THE SWEAT GLANDS AND HAIR FOLLICLES OF ASIAN, AFRICAN, AND SOUTH AMERICAN CATTLE

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Abstract

Measurements were made on the skins of 471 Asian, 281 African, and 186 South American cattle from different breeds, and the mean values have been tabulated. The skin types present in each breed or group of breeds were determined using sweat gland shape (L/D), i.e. the ratio of the length to the diameter of the gland, and hair follicle depth (FD) as the principal bases of comparison, and compared with those previously found in European cattle.

The majority of African and Asian cattle had type I skin ($L/D < 8 \cdot 0$; $FD < 1 \cdot 5$ mm) most of the exceptions being found in a few breeds which included the Ankole, Barotse, Red Bororo, Ponwar, Laos Native, and the cattle of Japan. Type II skin ($L/D > 12 \cdot 0$; $FD > 2 \cdot 0$ mm) was not detected in African, Asian, and South American cattle which had, in general, a shallower FD than European cattle. A third skin type (type III: $L/D > 12 \cdot 0$; $FD < 1 \cdot 5$ mm) which was not found in European cattle, occurred in a high percentage of South American cattle, and in some Asian and African animals, especially of the breeds noted above. Paucity of numbers prevented more detailed classification of the ranges of skin types between I and II and I and III. Asian, African, and South American cattle tended to have shorter, thicker hairs and smaller sweat gland volumes than European.

It has been suggested that in European breeds, such as the Ayrshire and Friesian, which have a wide range of skin types, selection of animals with a type I skin for tropical regions could perhaps lead to improved heat tolerance and milk production of the breed in warm climates.

I. Introduction

Jenkinson and Nay (1968), after study of a number of skin measurements, concluded that sweat gland shape (L/D), i.e. the ratio of the length to the diameter of the gland, and hair follicle depth (FD) were reliable indices of skin type in adult cattle, and used these measurements as the principal bases of comparison in a study of the skin structures of European cattle (Jenkinson and Nay 1972). They found that European cattle breeds were composed of varying proportions of animals exhibiting two extreme skin types, I with an $L/D < 8 \cdot 0$ and $FD < 1 \cdot 5$ mm and II with an $L/D > 12 \cdot 0$ and $FD > 2 \cdot 0$ mm, and skin types intermediate to them. The present investigation of the skin structures of Asian, African, and South American cattle is an extension of the study of European cattle and forms the second part of a survey of world cattle skin types which was designed (1) to provide information on the comparative anatomy of cattle skin; (2) to determine whether skin type could be of value in the selection of cattle for tolerance to different environments; and (3) to permit evaluation of evolutionary trends in sweat gland development.

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II. Materials and Methods

Over the past 12 years duplicate post-mortem skin specimens from the neck or midside of cattle were generously supplied by scientists and veterinarians throughout Asia, Africa, and South America. Specimens from North American cattle, save for the Texas Longhorn and Santa Gertrudis, were not solicited since they are largely European in origin. Whenever possible, at least 10 animals over 2 yr old from each breed and on a good plane of nutrition were sampled. The skin specimens were taken with a trephine 1 cm in diameter and were processed and measured as described by Jenkinson and Nay (1968). Measurements were made of hair follicle depth (*FD*), length (*FL*) and diameter (*FDM*) and of sweat gland length (*L*) and diameter (*D*) as defined by Jenkinson and Nay (1968). From these measurements sweat gland shape (L/D) and volume (*V*), hair follicle shape (FL/FDM) and the mean angle of slope of the hairs were calculated. Details of the breeds studied and the number of animals sampled in Asia, Africa and South America are given in appendices A, B, and C respectively.* The skin specimens from each breed were, in general, obtained from different herds. Although the conditions of processing and measurement, and as far as possible those of sampling, were standardized, only small numbers were available for sampling in some instances, and, as was found with the results from European cattle, the data were not homogeneous or normally distributed. Transformation of the data failed to provide a suitable form for statistical analysis and consequently it was not possible to statistically analyse the results.

The data from each continent were, therefore, divided as were those for European cattle, into groups based on an independent classification of cattle breeds (Mason 1969) and these groups and some of the breeds within them have been compared, using sweat gland shape and hair follicle depth as the main bases of comparison.

III. Results

The general structure of the skin was similar in all of the breeds of cattle studied, and consisted of an epidermis and dermis. All follicles had an arrector pili muscle, sebaceous gland, and sweat gland associated with them. The main differences between the skins of different breeds were in the sizes of their component organs. The means and standard deviations of skin measurements made on each cattle breed in the three continents are, therefore, given in appendices A (Asia), B (Africa), and C (South America).* The mean values and standard deviations for all 471 Asian, 281 African, and 186 American cattle were as follows:

	Asia	Africa	America
Sweat gland			
Length L (μm)	738 ± 87	695 ± 223	972 ± 394
Diameter D (μm)	87 ± 18	85 ± 18	90 ± 15
Shape (L/D)	$8\cdot59\pm3\cdot07$	$8\cdot36\pm2\cdot97$	$10\cdot79\pm3\cdot92$
$10^{-6}\times$ volume V (μm^3)	$4\cdot89\pm3\cdot70$	$4\cdot26\pm2\cdot51$	$6\cdot69\pm4\cdot31$
Hair follicle			
Length FL (mm)	$1\cdot50\pm0\cdot29$	$1\cdot58\pm0\cdot24$	$1\cdot74\pm0\cdot19$
Diameter FDM (μm)	$47\cdot3\pm8\cdot0$	$53\cdot5\pm7\cdot3$	$54\cdot7\pm8\cdot1$
Depth FD (mm)	$1\cdot29\pm0\cdot22$	$1\cdot35\pm0\cdot19$	$1\cdot51\pm0\cdot18$
Shape (FL/FDM)	$32\cdot4\pm9\cdot1$	$30\cdot2\pm6\cdot6$	$32\cdot5\pm5\cdot9$
Mean angle of slope of hair	59° 19′	58° 41′	60° 13′

Although L/D ranged in general from about 4 to 27 and FD from about 0·8 to 2·0 mm, these ranges were not characteristic of every breed, as can be seen by examination of different groups formed from the breeds studied in each of the three continents.

* Copies of these Appendices may be obtained on application to the Editor-in-Chief, Editorial and Publications Section, CSIRO, 372 Albert St., East Melbourne, Victoria 3002.

(*a*) *Asia*

For ease of illustration, the cattle from this continent have been divided into three categories: (i) humped cattle, (ii) humpless cattle, and (iii) intermediate zeboid cattle, generally with a small hump.

