Food selection under natural conditions and the possible relationship to heart disease in man

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Introduction

The concept of biological separation with regard to food selection states that the different species use different types of foodstuff. At the first level of analysis there are the herbivores, the omnivores and the carnivores. Within each group separation exists with regard to food selection. The most obvious examples can be obtained from the African environment where the giraffe with its long neck eats the tops of trees, the eland uses the bush, the buffalo tufted grasses, kob use fine grasses and wild pigs root for rhizomes and bulbils. The carnivores include the cheetah which hunts in open plains relying on speed; the lion which hunts in bush country relying on cover, the leopard which hunts from trees relying on cunning and camouflage. This geographical separation in the carnivores means that they each take different groups of herbivores which use either grassland, bush or forest vegetation.

The diversity of biological separation

The meaning that emerges from biological separation is diversity. Fraser Darling (1960*a*) described the interplay, and proposed that this interplay amongst the herbivores was a system of crop rotation which could provide a more viable agricultural basis than a monoculture of cattle (Darling, 1960*a*; Lambrecht, 1966; Crawford 1968*a*).

The extremes of biological separation can be seen in the giraffe with its long neck designed to use the tops of the trees; the gerenuk (giraffe antelope) although only weighing 200 lb also has a long neck for browsing on bushes. Again, the eland and the oryx inhabit semi-arid regions where animals like the buffalo cannot survive. On the other hand, the buffalo lives in woodland and swamp or riverine areas where it can make use of the high productivity associated with the higher rainfalls. Lamprey (1963) has described the operation of biological separation in the Tarangire Reserve, Tanzania. In Fig. 1, his method of presentation is used to describe the geographical division of labour amongst some of the African herbivores. The so-called rooters also fall into different food selecting habitats which are made obvious by their names; for example, the wart-hog, the bush-pig and the giant forest hog.

This simplified presentation hints at the details that we are beginning to understand. For example, Field (1968) has studied buffalo and hippopotamus. Whilst the buffalo can cut the tufted grasses like *Sporobolus*, the hippopotamus cannot. The latter use their lips to pluck at the grasses and hence they select the creeping grasses like *Cynodon*.

Both the time of year and the nature of the habitat will alter the feeding habits of many species. During the dry season many animals such as the buffalo and

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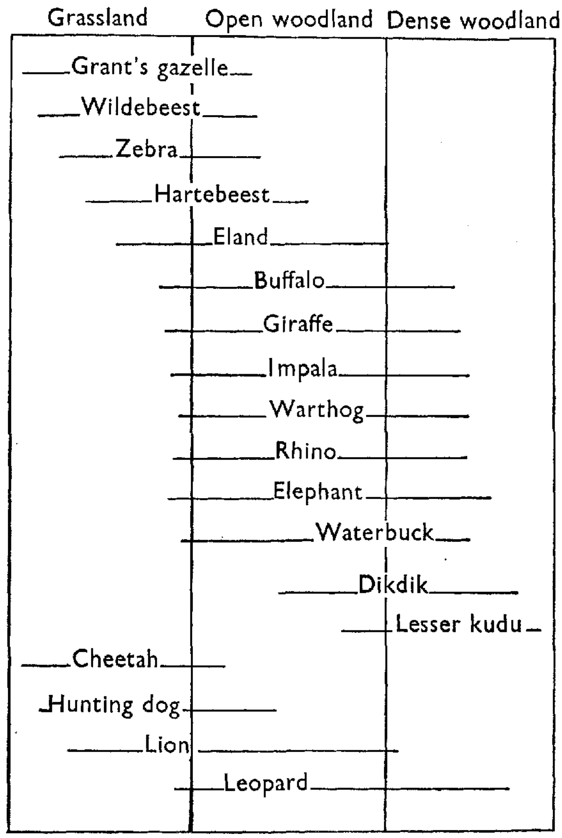

Fig. 1. The concept of biological separation is illustrated from Lamprey's (1963) study in the Tarangire Reserve. The time spent in different habitats is shown by the length of the horizontal line.

hartebeest that are thought of as grass-using species will browse heavily; the extent of this behaviour will depend often on the availability of such browse material. Another example of separation is the black rhinoceros with its prehensile lip used for selecting leaves, buds, seeds, fruits and other browse material. Although the white rhinoceros looks similar, it is distinguished by its square lip which it uses as a lawn mower. Hence the black rhinoceros is found in semi-arid areas and the white rhinoceros in riverine regions.

