Bos indicus Breeds and Bos indicus × Bos taurus Crosses

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Introduction

Bos indicus breeds have special adaptations to tropical environments that may be conveniently used for dairy production. The crosses between them and Bos taurus show increased production while retaining adaptation. The biological, economic and practical aspects of the utilization of these animals are discussed in this article and a brief description of the main breeds is given.

Domestic cattle belong to the genus Bos of the order Artiodactyla, suborder Ruminantia, family Bovidae, subfamily Bovinae, tribe Bovini. Bos taurus L., the common cattle of temperate countries, and Bos indicus L., the zebu, are believed to have originated in the Neolithic from the aurochs or wild ox (Bos primigenius), and were probably separated by domestications in the Near East and Baluchistan.

Bos indicus is characterized by a pronounced hump, which is present in both sexes but more pronounced in the males; long, wide ears; a large dewlap; and an abdominal skinfold, including a large sheath in males. Wide variation exists both between and within breeds in the size of these features. Most breeds are horned, with horns varying in size and shape, but polled varieties exist. Most breeds are white, grey or red in colour, with ample variation in shade and colour pattern. Their bellowing call is very characteristic and distinct from that of Bos taurus.

Both Bos taurus and Bos indicus have 30 pairs of chromosomes. The 29 autosomes are acrocentric and the X sex chromosome is submetacentric in both species. However, the morphology of the Y chromosome is submetacentric in Bos taurus but acrocentric in Bos indicus. Chromosome pairing abnormalities at meiosis have been reported in male hybrids. However, hybrids are fertile. A high proportion of young hybrid bulls have been considered inadequate for frozen semen production (ranging from 0.36 to 0.50 in three programmes in Brazil and India). Nonetheless, the fertility of hybrid bulls in natural mating has been generally higher or equal to that of pure Bos taurus or pure Bos indicus bulls. Fertility of hybrid cows has been generally higher than that of purebreds.

Although Bos indicus breeds have a long gestation period (a mean of 289 days in several breeds), the cows are able to limit the birth weights of their calves, so they have practically no calving difficulties. Mean birth weights in the Gir are 24 kg for males and 23 kg for females and, in the Guzera, 28 and 27 kg. The absence of calving difficulties has been reported even for primiparous Bos indicus cows carrying calves sired by bulls of large Continental Bos taurus breeds.

Bos indicus cattle have a particular behaviour. They are affectionate animals if frequently handled as, for example, in the Indian subcontinent, where they are often housed next to humans. However, in the less densely populated areas of Latin America, they may be more difficult to handle. In pastures, they tend to herd together in a very gregarious manner. Cows need to be stimulated by the presence of the call for milk letdown.

Main Bos indicus Dairy Breeds

Although breed differences in dairy traits have not been well documented in comparative trials, some breeds have a reputation as dairy animals. Brief descriptions of some of them are given below. Production characteristics in India, Pakistan and Brazil are given in Table 1. It should be emphasized that the data for each breed are not comparative
Table 1 Noncomparative means in *Bos indicus* breeds

<table>
<thead>
<tr>
<th>Breed</th>
<th>Age at first calving (months)</th>
<th>Calving interval (months)</th>
<th>Lactation yield (kg)</th>
<th>Lactation length (days)</th>
<th>Milk fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>India</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gir</td>
<td>47</td>
<td>15.7</td>
<td>1403</td>
<td>257</td>
<td>—</td>
</tr>
<tr>
<td>Kankej</td>
<td>47</td>
<td>16.2</td>
<td>1850</td>
<td>351</td>
<td>—</td>
</tr>
<tr>
<td>Rath</td>
<td>40</td>
<td>19.3</td>
<td>1931</td>
<td>331</td>
<td>—</td>
</tr>
<tr>
<td>Red Sindh</td>
<td>42</td>
<td>14.7</td>
<td>1605</td>
<td>284</td>
<td>—</td>
</tr>
<tr>
<td>Sahiwal</td>
<td>40</td>
<td>15.0</td>
<td>1718</td>
<td>283</td>
<td>—</td>
</tr>
<tr>
<td>Tharpharkar</td>
<td>49</td>
<td>14.9</td>
<td>1659</td>
<td>280</td>
<td>—</td>
</tr>
<tr>
<td><strong>Brazil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gir</td>
<td>45.2 (6911)</td>
<td>16.1 (15.365)</td>
<td>2778 (27.431)</td>
<td>291 (27.431)</td>
<td>4.6 (16.771)</td>
</tr>
<tr>
<td>Guzerá</td>
<td>44.2 (575)</td>
<td>14.9 (1040)</td>
<td>2400 (2298)</td>
<td>285 (2298)</td>
<td>4.9 (851)</td>
</tr>
<tr>
<td><strong>Pakistan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sahiwal</td>
<td>44.0 (4601)</td>
<td>15.3 (13.951)</td>
<td>1522 (17.292)</td>
<td>256 (17.469)</td>
<td>4.5 (293)</td>
</tr>
</tbody>
</table>