(i) *Humped Cattle*

Details of the breeds of humped cattle comprising the groups in this category are given in the key to Figure 1, and the distributions of L/D and FD for each of these groups are illustrated in Figures 1(*a*) and 1(*b*). From Figure 1(*a*) it can be seen

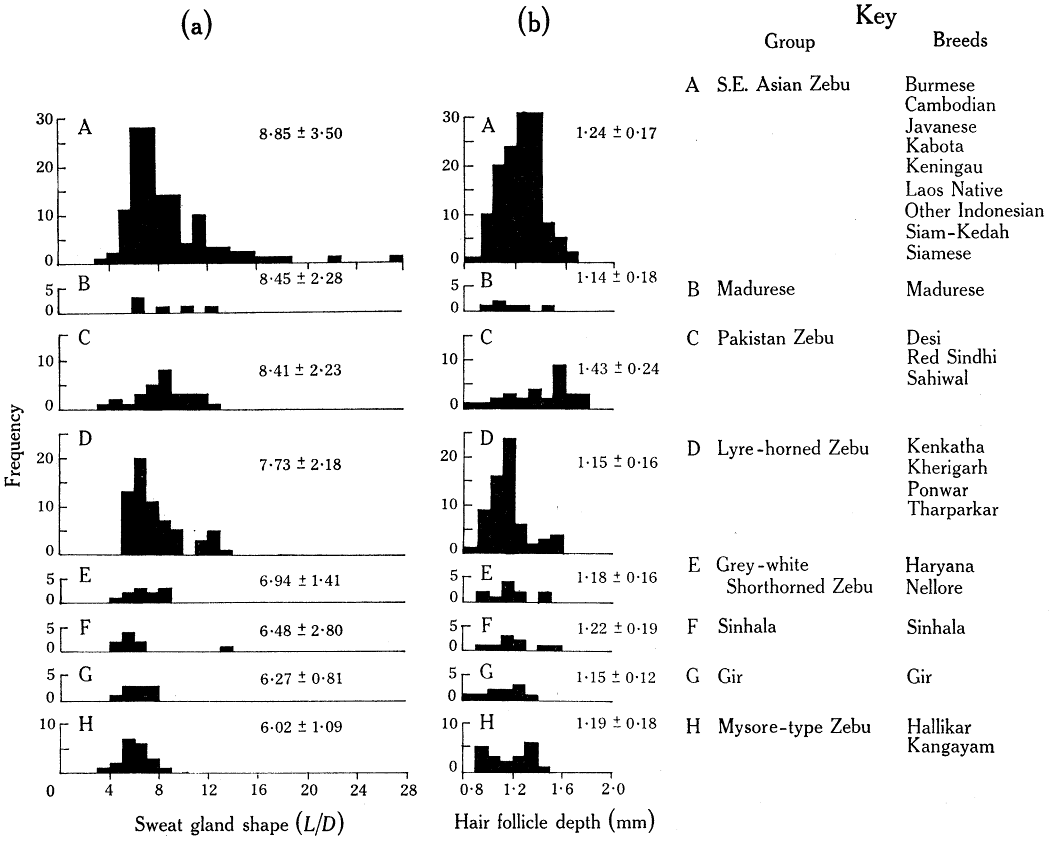

Fig. 1.—Distributions of (*a*) sweat gland shape and (*b*) hair follicle depth for groups A–H of humped cattle detailed in the above key. The mean values and standard deviations for each group are also given.

that the variation in mean L/D, from 6·02 in the Mysore-type Zebu to 8·85 in the south-east Asian Zebu, was not large. The majority of animals in each group, with the possible exception of group C, had sac-like sweat glands with an L/D less than 8·0 [Fig. 2(*a*)]. Some individuals, however, had L/D ratios greater than 12·0; most of these belonged to a small number of cattle breeds. The group mean values were in general representative of all the breeds within them. There were, however, a few notable exceptions:

(1) *Group A*: The wide distribution of L/D in this group is largely due to three breeds, the Cambodian, Javanese, and Laos Zebu, which had mean L/D ratios of 9·89, 11·18, and 14·55 respectively. Cattle from these breeds, therefore, tended to have longer, more coiled, sweat glands [Fig. 2(*b*)]. The remaining breeds in this group had lower mean L/D values of the same order of magnitude as the group mean.

(2) *Group C*: In this group the Desi had a typical sac-like gland with a mean L/D value of 6·30 and differed from the Sindhi and Sahiwal [Fig. 2(*c*)], the L/D of which fell within the range of the group mean and standard deviation.

(3) *Group D*: In this group, one breed, the Ponwar, differed markedly from the remainder. Ponwar cattle tended to have long, convoluted or coiled, tubular sweat glands [Fig. 2(*d*)], some with an L/D ratio greater than 15·0. They were in some instances so coiled that they were difficult to measure and were quite different in appearance from the simple sac-like sweat glands of the other breeds in this group.

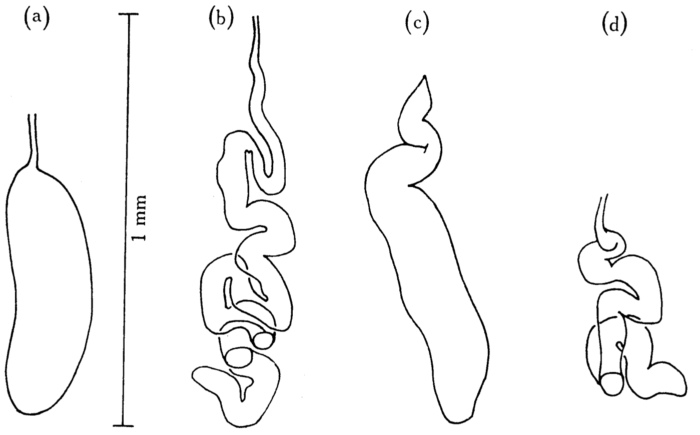

Fig. 2.—Tracings of sweat glands from (*a*) Kangayam, (*b*) Laos Native, (*c*) Sindhi, and (*d*) Ponwar cattle. The shape of the gland of the Kangayam is characteristic of most of the Zebu breeds studied.

It can be readily seen from Figure 1(*b*) that no humped Asian cattle had an *FD* greater than 1·8 mm and that a very high proportion of Asian cattle had a value less than 1·5 mm, some with values less than 1·0 mm. The group mean values of *FD*, which ranged from 1·14 to 1·43, were found to be representative of all the breeds within them with the exception of Group C. In this group the Sindhi and Sahiwal (with mean *FD*'s of $1·55 \pm 0·15$ and $1·59 \pm 0·10$ respectively) tended to have a higher *FD* than the Desi ($1·14 \pm 0·14$ mm).

(ii) *Humpless Cattle*

The mean L/D for the groups of humpless cattle studied (key to Figure 3) varied from 7·44 to 11·20 as can be seen from Figure 3(*a*). In group A, the only one composed of more than one breed, the group mean was found to be representative of all the breeds within it. Almost all the animals in the group had an L/D greater than 8·0 and a proportion had an L/D greater than 12·0. Groups B and C, the Banteng and Kalmyk, had similar distributions of L/D to those found in humped cattle. The Japanese breeds, however, had sweat glands which were more coiled than those found in most of the humped breeds; in this respect they tended to resemble the few exceptional humped breeds such as the Ponwar and Laos Native.