In the semi-arid areas species like the eland owe their survival to their ability to use browse material from which they not only obtain food of a high nutrient quality but also tap a water table at some depth through the roots of the trees and bushes which they eat (Taylor, 1968). The eland is said to be independent of surface water and a herd has been observed to survive though an 18 month long drought (Taylor & Lyman, 1967). According to Taylor (1968), the eland survives, not because it has lower water requirements, but because it can extract from its environment four times the amount of water available to conventional grazing species by a combination of browse, feeding at night, seeking shade in the day and by having an increase in oxygen consumption in response to the night fall in temperature. This increased oxygen consumption both increases the metabolic water and increases the food and hence water intake (Taylor & Lyman, 1967). The milk of the eland also shows an adaptation to its environment, being twice as concentrated with respect to protein and fat as that of the buffalo or domestic cow (Treus & Kravchenko, 1968). It is possible that the high fat content of eland milk may constitute a water-sparing device for the mother and also provide for the high metabolic needs of the calf which might again be related to water sparing. Zebu cattle have been subjected to heat stress and drought over a period of 4000 years and, although they have reduced their water requirements to below that of the eland, they have still to reach the degree of proficiency evolved by the eland in dealing with the semi-arid habitat (Taylor, 1968).

Stretching south from the southern edge of the Sahara, with its own desert fauna (Schmidt-Nielsen, 1964), this system of biological separation functioned as a system of land management with giraffe, eland and oryx and a complete range of complementary feeders occupying the semi-arid areas which merge with the buffalo (Stewart & Stewart, 1963) in riverine and seasonal swamp areas and elephant in the forest regions.

The success of this system was based on diversity and operated for at least 2 000 000 years. The evidence to date is that it is now in the process of breaking down and that this breakdown is attributable to human interference (Darling, 1960*b*; Simon, 1962; Robins, 1963). This interference produces a non-diverse state (Crawford, 1968*a*) and, in nutritional terms, this non-diversity so far has meant an imbalance with respect to the primary essential nutrients.

Misconceptions from too rigorous application of the concept of 'separation'

The above summary is almost certainly an oversimplification and is likely to lead to misconceptions. For example, feeding to carnivores diets that are predominantly of meat leads to trouble because meat is not a balanced diet, being grossly deficient in calcium but rich in phosphorus (Scott, 1968). In the wild state, carnivores first eat the intestine, stomach, liver and lungs of the prey. The large cats will eat the rib cage but are not able to crack the long bones of large ungulates. Should there be ample food available they may leave a substantial proportion of the carcass to the smaller carnivores which will use the remains as a supplement. The hyena, despite its smaller dimensions, has extremely powerful jaws and teeth and can break the long bones left by the lions.

Primates fit into the general pattern as omnivores, but again, because they are associated with trees and forests people consider that they are vegetarians. Within the primate group there are certain species such as the *Colobus* which apparently have compartmented stomachs like the rumen of a cow. These species may be true vegetarians, but monogastric primates, which constitute the majority, are almost certainly omnivorous. When fed on diets of fruit and vegetables available in this country, they become severely deficient in a number of essential components, particularly protein, calcium, phosphorus and fat-soluble vitamins (Du Boulay &

Crawford, 1968). The vegetation in the forests from which these animals originate is richer in protein and minerals than the cultivated fruits and vegetables available here; also, in the wild state primates will eat insects, lizards and birds' eggs which provide an essential part of their intake. Larger primates such as baboons may even kill small antelopes for food. Certainly the dentition of the wild primates, even excluding the large canines, is more relevant to omnivorous activities than vegetarian. The Potto, and other nocturnal species, are almost certainly not exposed to sufficient sunlight to provide for vitamin D and either one postulates that they have no requirement for this vitamin, or they must obtain such components through insects, small rodents and lizards that do bask in the sun.

