental Inquiry into the Composition of some of the Animals Fed and Slaughtered as Human Food," Phil. Trans. part 2, 1859; also Proceedings of the Royal Society, vol. ix. p. 348. "On the Composition of Oxen, Sheep, and Pigs, and of their Increase whilst Fattening," Journ. Roy. Ag. Soc. Eng. vol. xxi. part 2, 1860. "On the Chemistry of the Feeding of Animals for the production of Meat and Manure," Proc. Roy. Dub. Soc. March 31, 1864.

It is obvious that in the case of fattening animals, the amount of food consumed *in relation to a given body-weight within a given time* will be regulated, not only by the demands of the system for the support of respiration, perspiration, &c., and for the repair of normal waste of nitrogenous substance, but also by the additional requirements for growth and increase; whilst, on the other hand, the amount required to be consumed *for the production of a given amount of increase* will, in its turn, include that due to the demands of the system for respirable and perspirable matter and the repair of the waste of nitrogenous substance. Whether, however, the experimental results were calculated so as to show the amount consumed per 100 lbs. live-weight per week, or to produce 100 lbs. increase in live-weight, it was strikingly brought out in all comparable experiments that it was in neither case the amount of nitrogenous constituents, but in both the amount of digestible or available non-nitrogenous (or total organic) substance of the food that had regulated the result obtained.

Referring the reader to our former papers for all experimental details, and for the fuller discussion of the results and statement of our conclusions, we will close this part of the subject in words quoted from a paper given at the Meeting of the British Association at Belfast in 1852*. The sentence as quoted had reference to the results obtained with sheep; but subsequently those obtained with pigs were summarized in almost the same words:—

"... if we consider that it is the results obtained under the subtle agency of animal life that we are seeking to measure and express in figures, and if we also bear in mind the various sources of modification to which our actual figures must be submitted in order to attain their true indications, we think that it cannot be doubted that, beyond a limit below which few, if any, of our current fattening food-stuffs are found to go, it is their available non-nitrogenous constituents, rather than their richness in the nitrogenous ones, that measure both the amount consumed to a given weight of animal, within a given time, and the increase in weight obtained."

Bearing in mind the nature of the respiratory process, and the great influence which its demands must necessarily exercise over the amount of food consumed, it will scarcely appear surprising that *consumption* at least should be chiefly regulated by the supply in the food of non-nitrogenous constituents; but that *the amount of increase* obtained in feeding animals for the butcher should also bear a closer relationship to the supply of the non-nitrogenous than to that of the nitrogenous constituents,

* "On the Composition of Foods in relation to Respiration and the Feeding of Animals," Report of the British Association for the Advancement of Science for 1852.

might perhaps well be looked upon as inconsistent with the currently adopted views as to the highly nitrogenous character of the increase of animals fed for human food, and, indeed, of the highly nitrogenous character of the animal portion of human food generally.

The investigation into the composition of the fattening animals, and their increase, above alluded to, showed, however, how small was the proportion of the nitrogenous substance of the food that was stored up in the increase of the animal, and also that the proportion of fat in the increase was much greater than had previously been supposed. The results further led to the remarkable conclusion, that, reckoning the fat of the estimated total consumed portions of animals admitted to be in only a proper condition of fatness into its starch-equivalent, there was, on the average, a higher proportion of so-reckoned non-nitrogenous substance to one of nitrogenous substance in such animal food than in bread itself. It was concluded, indeed, that, on the large scale, the introduction of animal aliments into our otherwise chiefly farinaceous diet did not increase, but diminish the *relation* of the nitrogenous or so-called "flesh-forming," to the non-nitrogenous constituents (reckoned according to their respiratory and fat-forming capacity) in the collective food. The important bearing of these facts in forming an estimate of the characteristics of different human dietaries will be at once apparent.