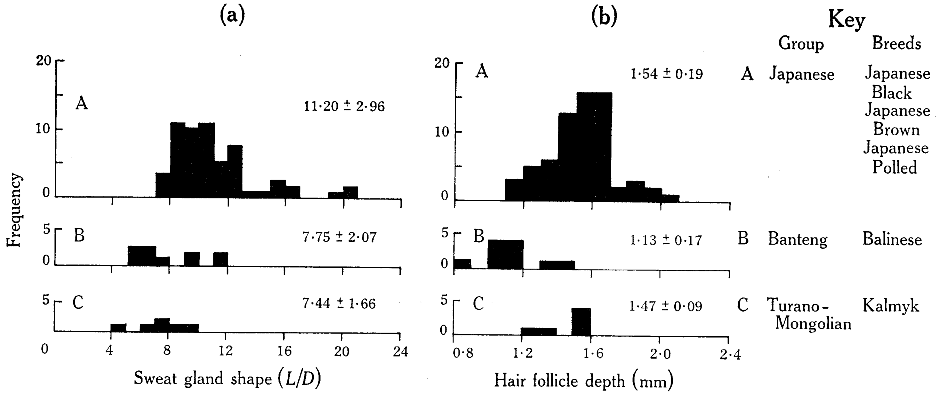

Fig. 3.—Distributions of (*a*) sweat gland shape and (*b*) hair follicle depth for the groups of humpless cattle detailed in the above key. The mean values and standard deviations for each group are also given.

Although the range of group means of *FD* [Fig. 3(*b*)] was similar to that of humped cattle and the group A mean was found to be representative of all the breeds within it, some of the Japanese cattle had larger *FD* values ranging between 1·5 and 2·0 mm. The Banteng group, on the other hand, tended to have a shallow *FD*. However, no humpless Asian animal was found to have an *FD* greater than 2·0 mm and the majority of animals in groups B and C resembled the humped cattle in having an *FD* less than 1·5 mm.

(iii) *Intermediate* (*Zeboid*) *Cattle*

The range of group means for L/D [Fig. 4(*a*)] was similar to that of humped cattle and the distributions within the groups were not dissimilar to those observed in humped breeds. The group means were in all instances representative of all the breeds (key to Figure 4) within them. This was true also of the group means of *FD* [Fig. 4(*b*)] which did not vary markedly between the zeboid groups. The distributions of *FD* were similar to those observed in humped breeds, no zeboid animal having an *FD* greater than 1·8 mm and the majority having a value less than 1·5 mm.

It was not possible, due to paucity of numbers, to divide the ranges of L/D and *FD* into detailed classes to give differences in skin type between Asian breeds of cattle. However, the overall ranges of skin types in Asian cattle, based on L/D and *FD*, are illustrated in the form of "tolerance ellipses" in Figure 5, using the breeds from which sufficient samples were obtained. The measurements from breeds not illustrated all fall within the overall range shown in Figure 5 which can, therefore, be considered as representative of Asian cattle in general. The similarity of distribution within each of the groups can be seen from the examples in Figure 6, which illustrate that the range of Cambodian Zebu skin types is representative of the other south-east Asian breeds save for some Laos and Javanese Zebu animals which had *L*/*D* values between 15 and 18 and *FD* values between 1·0 and 2·0 mm. These latter cattle tend to fall within the same range as the Japanese breeds (Fig. 5).

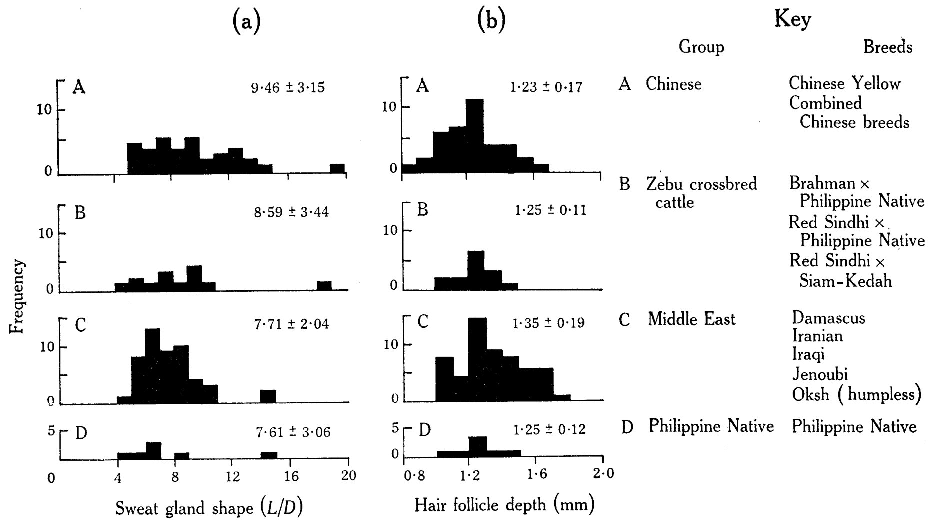

Fig. 4.—Distributions of (*a*) sweat gland shape and (*b*) hair follicle depth for the groups of zeboid cattle detailed in the above key. The mean values and standard deviations for each group are also given.

It can be clearly seen from Figure 5 that no Asian cow has an *FD* greater than 2·0 mm and that the vast majority of animals have an *FD* value less than 1·5 mm. The appendix illustrates that, of all the Asian breeds studied, only five—the Sindhi, Sahiwal, and the three Japanese humpless breeds—have a mean *FD* value greater than 1·5 mm, confirming the fact that, in general, Asian cattle have a shallow hair follicle depth. "Follicle giantism" which was detected in European cattle (Jenkinson and Nay 1972) was therefore not found. It is also clear that skin type II, which was defined by Jenkinson and Nay (1972) as having an *L*/*D* > 12·0 and *FD* > 2·0 mm does not occur in Asian cattle. Skin type I (Fig. 7), with a sac-like sweat gland and a thin hair follicle depth, is the predominant skin type found in Asian cattle. Animals with this skin type also tended to have a low sweat gland volume and short thick hairs.