Man automatically places these species into different feeding categories and it is evident that in so doing a situation is created in which the diversity of the natural habitat is lost. Carnivores fed on meat do not survive because they are calcium-deficient, primates because they are deficient in protein and minerals and recently Sikes (1968*a*,*b*) has reported that elephants confined to an African grassland have severe arterial disease which is analogous to human atheroma (McCullagh & Lewis, 1967). Laws & Parker (1968) examined the longevity and mortality in these grassland elephants and observed that, although the populations had increased, there was already clear evidence that the population structure had changed and was starting a severe rate of decline.

Biological separation and protein

The fundamental question to be asked of this system of different species using different starting materials is, are they using different nutrients or different methods to obtain the same nutrients? To examine this in detail would be a substantial task but an approach has been made to the question of the quantitative amino acid requirements as a first level of analysis. Crawford (1968*b*) examined the blood plasma of different species from the African environment. There was a wide species variation which was particularly noticeable amongst the non-essential amino acids. The essential amino acids tended to be within closer limits. Whitehead (1964, 1965) has shown that in man the ratio of essential to non-essential amino acids varies with nutritional state and differences in the individual plasma amino acids could be related to nutrient intake or nutritional status. Consequently, the major fixed protein depot of the body (muscle) was studied in fourteen different species. The proportional amino acid composition in terms of molar units was found to be of the same order, regardless of species and the method of food selection (Fig. 2).

The close agreement of these amino acids in the muscle protein suggests that such variations as are observed may be experimental and procedural errors. Many data books provide information on the amino acid composition of different muscles from different sites in the same animal but in our experience the difference between two runs on the analyser may be of the same order as that reported for different muscle sites. Artefacts may result from the fact that it is both tedious and time consuming to carry out analyses in sufficient numbers to make a valid comparison showing a significant statistical difference.

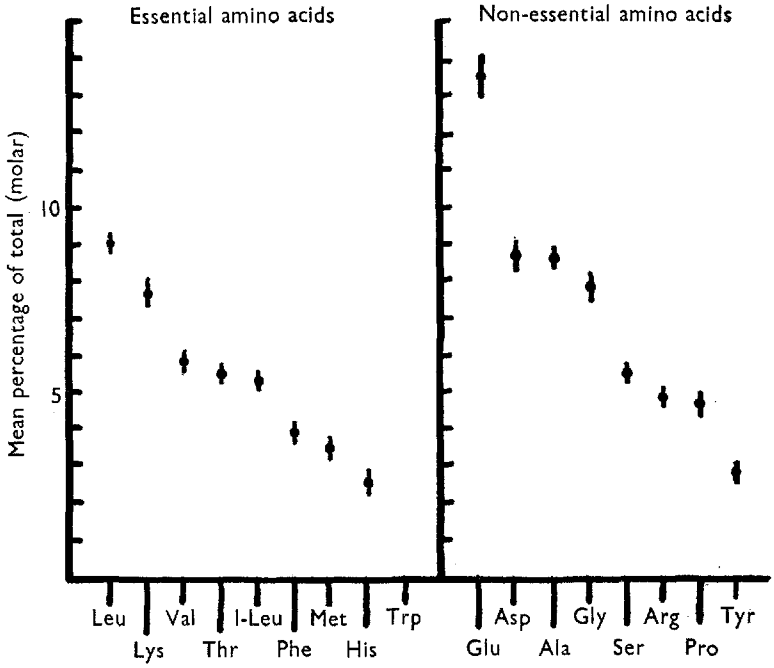

Fig. 2. Protein hydrolysates from muscle of leopard, hyena, man, warthog, kob, buffalo, topi, hartebeest, eland, giraffe, elephant, domestic ox, pig and sheep have been plotted as means ± twice the standard errors. The length of the vertical stroke accordingly corresponds to four times the SE. The composition shows a consistency in the profile regardless of species. Tryptophan occurs in muscle at approximately 1%; because it is unstable during hydrolysis and on the column other methods are used for its assay and the proportion may not be precisely comparable.