So much, then, for the characteristic food requirements of animals exposed to as little exertion as possible, and fed with the express view of accumulating flesh and fat in their bodies. Concurrently with the earlier experiments to determine the relations of food and body-weight and increase above referred to, the question of the relation of the amount of the constituents voided (especially the nitrogen) in the liquid and solid excrements to that in the food consumed, was also investigated. Consistently with the results obtained in regard to the amount and character of the increase resulting from the consumption of very different amounts of nitrogenous substance, it was found that the amount of nitrogen voided by fattening animals fed under equal conditions as to the exercise of force, bore a very direct relation to that supplied in the food. So direct, indeed, is the connexion between the composition of the matters excreted and that of the food consumed, that we have constructed Tables showing the relative value of the manure produced by fattening animals from a given weight of different food-stuffs according to the composition of the latter.

But more to our present purpose—so striking were the results obtained in regard to the connexion between the composi-

tion of the food on the one hand, and the amount consumed, the amount and character of the increase produced, and the composition of the excreted matters, on the other, and, on some important points, so contrary in their indications to the prevailing views, that we were led at once to turn our attention to human dietaries, and especially to a consideration of the management of the animal body undergoing somewhat excessive labour, as, for instance, the hunting horse, the racer, the cab-horse, and the fox-hound, and also pugilists and runners. The conclusions to which we were led by this study were briefly summarized in 1852 as follows *:—

"..... that in the cases, at least of ordinary exercise of force, the exigencies of the respiratory system keep pace more nearly with the demand for nitrogenous constituents of food than is usually supposed;"

And further:—

"A somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is over-taxed; as for instance, when day by day, more labour is demanded of the animal body than it is competent without deterioration to keep up; and perhaps also, in the human body, when under excitement or excessive mental exercise. It must be remembered, however, that it is in butchers' meat, to which is attributed such high flesh-forming capacity, that we have also, in the fat which it contains, a large proportion of respiratory material of the most concentrated kind. It is found, too, that of the dry substance of the *egg*, 40 per cent. is pure fat.

"A consideration of the habits of those of the labouring classes who are under- rather than over-fed, will show, that they first have recourse to fat meat, such as pork, rather than to those which are leaner and more nitrogenous; thus perhaps indicating, that the first instinctive call is for an increase of the respiratory constituents of food. It cannot be doubted, however, that the higher classes do consume a larger proportion of the leaner meats; though it is probable, as we have said, that even with these as well as pork, more *fat*, possessing a higher respiratory capacity than any other constituent of food, is taken into the system than is generally imagined. Fat and butter, indeed, may be said to have about twice and a half the respiratory capacity of starch, sugar, &c. It should be remembered, too, that the classes which consume most of the leaner meats, are also those which consume the most butter, sugar, and in many cases, alcoholic drinks also.

"It is further worthy of remark, that wherever labour is expended in the manufacture of staple articles of food, it has

* Report of the British Association for the Advancement of Science for 1852.

generally for its object the concentration of the *non*-nitrogenous, or more peculiarly respiratory constituents. Sugar, butter, and alcoholic drinks are notable instances of this. Cheese, which at first sight might appear an exception, is in reality not so; for those cheeses which bring the highest price are always those which contain the most butter; whilst butter itself is always dearer than cheese.

"In conclusion, it must by no means be understood that we would in any way depreciate the value of even a somewhat liberal amount of nitrogen in food. We believe, however, that on the current views too high a relative importance is attached to it; and that it would conduce to further progress in this most important field of inquiry if the prevailing opinions on the subject were somewhat modified" *.

It will be borne in mind that at the time the statement of view here quoted was made, the opinions expressed were directly contrary to all recognized authority on the subject, and it is since that date that so much evidence has been accumulated in regard to the amounts of urea, and the amounts of carbonic acid and other products, given off under varied conditions as to food and exercise. Still, from the facts even then at command, it was concluded that the increased demand for food resulting from the exercise of muscular power was specially characterized by the requirement for an enhanced amount of the non-nitrogenous constituents. Confirmatory evidence was, however, not long wanting.