With the exception of the Sindhi and Sahiwal and the Ponwar, all the breeds on the Indian subcontinent tended to contain animals with a type I skin or one close to it. A proportion of the Sindhi and Sahiwal cattle were also of this type, but the majority of animals in these breeds tended to have a skin type intermediate between I and II, i.e. *L*/*D* 8·0–12·0; *FD* 1·5–2·0 mm. Due to paucity of numbers it was not possible to readily subdivide this range. The Ponwar breed is clearly different from the remainder of the breeds on the Indian subcontinent. All the animals in this breed had an *FD* less than 1·5 mm, but whereas some had *L/D* ratios less than 8·0, others had very high ratios. The skins of the latter, therefore, do not fall within the ranges of either skin type I or II, nor are they intermediate to them. This skin type, with an $L/D > 12{\cdot}0$ and $FD < 1{\cdot}5$ mm, can be readily distinguished histologically (Fig. 7) and may therefore be defined as type III. Consequently the Ponwar breed consists of animals exhibiting type I or type III skin and those intermediate to them in varying proportions.

Fig. 5

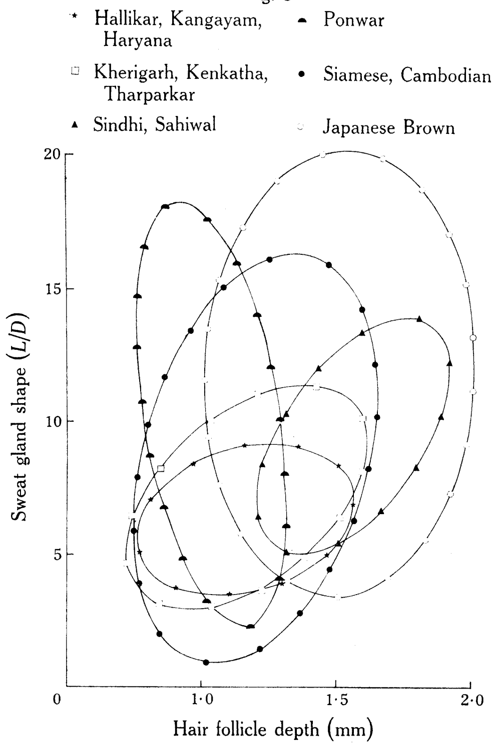

Fig. 6

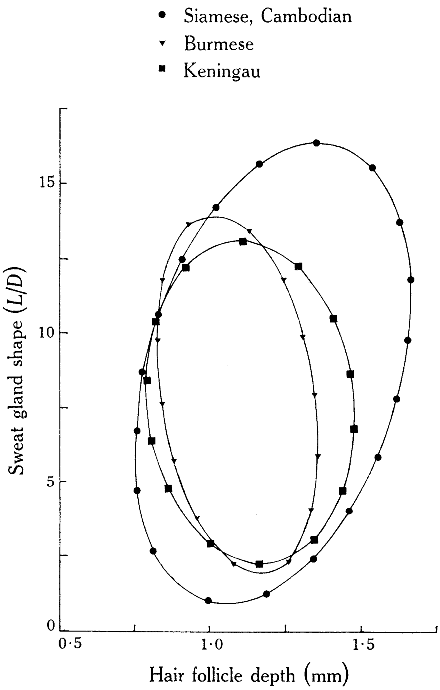

Fig. 5.—Tolerance ellipses illustrating the extent and position of the variation in *L/D* and *FD* among six groups of cattle. The remaining breeds had *L/D* and *FD* values within the overall range, which can therefore be considered representative of all Asian cattle.

Fig. 6.—Tolerance ellipses illustrating the variation in *L/D* and *FD* in four breeds of south-east Asian cattle. It can be seen that the skin types are similar and the ellipses in Figure 5 are consequently representative of the other breeds in each group with the exceptions noted in the text.

The south-east Asian cattle breeds were also composed mainly of animals with a type I skin but, as can be seen from Figure 6, the skin types ranged between and included types I and III. A relatively high proportion of type III skins were found in the Laos and Javanese Zebu which, due to paucity of numbers, were not included in Figure 6. A few of the south-east Asian cattle, however, had *FD* values greater than 1·5 mm and *L/D* values between 8·0 and 12·0, and consequently had skins intermediate between types I and II. Almost all the Middle East breeds and the Chinese Yellow cattle had a type I skin, but some of the other Chinese cattle exhibited skin types intermediate to and including types I and III.

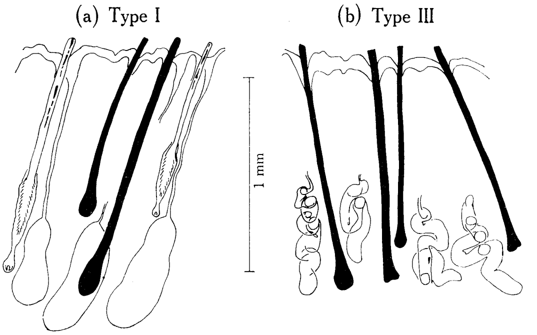

Fig. 7.—Tracing of the skin of (*a*) a Gir and (*b*) a Ponwar cow illustrating type I and type III skin. Both types exhibit a thin hair follicle depth but the latter has a long convoluted sweat gland in contrast with the simple sac-like gland of the former.

The Japanese cattle in general had a greater follicle depth than any of the other Asian breeds; a proportion of these animals exhibited skin types intermediate to

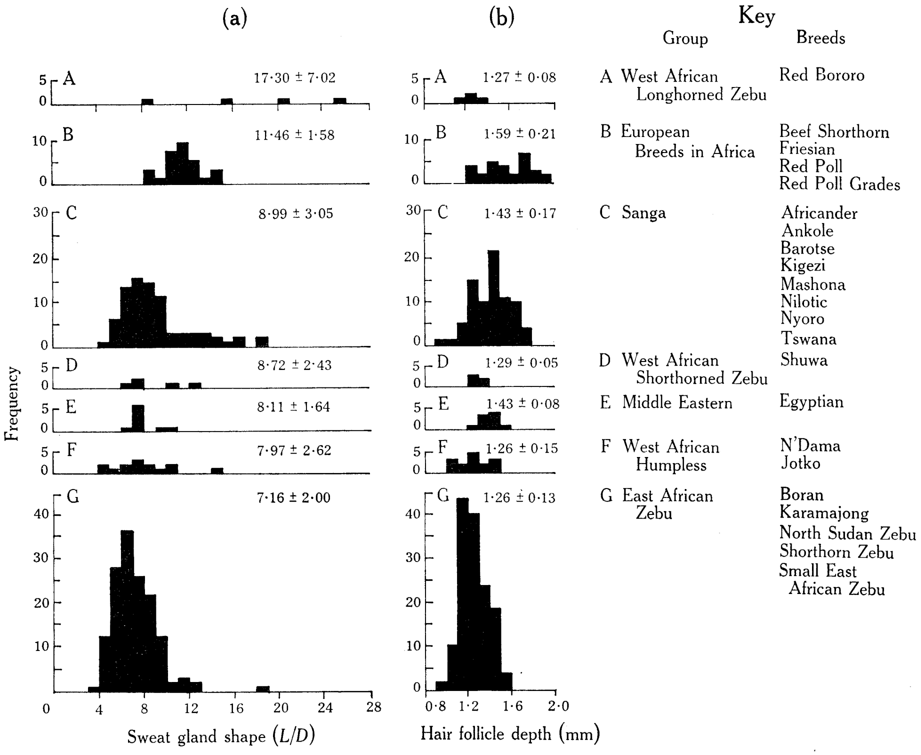

Fig. 8.—Distributions of (*a*) sweat gland shape and (*b*) hair follicle depth for groups A–G of African cattle detailed in the above key. The mean values and standard deviations for each group are also given.

types I and II. The Japanese breeds, however, exhibited a wide range of skin types and individuals with type I, type III, and intermediate skin types were also present. Larger numbers of cattle from Asian breeds may enable more detailed classification of the ranges of skin types intermediate between I and II and I and III. However, at present, only the three widely different types at the extremes of the ranges can be clearly defined and readily distinguished.