The fact that the protein composition of muscle from the different species is basically of a similar order suggests that the different species will have similar quantitative requirements with respect to muscle tissue. Because these species use completely different starting material from grass to acacia bush (Busson, 1965) for the herbivores, and from zebra to warthog for the carnivores, this finding suggests that it is the method of food selection and digestion that is the dominant difference between the species.

In analysing muscle protein we are predominantly concerned with contractile protein, and the similarity of composition between the different species is consistent with the principle that the general code or pattern for protein structures was set early in evolutionary history. It is not, of course, claimed that the protein structures will be identical although they are likely to be similar.

Quantitative requirements considered in terms of the balance of amino acids

By plotting the amino acids in order of their quantitative importance (Fig. 2) attention is drawn to the simple fact that to build a protein we need ten times as much leucine as tryptophan. Leucine would therefore be limiting when present at 8%; a fact that is not readily apparent when protein value is assessed on the assumption that the limiting amino acid is that present in least concentration.

In many parts of Africa man relies on a few staples (Dean & Burgess, 1962), many of which have imbalanced profiles. For example, cassava contains approximately 10% arginine and this amino acid is known to compete with other similar basic amino acids. Plantain is rich in histidine (8·5%).

Non-diversity and man in relation to protein

Man's tendency to extract aspects of the diverse system and use them as monocultures can be seen from studies of the diets of advanced communities such as in Africa where many restrict their diet to plantains and root crops (Dean & Burgess, 1962) or in parts of America and Europe where cattle products dominate our diet (Greaves & Tan, 1966).

On the basis that plasma amino acids are related to diet (Whitehead, 1964, 1965), studies (Crawford, Hansen & Somers, 1968, unpublished) on plasma amino acids in human communities whose diet was based on (i) plantain and rootcrops, (ii) mixed grain, (iii) flesh and milk revealed that in the first group which used little animal protein, there was an imbalance in the amino acid profile. The amino acids that were quantitatively most important to muscle were those that tended to be present in the least proportion (Fig. 3).

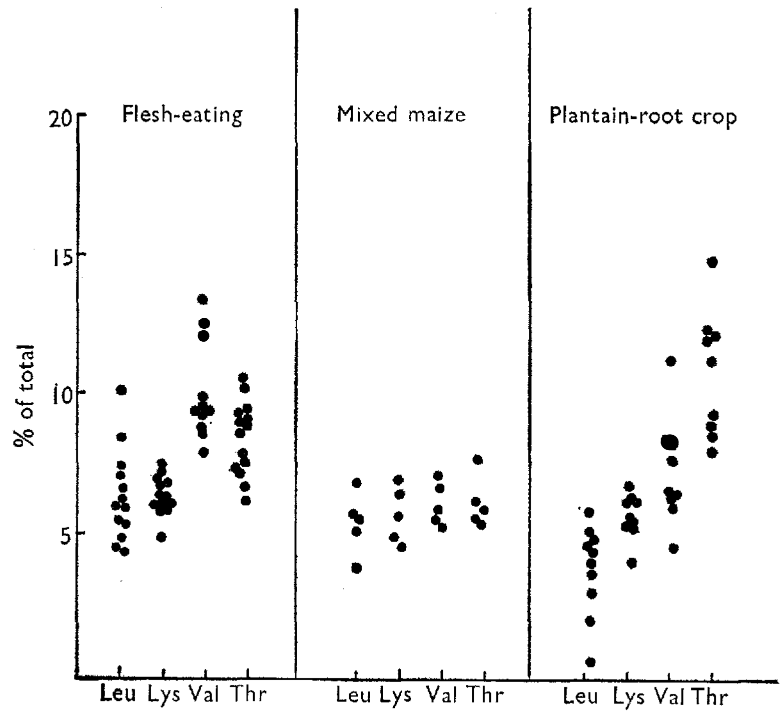

Fig. 3. The balance of leucine, lysine, valine and threonine in the plasma from three communities using different dietary regimes should be compared with the profile for muscle (Fig. 2). In the plantain-root crop group (tropical cardiomyopathy group) the essential amino acids of greatest quantitative importance to muscle produce a profile shaped in the opposite direction to that required for muscle. The leucine proportion in a mean of fifteen samples from the plantain-root crop group was 3·7 compared with 5·9 for the flesh-eating communities; the level of significance was $0.005 < P < 0.01$.