In 1854 we selected two pigs as nearly as possible of equal weight and character; to one was given, *ad libitum*, lentil-meal (containing about 4 per cent. of nitrogen), and to the other, also *ad libitum*, barley-meal (containing less than 2 per cent.). After the animals had been kept for a certain time on their respective foods, one comparative experiment was conducted for a period of three days, and another for a period of ten days. The weights of the animals were taken at the beginning and at the end of each experiment, and, besides other particulars, the amounts of nitrogen consumed in food, and voided as urea, were determined †. The result was, that with exactly equal conditions as to exercise, both animals being in fact at rest, the amount of urea passed by the one feeding on the highly nitrogenous lentil-meal was more than twice as great as that passed

* It is worthy of remark, too, that neither are the most highly nitrogenous wheats the most valued by the baker for the purposes of bread-making, nor is the most highly nitrogenous bread the most valued by the chiefly bread-fed working man. See "On some Points in the Composition of Wheat-grain, its Products in the Mill, and Bread," Journ. Chem. Soc. vol. x. 1858.

† Phil. Trans. part 2, 1859, p. 554.

by the one fed on the barley-meal. We have since made other such experiments with similar results.

It was clear, therefore, that the rule laid down by Liebig, and assumed to be substantially correct by so many writers, did not hold good—namely, that "The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera"—unless, indeed, as has been assumed by some experimenters, there is, with increased nitrogen in the food, an increased amount of mechanical force employed in the "involuntary motions" sufficient to account for the increased amount of urea voided.

It was at any rate obvious that, if the amount of urea voided by one animal at rest could be from two to three times as great as that voided by a similar animal also at rest, and under otherwise equal conditions, provided only that the food of the one contained from two to three times as much nitrogen as that of the other, the amount of urea passed could not be any measure of the amount of muscular power exerted; and this evidence, considered in connexion with that relating to the demands of the system not only of the fattening animal but of the animal body fed with a view to mechanical exertion, afforded further confirmation of the view we had already put forward as above quoted, and also led to the extension and more definite expression of it.

The results of Bischoff and Voit, conducted through a period of many months, with a dog, either submitted to hunger or fed from time to time on foods containing very different amounts of nitrogenous substance, showed a very variable amount of urea voided, although the animal were kept under equal conditions as to exercise. Still, on the publication of those results in 1860, the authors assumed that although there had been no greater exercise of force manifested in the form of external work, yet when the amount of nitrogenous substance in the food was greater, and the amount of urea voided correspondingly greater, there must have been a corresponding increase in the force exercised in the conduct of the actions proceeding within the body itself in connexion with the disposition of the increased amount of nitrogenous substance consumed. When, however, they subsequently found that the amount of urea passed by the animal when subjected to somewhat severe labour was, other things being equal, no greater than when at rest, whilst the carbonic acid evolved was much increased by such exercise, their view was of necessity somewhat modified.

Again, the results of Dr. Edward Smith, which showed great

variation in the amount of urea passed when there was concurrent variation in the amount of nitrogenous substance in the food, and comparatively little variation in the amount of urea voided with great variation in the amount of labour performed, but, on the other hand, great increase in the carbonic acid evolved with increased exercise of force, obviously still further pointed to the correctness of the view that with muscular exertion there was a more marked increased demand for the non-nitrogenous than for the nitrogenous constituents of food.

That this was the necessary conclusion from the results of our own investigations, and also from those of the researches of Bidder and Schmidt, Bischoff, Voit, Pettenkofer, E. Smith, and others, we have frequently maintained. Indeed the view urged in public discussion has been, that all the evidence at command tended to show that by an increased exercise of muscular power there was, with increased requirement for respirable material, probably no increased production and voidance of urea, unless, owing to excess of nitrogenous matter in the food, or a deficiency of available non-nitrogenous substance, or diseased action, the nitrogenous constituents of the fluids or solids of the body were drawn upon in an abnormal degree for the supply of respirable material.

From the facts briefly summarized in the foregoing pages, it will be obvious that the generally accepted views in regard to the adaptation of food, according to its composition, to the various exigencies of the animal body, require modification in other respects than in so far as they relate to the source or development of muscular power alone. At the same time we hail with much satisfaction the confirmation of the views we have so long maintained on the point in opposition to general authority, which has recently been afforded by the results of the interesting, though limited experiment of Professors Fick and Wislicenus, so ably discussed by them in their paper, and by Professor Frankland in his lecture.