Number of observations are in parentheses.

because they have been obtained from cattle in different environments; as a result, breed and environmental differences are confounded. However, the data give an indication of the mean production traits involved.

**Gir**

This breed is predominantly red and white in colour, with patterns varying from solid to mottled and shades from yellowish to dark red (Figure 1). The animals display a very characteristic broad, prominent forehead, with horns curving downwards, backwards and outwards and then upwards. A herd book for a polled variety exists in Brazil. The ears are long and pendulous and the temperament is generally tranquil.

The breed is found on the central west coast of India. It has been exported to Brazil, where it is considered to be the main *Bos indicus* dairy breed, with some 7000 animals of both sexes being registered each year. It is also found in other countries, including Colombia and the United States. Frozen semen sales in Brazil amount to 344,000 doses per year, 76% of which is milking Gir. The Brazilian Milking Gir Breed Society (ABCGIL) and the Federal Research Organization (EMBRAPA) have run a conventional progeny-testing programme of approximately 10 bulls per year since 1985. Genetic evaluations are based on animal model best linear unbiased prediction (BLUP) methods. As a matter

Figure 1 (see colour plate 20) Gir females. Courtesy of Beef Milk Brasil Marketing, Brazil.
of interest, the record milk yield was 15 126 kg in a 361-day lactation.

**Guzera/Kankrej**

Predominantly light to dark grey in colour, this breed has characteristically lyre-shape horns (**Figure 2**). Animals are tall and the ears are shorter than in the Gir and not as pendulous. Animals of this breed display an attentive, active temperament.

The Guzera is a Brazilian breed derived from the Kankrej, an Indian breed found in Gujarat. These cattle are remarkably similar to those depicted in a famous Mohenjo-Daro seal dating from more than 2000 bc. The Guzera has been exported to other countries of Latin America and Africa. Along with the Nelore and the Gir, it was the most important founder breed of the Brahman. In Brazil, about 6000 animals of both sexes are registered per year and semen sales amount to 134 000 doses per year, 23% of which is from the dairy improvement programme. The breed has a conventional progeny-testing of approximately six bulls per year, coupled with a multiple ovulation and embryo transfer (MOET) selection nucleus of 12 donors per year, run with technical support from the Federal University of Minas Gerais. The genetic evaluations are run by EMBRAPA, using modern statistical methods (animal model–BLUP).

**Sahiwal**

The Sahiwal is usually various shades of red to brown, with varying white markings (**Figure 3**). Originally from Pakistan, it may have influences from the Gir and Red Sindhi. It is now an international breed found in many countries. The number of animals worldwide has been reported to be in the order of 15 000, of which 4000 are breeding females.

**Tharparker**

Usually white or grey, with lyre-shaped horns, the Tharparker is strongly built and short-legged. Found in Hyderabad Sindh Province, India, it has been interbred with the Kankrej, Red Sindhi and Gir. Its original habitat is arid and the breed is considered to be a good milker under poor feeding conditions; it is also used for work and has a reputation for resistance to draught. The breed has been exported to several countries.

**New Synthetic Bos taurus × Bos indicus Breeds**

Countless attempts have been made and continue to be made to develop new synthetic breeds from *Bos taurus × Bos indicus* crosses. When evaluating these efforts, it should be borne in mind that successful development of new composite breeds requires a combination of genetic soundness, operational
effectiveness and commercial organization. Genetic soundness involves the appropriate choice of breeds and breed composition; the avoidance of inbreeding, which requires the use of large populations and an adequate breeding programme, based on progeny testing or, more recently, MOET nucleus selection schemes; scientifically based methods of genetic evaluation, such as animal model-GLUP or formerly herd mate comparisons; appropriate definitions of economic selection objectives and criteria; and optimization of generation intervals. Operational effectiveness is rare in the public organizations of developing countries while commercial breeders have tended to place too much emphasis on traditional show-ring competitions and other ineffective methods of genetic improvement. For example, due perhaps to the influence of the Santa Gertrudis (an early new tropical synthetic beef breed that met with commercial success worldwide), several populations have been based on a 3/8 Bos taurus x 3/8 Bos indicus cross, although there is no experimental demonstration of that fraction being superior. The combination of large-scale investment and managerial commercial organization required for optimal results in the development of tropical dairy breeds is not yet been available.