The nature of this imbalance in the normal plantain-and-tuber-eating community suggests that the imbalance could be an important factor in setting the stage for the cardiomyopathies commonly seen in these communities. Heart muscle has the same general amino acid composition as skeletal muscle and impairment of its function is readily observed.

Non-diversity and man in relation to fat

A fundamentally different approach to the lipids is required. The amino acids are relatively water soluble, the lipids are not. In plasma, the lipids appear mostly bound to protein and conjugated with a variety of compounds, the role of which is not clearly understood. In analogous fields of nutrition and pathology, biochemists are frequently severely limited when it comes to providing answers from blood analyses. For example, three-quarters of the total renal tissue can be out of action before there are really significant changes in the blood urea; our own experience on the El Molo (Brown, Shaffer, Hansen, Hansen & Crawford, 1966; Hansen, Brown, Shaffer & Crawford, 1966) and with primates (Du Boulay & Crawford, 1968) indicated that in human and primate calcium deficiencies, the plasma calcium remains steady although there may be a 30% reduction of bone calcium radiologically. The same story is true for cats (Scott, 1968). In these situations estimation of the main body stores would reveal an abnormality.

The problem of the normal pattern

The first requirement was to attempt to analyse a 'normal' situation with regard to the lipids. The normality of our Western environment has been questioned previously (Crawford, 1964, 1968*a*). Much of Africa has been radically altered by man over the past 4000 years; this alteration, recent in biological history, has reached a peak of interference within this century. Climax vegetation in Africa consists of dense woodland and it is likely that the only place to look for an approach to 'normality' is within a diverse woodland environment.

It was difficult to obtain a human population living under such conditions and therefore a comparative approach was made with the object of comparing tissue samples from African species as a reflection of what they eat and comparing these with our own domestic bovids as a reflection of what we eat. In this way we hoped to obtain an insight into our present-day dietary structure in comparison with one on which man evolved. Tissue samples were chosen to reflect availability because the mechanism of digestion is ill understood.

The findings (Fig. 4) (Crawford, 1968*c*) were simply that the African bovids from the mixed woodland environments had tissue lipids that contained more polyunsaturated acids than were found in domestic bovid tissues. Every polyunsaturated fatty acid molecule in meat from domestic cattle is accompanied by some fifty saturated and mono-unsaturated fatty acid molecules; in the natural woodland environment, each polyunsaturated molecule was accompanied by only two or three saturated and mono-unsaturated molecules. The 1 to 50 proportion associated with domestic bovids, which supplies our basic fat diet in meat, milk, butter

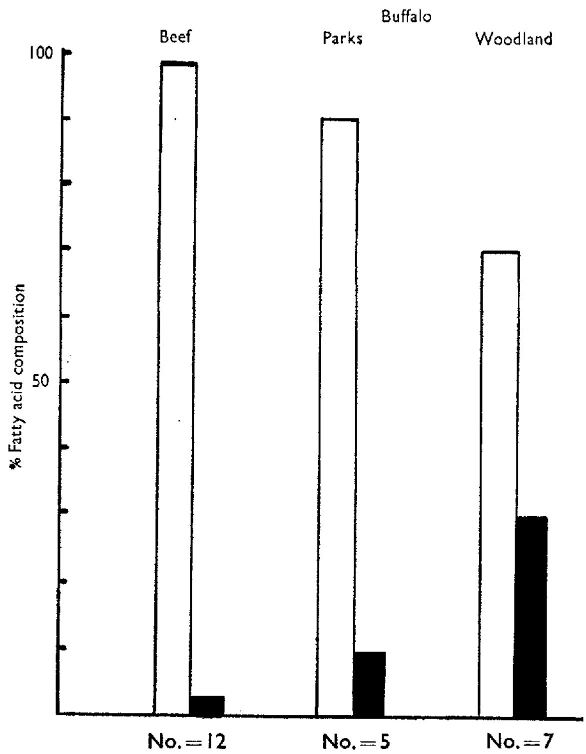

Fig. 4. Illustration of the mean gross quantitative difference in the main mono-unsaturated and saturated fatty acids compared with the polyunsaturated group in muscle tissue of woodlands and parkland buffalo as compared with grassland beef. All six means are significantly different ($P<0.001$). □, saturated and monosaturated; ■, polyunsaturated.

and shortening, has been accepted as the 'normal' state. Our findings suggest that it may not be 'biologically' normal.