(*b*) *Africa*

The mean L/D values of the different groups ranged from 7·16 in the East African Zebu to 17·30 in the West African Longhorned Zebu [Fig. 8(*a*)] and these group means were, in general, representative of all the breeds within them. The exceptions were the Ankole and Barotse breeds in group C. A proportion of the animals in each of these breeds had longer, more serpentine sweat glands [Fig. 9(*d*)], and hence these breeds had higher L/D values (Ankole 10·22; Barotse 11·56) than the others in this group. The small East African Zebu also tended to have a higher mean L/D than the other breeds in group G. The ranges of L/D were not dissimilar between the groups of cattle studied with the exception of the Red Bororo animals (group A) and the European breeds resident in South Africa (group B). A high proportion of African cattle had sac-like sweat glands and hence L/D values less than 8·0 [Figs. 9(*a*)–9(*c*)].

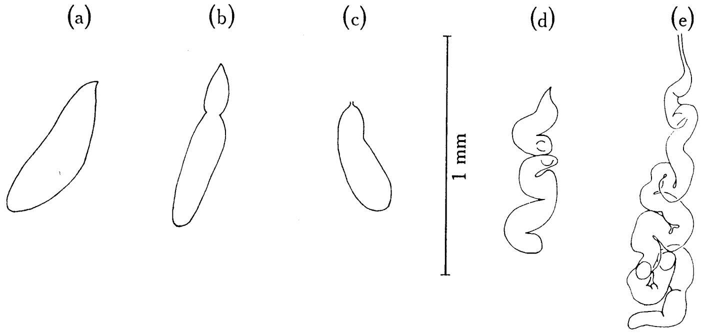

Fig. 9.—Tracings of sweat glands from (*a*) Boran (East African Zebu), (*b*) Dahomey (West African dwarf shorthorn), (*c*) Shuwa (West African Shorthorned Zebu), (*d*) Ankole (Sanga), (*e*) Red Bororo (West African Longhorned Zebu). The shapes of the glands of the Boran, Dahomey, and Shuwa are characteristic of most of the Zebu breeds studied.

It can be seen from Figure 8(*b*) that none of the African cattle had an *FD* value greater than 1·8 mm. The European breeds from South Africa also appeared to have relatively low *FD* values compared with their counterparts in Europe; none of these Afro-European animals had an *FD* greater than 2·0 mm. Follicle giantism was not, therefore, found in African cattle. The mean *FD* values of the African group ranged from 1·26 to 1·43, with the European cattle resident in Africa having a larger mean value of 1·59. The group mean values were representative of all the breeds within them. The main exception was the North Sudan Zebu in group G (*FD* $1\cdot38\pm0\cdot11$) which had a slightly higher mean value than the other breeds in the group. In the European group (B) the Beef Shorthorn (*FD* $1\cdot83\pm0\cdot08$) also tended to have a thicker *FD* than the other breeds in this group.

Paucity of numbers prevented classification of the skins of African cattle, but an indication of the overall range of skin types can be obtained from perusal of Figure 10. Tolerance ellipses have been constructed using breeds from which sufficient samples were obtained to illustrate the range of skin types in African cattle. All the breeds studied but not illustrated fall within the range shown, with the exception of the Red Bororo animals which had similar *FD* values but higher *L*/*D* ratios [Fig. 9(*e*)] than those found in Sanga cattle. The European breeds have been excluded from this range as they are not truly representative of African cattle. From Figure 10 it can be seen that a high proportion of African cattle have a type I skin. Animals with type III skin are also found in some African breeds, in particular, the Red Bororo, the Ankole, and the Barotse. Type II skin was not observed in any of the African animals studied, nor was it present in any of the European cattle resident in South Africa.

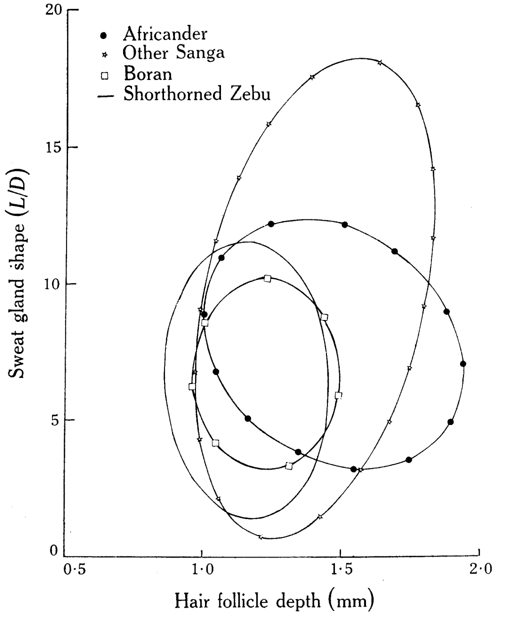

Fig. 10.—Tolerance ellipses illustrating the extent and position of the variation in *L*/*D* and *FD* in four breeds of African cattle. The remaining breeds had *L*/*D* and *FD* values within the overall range which can therefore be considered as representative of African cattle. The exception was the Red Bororo which had similar *FD* values but higher *L*/*D* values than the Sanga. European animals were not included.