Some tropical dairy breed development programmes are briefly described below. Noncomparative means for dairy traits are shown in Table 2.

**Table 2** Noncomparative means in new composite Bos taurus x Bos indicus breeds

<table>
<thead>
<tr>
<th>Breed</th>
<th>Number of herds</th>
<th>Number of lactations</th>
<th>Lactation yield (kg)</th>
<th>Lactation length (days)</th>
<th>Milk fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Milking Zebu</td>
<td>651</td>
<td>1763</td>
<td>262</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Australian Friesian Sahiwal</td>
<td>27</td>
<td>269</td>
<td>2342</td>
<td>--</td>
<td>4.2</td>
</tr>
<tr>
<td>Brazilian Milking Hybrid</td>
<td>14</td>
<td>6592</td>
<td>2549</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Brazilian Milking Hybrid</td>
<td>23</td>
<td>2321</td>
<td>1793</td>
<td>248</td>
<td>3.4</td>
</tr>
<tr>
<td>Carora5</td>
<td>19</td>
<td>13257</td>
<td>2701</td>
<td>267</td>
<td>--</td>
</tr>
<tr>
<td>Girdano6</td>
<td>153</td>
<td>12610</td>
<td>3335</td>
<td>280</td>
<td>--</td>
</tr>
<tr>
<td>Jamaica Hopeb</td>
<td>12</td>
<td>2158</td>
<td>2737</td>
<td>--</td>
<td>4.7</td>
</tr>
<tr>
<td>Mambib</td>
<td>--</td>
<td>11515</td>
<td>2873</td>
<td>300</td>
<td>3.5</td>
</tr>
<tr>
<td>Siboneyc</td>
<td>2</td>
<td>8040</td>
<td>2606</td>
<td>262</td>
<td>3.6</td>
</tr>
<tr>
<td>Sunaninid</td>
<td>--</td>
<td>2072</td>
<td>2194</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

6 Elite herds, mature equivalent yields.
Bos indicus × Jersey females at the field station. A high incidence of short lactations in the first cross (70%) was reduced to less than 10% after three generations of strict selection. A second stage was based on progeny-testing of young bulls from top-yielding cows in cooperating herds of predominantly Jersey breeding, selecting from the crossbred population. The Bos indicus gene fraction stabilized at around 0.25. The breeding programme consisted of producing 30–40 candidate bulls per annum, after three independent successive stages of selection:

1. Approximately half (i.e. 20) were selected for heat tolerance assessed in a climatic room.
2. Approximately half of these (i.e. 10) selected for tick resistance under artificial infestation.
3. The best one on progeny-testing for milk yield, provided it was adequate for frozen semen production.

The programme showed that it was possible to select simultaneously for milk yield and adaptation so that, in about 20 years, the animals had reached the milk yield of the Jersey base population but with increased heat tolerance and tick resistance.

**Australian Friesian Sahiwal (AFS)**

The Australian Friesian Sahiwal (AFS) was developed by the Queensland Department of Primary Industries from a closed population of half-bred Friesian × Sahiwal, the latter having the same origin as in the AMZ. Emphasis was on milk yield and tick resistance; it was not considered necessary to test for heat tolerance because the climate was considered stressful to Bos taurus dairy cattle. The programme was initiated in 1961 by crossing Sahiwal × Bos taurus dairy breeds, but only the Friesian crosses were retained. A small nucleus Sahiwal herd was developed, including testing of Sahiwal sires with Bos taurus cross progeny. Progeny testing of AFS sires of F₂ or a higher generation commenced in 1976, also with selection for tick resistance. The AFS females were kept at the Kairi Research Station near Atherton, in Queensland, and with loan cooperating farmers. The cow population was more than 2000 strong in 1982. A MOET selection nucleus scheme was adopted at a later stage. A similar fast elimination of short lactations by selection was observed, as in the AMZ. However, such a high incidence of short lactations as found in the AMZ and AFS has not been found elsewhere, so this might have been inherent to the small sample in the Bos indicus founders of the Australian breeds.