The cause of this low proportion of essential fatty acids in our Western bovids appears to be related to the use of grassland. Buffalo on parkland have lower proportions (10%) than those in thick woodland (30%) (Fig. 4), species like the Uganda kob (2%) and the topi (8%) from a grassland environment had proportions that approached the domestic order. Zoo animals also had low proportions of the polyunsaturated fatty acids.

Comparison of the polyunsaturated fatty acid profiles from the natural and domestic states reveals that the two giraffe from London Zoo had a fatty acid profile that was analogous to that of domestic cattle and that of man himself. Indeed, the pattern from the human (Western) muscle was more closely analogous to the pattern of the captive grass-fed giraffe than to that of any other species.

Sikes reported (Sikes, 1968*a*,*b*) that elephants living in a grassland environment in the Murchison Falls National Park had a high incidence of atheroma with some 44% of the aortic area containing calcium deposits. In montane (which is a diverse woodland) environment, the incidence of calcification was negligible.

Perhaps the imbalance of the polyunsaturated with non-essential fatty acids, resulting from our grassland agriculture and hydrogenation of edible oils, may be the basic reason for the high incidence of human atheroma in Western communities. Sinclair (1964) has argued cogently that atheroma is a process of essential fatty acid deficiency, but up to now there has been no system which could be used for comparison. Our information on the diverse and European systems suggests that an imbalance could be of greater significance. This imbalance could be created directly by domestic animal fat or metabolically by excess carbohydrate foods low in essential fats.

In progressing towards a highly developed agricultural pasture system, man has inevitably eliminated the oil-rich aspects of vegetation in which polyunsaturated fatty acids are abundant. Grassland is not a 'natural' environment. Climax vegetation, whether in Africa or Europe, consists of bush and trees. The alternation between bush, trees and grasslands is an animal-controlled system which in Africa acted as a form of crop rotation when left to itself and it is likely that the mammalian genetic patterns were set at a time when land animals lived in a diverse environment.

If human atheroma is basically a process of chronic imbalance with respect to the polyunsaturated fatty acids, which can be exacerbated by excess sugar or calories, then the future outlook, without a change in dietary policy, would be an increasing appearance of arterial degeneration in children. It might be of marginal value to attempt to correct this imbalance in adults but there would be every reason to start with bottle-fed children.

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Methods of studying the food habits of some wild ungulates in Uganda

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Introduction

Large numbers of a heterogenous assembly of mammals occur in East Africa, and in certain areas their biomass compares favourably with some of man's most intensively managed ranch land (Talbot & Talbot, 1963; Petridges & Swank, 1965). Conspicuous for their high biomasses, some parts of the Nile basin support about 25 000 kg/km² (61 tons/square mile) of large mammals (Bourlière, 1965).

The present study

The many and varied ungulates which feed on apparently the same vegetation appear to conflict with the principle of the ecological separation of species (Gause, 1934). Two hypotheses have been suggested in an attempt to reconcile these observations with the Gausian theory: (1) a high primary production of vegetation permits high secondary biomasses; (2) a variety of herbivores may utilize the vegetation spectrum more fully.

The study area, the Queen Elizabeth Park in the Uganda Rift Valley, is more suited to plant growth than most grassland ecosystems, having volcanic soils, high radiation and moderate rainfall with good seasonal distribution. Primary productivity studies are planned in conjunction with the International Biological Programme; the present work, however, investigates the second hypothesis as follows:

(1) To test the concept of ecological separation of species based on food habits.
(2) To determine some of the factors affecting the food habits of large herbivores.
(3) A special study of the influence of a dominant herbivore, the hippopotamus (*Hippopotamus amphibus* Linn.) on other species through their diet.

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