(*c*) *South America*

The histograms in Figures 11(*a*) and 11(*b*) illustrate the ranges of *L*/*D* and *FD* found in the groups of South American cattle (key to Figure 11). The mean *L*/*D* values of the four groups ranged from 7·09 to 12·00 [Fig. 11(*a*)]. The mean value for group C was representative of both the Brahman and Indo-Brazilian breeds but in group B the polled and horned Sinú tended to have larger mean *L*/*D* values ($13{\cdot}51 \pm 3{\cdot}38$ and $15{\cdot}95 \pm 4{\cdot}07$ respectively) than the group in general. These breeds tended to have very long coiled sweat glands in comparison to the sac-like glands of the Indo-Brazilian cattle (Fig. 12). The highest degree of sweat gland convolution observed in world cattle was found in the skins of some horned Sinú animals [Fig. 12(*e*)]. The majority of cattle sampled in South America had *L*/*D* values greater than 8·0 and, with the exception of the Friesian, some of the animals in all the groups had *L*/*D* values greater than 12·0. None of the South American cattle had an *FD* value greater than 2·0 [Fig. 11(*b*)] and the Friesian animals from the Argentine had a low mean *FD* ($1{\cdot}48 \pm 0{\cdot}13$) relative to those of Friesians in Holland and Britain ($2{\cdot}03 \pm 0{\cdot}33$ and $1{\cdot}70 \pm 0{\cdot}25$ respectively). Follicle giantism was not found in South American cattle; the mean values of the four groups ranged from 1·43 to 1·53 and the group means were found to be representative of the breeds within them, with the exception of the Guyanan Criollo (*FD* 1·33±0·13) which had a lower mean *FD* than the other Criollo breeds within group B.

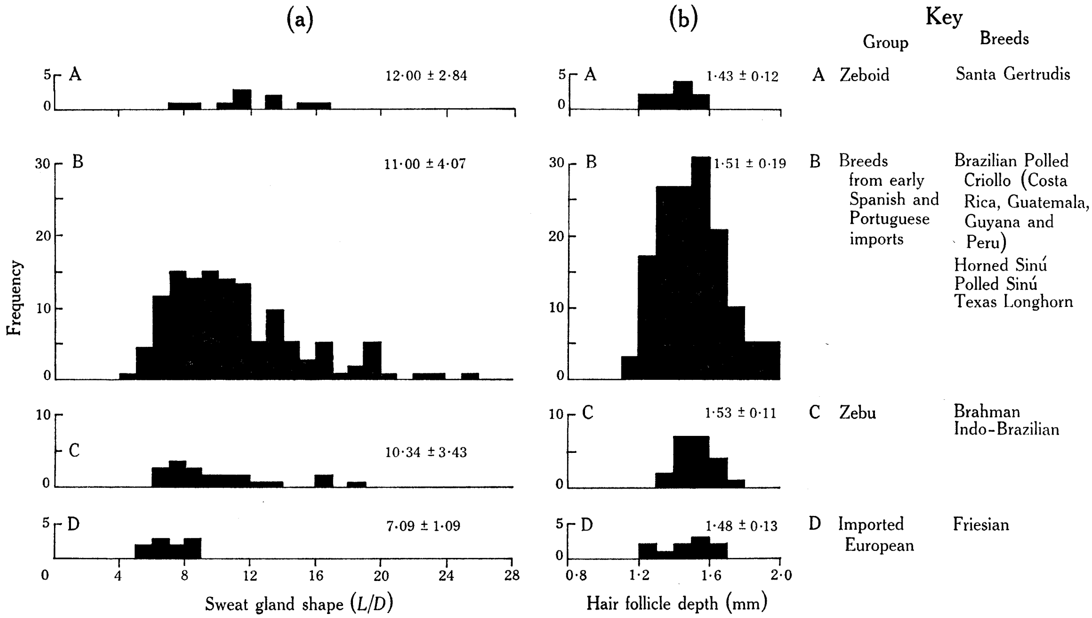

Fig. 11.—Distributions of (*a*) sweat gland shape and (*b*) hair follicle depth for groups A-D of South American cattle detailed in the above key. The mean values and standard deviations for each group are also given.

An indication of the overall range of skin types in South American cattle can be obtained from the tolerance ellipses in Figure 13, which have been constructed from the data from breeds for which sufficient samples were obtained. The remaining

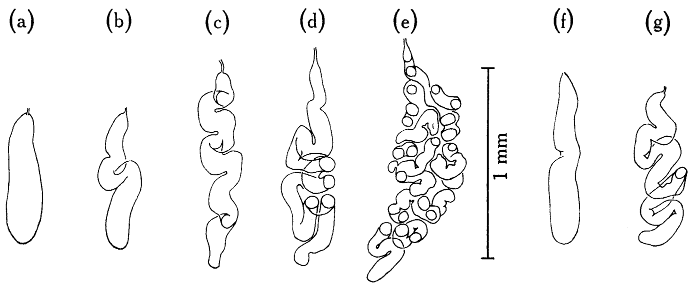

Fig. 12.—Tracings of sweat glands from: (*a*) Indo-Brazilian, (*b*) Santa Gertrudis, (*c*) polled Sinú, (*d*), (*e*) horned Sinú cattle, compared with two from Spanish cattle: (*f*) Segovia; (*g*) Malaguena. Apart from the extremely coiled glands of some horned Sinú cattle (*e*), most of the sweat gland shapes found in South American cattle were similar to those of Iberian breeds.

South American breeds studied had *L*/*D* and *FD* values within this overall range which appears, therefore, to be fairly representative of South American cattle as a whole. Figure 13 also illustrates the range of skin types found in 50 Spanish cattle from various breeds for comparison. It is evident that although about half of the animals studied had an *FD* less than 1·5 mm, only a small percentage had an *L/D* less than 8·0. Type I skin, therefore, apparently occurs in only a small proportion of American cattle. Although type II skin was not observed in any of the animals studied, the calculated ranges indicate that type II skin could, perhaps, be present in a few Criollo cattle A high proportion of South American cattle, particularly of the polled and horned Sinú breeds, had type III skin. All South American cattle, other than those with type I or type III skins, therefore, had skin types ranging between types I and II, or between types I and III. The distribution of skin types found among Spanish cattle was similar to those found for most of the Criollo breeds. The main exceptions were the polled and horned Sinú, many individuals of which had a typical type III skin which was not observed in European cattle.

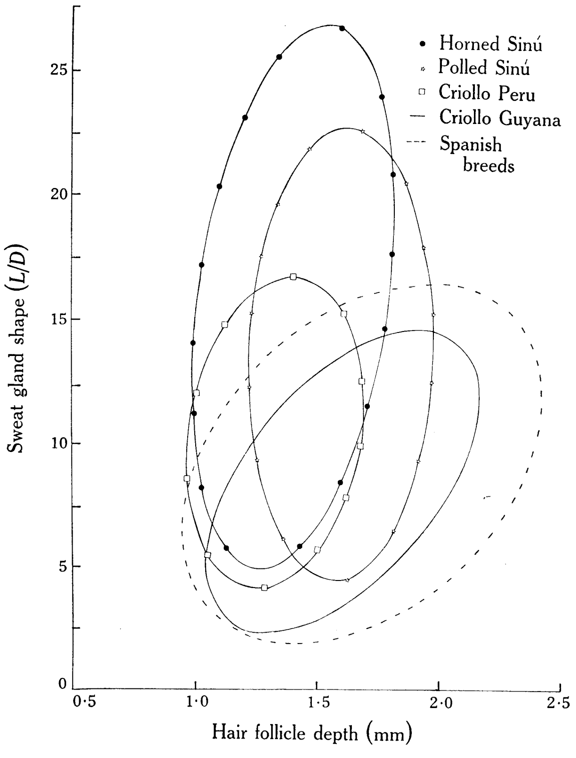

Fig. 13.—Tolerance ellipses illustrating the extent and position of the variation in *L/D* and *FD* in four breeds of South American cattle. The remaining breeds had *L/D* and *FD* values within the overall range, which can therefore be considered as representative of South American cattle in general. The variation in *L/D* and *FD* of 50 Spanish cattle is also shown for comparison.