**Brazilian Milking Hybrid (MLB)**

The Brazilian Milking Hybrid (MLB) (Figure 5) was the results of a research and development programme conducted by the National Dairy Cattle Centre of the Federal Research Organization of Brazil (EMBRAPA), with the assistance of the Food and Agriculture Organization’s United Nations Development Programme (FAO/UNDP). Its main objective was to obtain estimates of heritabilities and genetic correlations on the dairy, reproduction, growth and adaptation traits needed to design breeding programmes for synthetic dairy cattle breeds suitable for the dairy production systems of the Brazilian tropics. The programme operated through the progeny-testing of approximately 10 young bulls per annum, selected for their genetic value for milk, irrespectively of breed composition, coat colour or type. Thus, the population was a multibreed composite, reflecting the situation of the local cattle population of 7.5 million hybrid cows that varied widely in their Bos taurus and Bos indicus composition. The predominant breeds were the Holstein-Friesian, Gir and Guzera, but several other breeds were also represented in the gene pool. The programme ceased after progeny-testing 121 bulls for milk yield and composition between 1977 and 1994. Results are being analysed. The genetic correlations between tick burden and yields of milk, fat or protein were low (0.06 to -0.14) indicating that there is no important antagonism between yield and resistance.

**Carora**

Officially a breed since 1975, the Carora originated in 1935 from crosses of Brown Swiss and Criollo in a private farm in northeastern Venezuela. Other Bos taurus and Bos indicus breeds also had some influence in its formation, the later increasing its contribution over time. Carora animals have a coat colour similar to the Brown Swiss. The breed is some 6000 animals strong and has a breed society responsible for registration and the conducting of a sire progeny-testing scheme with the assistance of the University of Milan.

**Girolando**

This commercial breed (Figure 6) is nominally composed of $\frac{2}{3}$ Holstein-Friesian × $\frac{1}{3}$ Gir, although, in practice, other breeds intervene in its foundation
and the $\frac{1}{2}$ fraction has been somewhat relaxed. Animals are horned and usually black and white, with various colour patterns, including mottled. The breed society is officially responsible for keeping the herd book and also commenced a small-scale sire progeny-testing programme. It registers some 7000 animals of both sexes per year and semen sales amount to 44 000 doses per year.

**Jamaica Hope**

This was one of the earliest and most famous attempts to develop a tropical dairy cattle breed. The
Government of Jamaica established a dairy herd at the Hope Farm, near Kingston, where several dairy breeds were tested (Ayrshire, Brown Swiss, Guernsey, Holstein--Friesian, Jersey and Red Poll and creole and zebu crosses). A Sahiwal bull was imported from India in 1920. Breeds were successively dropped. In 1943, the second phase was begun by importing Jersey bulls and using Jersey × Sahiwal crossbred bulls and cows of breed composition varying from \( \frac{1}{2} \) to \( \frac{3}{4} \) Jersey genes and testing sires on progeny performance. In 1952 the Holstein--Friesian breeding was terminated because grade Jerseys were considered superior in their culling rates, age at first calving and milk production per hectare. In 1950 the herd was moved from another farm, Bodles Station. In 1952 the breed received official status and a breed society was formed, including the Bodles Station herd and animals of similar genotype in private farms. The breed stabilized at about 80% Jersey inheritance, 15% Sahiwal and 5% Holstein--Friesian. A national milk-recording scheme was implemented. Selection was based on production performance and fertility, with no conscious selection for colour or type. However, the programme suffered from the lack of a larger population on which to test more young bulls with sufficient numbers of daughters. Some 50 breeders were involved but the enthusiasm was reported to be less than that required for stronger breed development.

**Siboney**

This \( \frac{1}{2} \) Holstein × \( \frac{1}{2} \) nondescript *Bos indicus* composite breed was developed under the national cross-breeding policy of Cuba. Some 7500 cows have been involved in this project. The breed development involved intensive selection of \( \frac{1}{2} \) Holstein × \( \frac{1}{2} \) *Bos indicus* females, inseminated with Holsteins of Canadian origin to produce the \( \frac{1}{2} \) Holstein grades, which were then mated among themselves (inter se). A conventional sire progeny-testing programme was superimposed onto this crossbreeding scheme. A related breed, the Mambo, *inter se* of \( \frac{1}{2} \) Holstein × \( \frac{1}{2} \) *Bos indicus* composition, was developed on similar lines.

**Sunandini**

A \( \frac{1}{2} \) Brown Swiss × \( \frac{1}{2} \) local *Bos indicus* was developed in Kerala State by an Indo-Swiss project started in 1963. Half-breeds and \( \frac{1}{2} \) Brown Swiss were crossed to produce the \( \frac{1}{2} \) Brown Swiss crosses. The Brown Swiss base consisted of 33 sires and 45 cows. American Brown Swiss, Holstein and Jersey genes have also been introduced recently. The Indo--Swiss project evolved into the Kerala Livestock Development Board, which initiated a sire progeny-testing programme in 1977. This required the development of field performance and pedigree recording. Some 4000–5000 animals are registered annually and milk quantity is recorded on about 2300 cows.

**Bos indicus × Bos taurus Crosses**

**Breeds/Crosses and Production Systems**

*Bos taurus* breeds, highly selected for milk yield in developed temperate countries, do not perform well under the prevailing production systems in the tropics, where they are unable to cope with the stresses of heat, humidity, parasites and low-quality forages, to the point of being unable to sustain their numbers. For example, in Venezuela, it was estimated that imported and locally born Holstein cows produced only 0.6 and 0.7 replacement females respectively in their lifetimes. *Bos indicus* breeds, on the other hand, while adapted to the environmental challenges, showed little response in milk yield to improved management. Thus, the main interest in crossing is to combine milk yield and adaptation.

Use of purebred *Bos taurus* has been advocated for dairy systems that use coolers and ponds to alleviate heat and freestalls or other types of buildings to keep the cattle indoors. However, these expensive systems are not generally economic in developing countries, where capital is scarce and unemployment severe, favoring systems with a lower input. Also, systems based on high concentrate consumption are not feasible if cows are competing with humans for cereals. On the other hand, improved systems based on pasture may be extremely efficient economically although, in these conditions, milk yield per cow is not as high as in temperate countries. As an example, a model private farm in Brazil, keeping F\(_{1}\) Holstein × Guzera crosses on irrigated, fertilized pasture and feeding 3 kg concentrates day\(^{-1}\), had a production cost US\$0.98 E\(^{-1}\), which is extremely low on a world basis. This result was due mainly to the high stocking rate of 4.2 cows ha\(^{-1}\) and to the low input in terms of machines, buildings and veterinary costs.

Solar radiation, which might be seen as a hindrance for dairy production, is in fact the main asset of tropical systems, because it allows intense photosynthesis and plant growth; however, to make good use of it, adapted animals are required.
Adaptation Traits

*Bos indicus* tolerates heat better than *Bos taurus*, and this is reflected in a lower rise of body temperature under hot conditions. This tolerance is due to the high heat resistance of their sleek, dense coat, which prevents heat gain from the environment; low tissue resistance to heat transfer from the body core to the surface; and high sweating competence. Humidity has no adverse effect on *Bos indicus* sweating rate, while water vapour trapped in the air spaces between the hairs of *Bos taurus* impedes evaporation. *Bos indicus* can also store heat during the day and then dissipate it nnon-evaporatively at night, thus reducing the need for watering.

Dry matter intake relative to body weight is higher in *Bos indicus* than in *Bos taurus* when coarse forages are fed, but the contrary holds for good-quality forages. The greater ability of *Bos indicus* to recycle urea to the rumen makes it less dependent on feed nitrogen. For *Bos indicus* net energy requirements for maintenance are lower than in *Bos taurus*, but requirements for growth are higher. *Bos indicus* is also highly resistant to parasites.

In *Bos taurus × Bos indicus* crosses of up to 50% *Bos taurus* gene fraction, resistance to environmental stresses approaches that of *Bos indicus*, but it is much reduced above that level of *Bos taurus* inheritance. For example, burdens of the tick *Boophilus microplus* increase exponentially with the *Bos taurus* fraction in the cross.

Survival, reproduction and herd-life are generally higher at intermediate gene fractions of both species. Some examples of the effects of crosbreeding on adaptation traits are shown in Table 3.