IV. Discussion

Asian, African, and South American cattle resemble European cattle (Jenkinson and Nay 1972) in basic skin structure. The main cutaneous anatomical differences between cattle throughout the world are in the dimensions of the skin and its component organs. Although European, Asian, and African cattle have similar mean *L/D* values (8·80, 8·59, and 8·36 respectively) and the ranges of *L/D* are similar (Fig. 14), a higher percentage of Asian and African breeds had *L/D* values less than 8·0. Figure 14, which is a comparison of 10 British, 10 Indian, 10 African, and 10

South American breeds, is fairly representative of all European, Asian, African, and South American cattle, and clearly illustrates that the principal cutaneous difference between Asian and African cattle on the one hand, and European on the other, is in the hair follicle depth. European cattle, in general, had a greater hair follicle depth than African and Asian breeds. The shallowest depths were found among Asian breeds, some of which had mean values less than 1·2 mm, although the overall mean *FD* for the Asian breeds was not appreciably different from that of the African breeds.

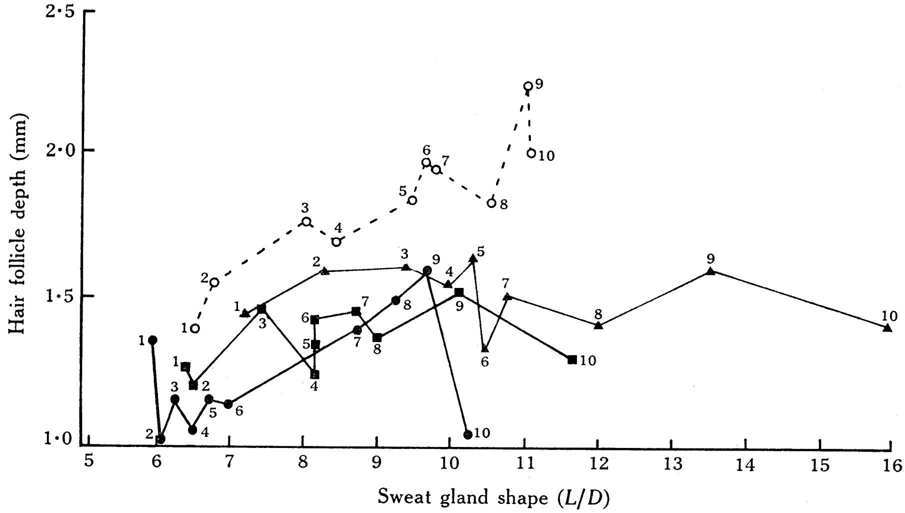

Fig. 14.—A comparison of the mean values of *L*/*D* and *FD* found in 10 British, 10 Indian, 10 African, and 10 South American breeds. These ranges are illustrative of European, Asian, African, and South American cattle as a whole. South American cattle have *L*/*D* values similar to those of cattle from the other continents with the exception of the Sinú breeds which tend to have larger, more convoluted glands than other cattle. The *FD* of South American cattle was intermediate between that of European, on the one hand, and Asian and African on the other, but was clearly thinner than that found in most European breeds.

○ British breeds	● Indian breeds	■ African breeds	▲ American breeds
1. Jersey	1. Kangayam	1. Boran (Tanzania)	1. Brazilian Polled
2. Guernsey	2. Hallikar	2. Shorthorn Zebu	2. Criollo (Peru)
3. Ayrshire	3. Gir	3. Africander (S. Africa)	3. Criollo (Costa Rica)
4. Friesian	4. Kenkatha	4. Karamajong	4. Brahman
5. Dairy Shorthorn	5. Haryana	5. Mashona	5. Criollo (Guatemala)
6. Hereford	6. Kherigarh	6. Egyptian	6. Criollo (Guyana)
7. Beef Shorthorn	7. Tharparkar	7. Kigezi	7. Indo-Brazilian
8. Lincoln Red	8. Red Sindhi	8. N. Sudan Zebu (Sudan)	8. Santa Gertrudis
9. Highland	9. Sahiwal	9. Ankole	9. Polled Sinú (Colombia)
10. Galloway	10. Ponwar	10. Barotse	10. Horned Sinú

Walker (1960*a*, 1960*b*) also found sac-like sweat glands and a thin papillary layer in most of the African cattle which he studied. Asian and African cattle, therefore, are characterized by a shallow hair follicle depth, and in general also tend to have a simple sac-like sweat gland (type I skin). Most of the animals which did not conform to this skin type were from only a few breeds such as the Red Sindhi, Sahiwal, Ponwar, Laos Native, Javanese Native, and the cattle of Japan in Asia, and the Ankole, Barotse, and Red Bororo in Africa. Some Sindhi and Sahiwal cattle, which are known to be partly descended from Afghanistan cattle (Olver 1938) had more convoluted sweat glands and a slightly thicker hair follicle depth than the other breeds on the Indian subcontinent, with the exception of the Ponwar. The Sindhi and Sahiwal breeds were consequently not typical of Zebu cattle in general, only a small proportion resembling the Gir to which they are reputedly closely related (Olver 1938).

Although the cattle of the Ponwar, Laos Native, and Javanese breeds exhibited a shallow hair follicle depth, many individuals within them had long, tubular, convoluted or coiled sweat glands. This clearly distinguishable skin type (defined as type III) was also found in a few animals from some other south-east Asian breeds. The Ponwar hill cattle are probably a breed of recent origin and do not fit into any definite group of Indian cattle (Ware 1942). The wide range of skin types and high proportion of animals with type III skin found in this breed suggest the hypothesis that they are partly derived from a non-Zebu ancestor. The skin types of breeds such as the Ponwar and Laos Native may, therefore, reflect a different origin or development from that of neighbouring Zebu cattle.