Table 3  Adaptation traits in Holstein-Friesian × Guzerá crosses

<table>
<thead>
<tr>
<th>Trait</th>
<th>Holstein-Friesian gene fraction</th>
<th>1/8</th>
<th>1/4</th>
<th>1/2</th>
<th>2/3</th>
<th>5/6</th>
<th>6/6</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Boophilus microplus</em> (ticks per animal)</td>
<td>4.4</td>
<td>71</td>
<td>151</td>
<td>220</td>
<td>262</td>
<td>501</td>
<td></td>
</tr>
<tr>
<td><em>Dermatobia hominii</em> (nodes per animal)</td>
<td>4.2</td>
<td>4.3</td>
<td>3.9</td>
<td>6.8</td>
<td>7.3</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>Age at first calving (months)</td>
<td>44.3</td>
<td>39.1</td>
<td>47.5</td>
<td>42.7</td>
<td>46.5</td>
<td>44.2</td>
<td></td>
</tr>
<tr>
<td>Heifer calf mortality to 1 year (%)</td>
<td>12.4</td>
<td>8.0</td>
<td>18.7</td>
<td>8.9</td>
<td>13.9</td>
<td>27.1</td>
<td></td>
</tr>
<tr>
<td>Heifers died/22-month-old heifers (%)</td>
<td>3.0</td>
<td>1.5</td>
<td>9.1</td>
<td>10.4</td>
<td>14.1</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>Cows died/22-month-old heifers (%)</td>
<td>10.5</td>
<td>13.7</td>
<td>19.7</td>
<td>25.4</td>
<td>42.2</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>Females calving/22-month-old heifers (%)</td>
<td>96.6</td>
<td>95.5</td>
<td>81.8</td>
<td>80.1</td>
<td>69.9</td>
<td>71.9</td>
<td></td>
</tr>
<tr>
<td>Number of lactations in 15 years (%)</td>
<td>3.8</td>
<td>3.0</td>
<td>3.6</td>
<td>4.5</td>
<td>3.7</td>
<td>3.2</td>
<td></td>
</tr>
</tbody>
</table>

* All crosses by purebred sires except for the 5/6 obtained by inter se matings of sires and dams of that fraction.
* Madalena FE (1990); Proceedings of the 4th World Congress on Genetics and Applied Livestock Production 14: 310–313.

Milking Traits

The rate of milk flow decreases linearly with the *Bos indicus* gene fraction in crosses; this may be due to a tauter teat sphincter, because the ease of handmilking follows a similar trend. The temperament of *Bos taurus* is better but crosses of up to 1/2 *Bos indicus* are considered docile by milkers.

Short lactations are a major problem in tropical dairy production because of the consequent increase in the proportion of dry cows in the herd. Crosses with a high fraction of *Bos taurus* have a high incidence of short lactations caused by underfeeding and environmental stresses. Crosses with a high fraction of *Bos indicus* also have a high incidence of short lactations but these are genetically determined. Removal of the calf causes drying-off in these cows and gestation has a greater adverse effect on milk yield than in *Bos taurus* cows. Lactation length has a heritability of the same order of magnitude as milk yield in *Bos indicus* or *Bos taurus × Bos indicus* breeds and also displays important heterosis effects. In crosses with improved dairy *Bos indicus* breeds, such as the Gir or the Guzerá, the F1 generations usually show a lower incidence of short lactations when milked by hand, either with or without the calf stimulus for milk letdown, and also when machine-milked in the presence of the calf. Whether F2 cows may be machine-milked without the presence of the calf is an open question, i.e. the proportion drying-off is not well documented nor is there consensus opinion among farmers in this respect, whereas it is accepted that *Bos taurus* grades of 1/4 or higher have no problems. F3 or other inter se crosses behave similarly to the high *Bos indicus* grades.
Dairy Performance

As may be seen in Figure 7, where milk yield per day of calving interval (MYCI) from several studies is plotted against the Bos taurus gene proportion, F₁ crosses outperform the other grades in the lower performance levels, which are the commonest. Discrepancies in the slopes shown in Figure 7 may be due to several factors, such as different editing-out of short lactations, or long CI, and to different breeds/samples being represented within both species in the various studies. However, all studies but one (Kenya) in Figure 7 were conducted with Holstein-Friesian and all used improved Bos indicus breeds (Sahiwal, Gir or Guzera).