The cattle of Japan were, in general, quite different from other Asian cattle in skin type and more closely resembled some European cattle breeds (Jenkinson and Nay 1972). Although the Middle Eastern breeds were not fully represented, the samples obtained indicated that the skins of cattle from this region did not vary markedly from those of other Asian breeds. The Ankole and Barotse tended to have long, serpentine, sweat glands, and a shallow hair follicle depth (type III skin), and therefore differed from the majority of African cattle, which a had type I skin. Cattle with skin types intermediate to types I and III were also found in Africa, and some of these exhibited the club-shaped sweat glands described by Walker (1960*a*). Only a few of the African cattle had skins ranging between types I and II, although some of the European breeds resident in South Africa had skin types within this range—a few exhibiting type I skin. It was not possible with the small number of samples available for study to further subdivide the ranges of skin type of African and Asian cattle. With a few possible exceptions, therefore, the skin types found in Asian and African cattle support current evidence on breed relationships (Mason 1969). The Balinese cattle, for example, had a skin type which was not dissimilar from that of a wild Banteng (L/D 4·02; FD 1·34) which was sampled at Munich Zoo.

Within Asia and Africa there was no obvious relationship between skin type and habitat. Cattle with similar skin types could be found among those from both highland and lowland regions, and those living at different temperatures and humidities. With the possible exception of the Japanese cattle, the humpless breeds studied had skin types within the range found in humped breeds. It is apparent, however, that, although there was little evidence of a relationship between skin type and habitat within Africa, Asia, and Europe (Jenkinson and Nay 1972), cattle indigenous to tropical regions have a shallower hair follicle than breeds from temperate climates. This finding is in agreement with the results of Walker (1960*b*) who found a thinner papillary layer in indigenous African cattle than in European breeds, and concluded that the thinner papillary layer of African cattle was highly correlated with their superior heat tolerance. It seems reasonable to conclude, therefore, that cattle with a shallower hair follicle depth are likely to be more tolerant to tropical environments. Consequently, animals with skin types I and III and types intermediate to them would appear to be more adapted to tropical conditions than animals with type II skin, which are not indigenous to Africa or Asia. This conclusion is supported by the fact that European breeds resident in South Africa and South America have shallower hair follicle depths, thicker hair follicles, and a tendency towards smaller sweat gland volumes than their counterparts in Europe. These features probably result either from adaptation to tropical conditions, or, more likely, from natural selection or selective breeding in hot conditions.

The conclusion is also endorsed by study of South American cattle, which have lower *FD* values than those found in all but a few European breeds (Jenkinson and Nay 1972). Type II skin was not observed in any of the South American cattle studied, although a few animals with skin types approaching it were observed. The depth of the hair follicle tended, in general, to be intermediate between that of Asian and African cattle, and that of those from Europe (Fig. 14). The overall range of L/D among South American cattle was similar to those found in cattle from the other three continents, with the exception of the Sinú breeds which had the longest and most convoluted sweat glands among world cattle. More animals with an L/D greater than 8·0 were found in South American breeds than in Asian or African cattle. Consequently, type III skin was apparently more widespread in South America than in Asia and Africa. An appreciable number of South American cattle, however, were observed to have type I skin and types intermediate between I and III. Since Criollo cattle are largely descended from Spanish and Portuguese animals, they may be expected to have sweat gland shapes similar to those of Iberian cattle. The range of sweat gland shapes observed in South American breeds was, in general, a reflection of the range found in Spain, with the exception of the extremely coiled glands found in some horned Sinú cattle [Fig. 12(*e*)]. A similar type of gland was not observed in Spanish cattle, although this could be a result of the paucity of Spanish samples obtained. It is possible, however, that this extremely coiled sweat gland, coupled with a thin hair follicle depth, may represent an adaptation to the wet winter and hot summer conditions of Colombia. The higher mean L/D value of the horned Sinú compared with that of the polled Sinú may be a reflection of the interbreeding of the latter with Red Poll and Aberdeen Angus cattle (Mason 1969).

The present results indicated that sweat gland volume was, in general, smaller in Asian and African cattle than in European cattle (Jenkinson and Nay 1972), although it varied appreciably between animals of the same breed, e.g. the Boran sampled in the same and different parts of Africa. Sweat gland volume in American cattle tended to be intermediate between the low values found for Asian and African cattle and the relatively high values of European cattle. Sweat gland volume in cattle is known to decrease in summer and after heat exposure (Hayman and Nay 1958; Findlay and Jenkinson 1964). The smaller sweat glands of tropical cattle may, therefore, be indicative of greater activity, and consequently lower sweat gland volumes may be expected in cattle which live in conditions of greater heat stress; sweat gland shape does not appear to reflect glandular activity since similar ranges of shape are found in different continents (Fig. 14). Nay and Hayman (1956), Hayman and Nay (1958), and Pan (1963), on the other hand, found that Sindhi and Sahiwal cattle in Australia had larger sweat gland volumes than cattle from some European breeds, e.g. the Jersey. However, the few Sindhi and Sahiwal animals examined in the Australian studies had much larger sweat gland volumes than those found in the present study for these and other Asian breeds, possibly due to the fact that the Australian animals were kept under excellent nutritional conditions in the relatively cooler climate of Victoria. They are probably not, therefore, typical of their respective breeds. Moreover, since the Sindhi and Sahiwal breeds are not representative of Asian cattle in general, it seems reasonable to conclude from the present results that tropical cattle in general and Asian in particular tend to have much smaller sweat glands than European cattle.

The mean angle of slope of the hair in Asian, African, and South American cattle was not appreciably different from that of European cattle, and therefore appears to be of little importance in the selection of animals for warm conditions. Asian, African, and South American cattle, however, tended to have shorter, thicker, hair follicles than European—a result which is in agreement with the findings of Pan (1964) who concluded that Sahiwals had shorter, thicker, hairs than Jerseys. South American cattle tended to have longer hair follicles than those from Asia and Africa. Cattle with a short coat of thick hairs tend to be more heat-tolerant than those with long woolly coats (Dowling 1959), and cattle have shorter, thicker, hairs in summer than in winter (Dowling and Nay 1960). The cattle with the greatest propensity to this coat type are those with a thin hair follicle depth, i.e. those with skin types ranging between and including types I and III.

It is apparent, therefore, that although within Europe, Asia, Africa, and South America, there was little evidence of a relationship between skin type and habitat, animals with skin types I and III and types intermediate to them may have an advantage in tropical regions. Type I is the most prevalent skin type throughout the tropical regions of the world, and the potential advantage of this skin type is emphasized by the fact that Jersey cattle, which mostly have a type I skin (Jenkinson and Nay 1972), are among the more heat-tolerant of European cattle. Skin type III does not occur in European cattle, but it is interesting to note that some breeds such as the Ayrshire and Friesian contain a percentage of animals with type I (Jenkinson and Nay 1972). Selection of these animals for tropical areas could, perhaps, provide not only animals with improved heat tolerance but, possibly, also better milk-producing cattle, since, within breeds, milk yield is negatively correlated with hair follicle depth (Nay and Jenkinson 1964). A comparison of skin type and heat tolerance within such European breeds with a wide range of skin types could, perhaps, provide a guide for the selection of cattle for tropical regions.

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