As performance increases, the high and Bos taurus grades reach F₁ level, there are no differences among those grades at a level of approximately 10 kg MYCI (Figure 7). At higher levels of MYCI, the purebred Bos taurus outperformed the crosses in early studies in the southeastern United States.

Figure 7 also shows the genetic limitation for milk production of high Bos indicus grades, as their response to improved management is less than that observed for Bos tauri. This genetic × environment interaction was demonstrated in the Brazilian trial, where crosses with the same origin were evaluated in farms of high and low management (Figure 7, Brazil-1 and Brazil-2).

Favourable heterosis is present in most traits of economic importance in Bos taurus × Bos indicus crosses. As a result, when the receipts and costs associated with fat and protein yield, salvage value, survival, age at first calving, herd life, feed consumption, milking time and other costs are combined in a profit function, the superiority of the F₁ cross is enhanced over that shown in Figure 7, because the effects of heterosis accumulate over traits, particularly under low inputs. For example, in the commercial farms of the Brazilian trial, net profit per day of herd-life in the ½ F₁ and ≥ ⅓ Holstein-Friesian groups was equivalent to 1.7, 4.4 and −1.3 kg of milk, respectively. Supporting results have been obtained elsewhere.

Heterosis is partially lost in inter se crosses of hybrid sires and dams. A review of 14 studies showed that the mean difference of F₁ minus F₂, expressed as a percentage of F₁ performance, was 7.0%, 5.8%, 24.4% and −3.6% for age at first calving, calving interval, milk yield and lactation length, respectively. However, the differences in the last two traits are underestimated in studies that exclude short lactations from the analysis on the grounds of them being "abnormal". Under the commercial conditions in the Brazilian trial (Figure 7, Brazil-1), the MYCI of the ⅓ inter se group was only 56% of the same trait in the F₁. One quarter of that difference was attributed to recombination loss of parental epistatic combinations.

Because heterosis is wasted in inter se crosses also for other economic traits (e.g. Table 3), the overall decline in profit with respect to the F₁ is high. As an example, the profit of the ½ inter se under commercial conditions in the Brazilian trial was only 30% of that of the F₁.

Crossbreeding Strategies

In several tropical regions, farmers have been keeping their herds intermediate between Bos taurus and Bos indicus for decades by ad hoc methods. In Latin America, these involve periodical switching of the bull species, generating less productive, extreme Bos indicus and Bos taurus grades, or using common hybrid bulls that are not properly selected.

Given its economic importance, exploitation of heterosis is the major genetic consideration in strategies for maintaining hybrid Bos taurus × Bos indicus populations. A system of continuous replacement with F₁ females maximizes the economic use of heterosis. Such a system is being applied commercially in Brazil by beef cattle-type ranches,
specializing in the production of F₁ heifers for sale, who use artificial insemination of Bos indicus dams. In Colombia Bos taurus females in the highlands are inseminated with Bos indicus semen to produce F₁ heifers which are sold to lowland farms. A similar cross is carried out in New Zealand for export to tropical countries.

The F₁ system requires the maintenance of large numbers of females of at least one of the purebred parental breeds, so that it is justifiable to exploit the breed economically, as in the situations mentioned above. Production of F₁ replacements is facilitated by generalization of embryo transfer techniques involving in vitro fertilization. Such a system has been announced by a prominent international breeding company. Semen-sexing would much enhance the economic value of this scheme.

Rotational crossing would be second to F₁ in genetic terms, as recombination loss is less than in inter se crosses. However, low usage of artificial insemination or controlled mating prevents wide use of this system. Moreover, many farms in tropical systems would not be large enough to justify keeping two bulls.

Using a hybrid bull is most practical but involves loss of heterosis. Counteracting selection would alleviate this, at least for milk yield, although mortality and fertility are unlikely to be effectively improved by selection. In any case, this option would require effective breed development programmes run on a much larger scale of investment than that applied up to now.


Further Reading


Goat Breeds

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Introduction

Goats are found worldwide on all continents and are well adapted to tropical and temperate, arid and humid, cold and hot, and steep mountainous environments (Table 1). The developing world is home to about 95% of the 700 million goats. They are valued for many different products and purposes.
in different parts of the world: for meat, milk, cheese, yoghurt, mohair, cashmere, even for leather, manure, self-sufficiency in family food, a cash savings account on the hoof, brush-clearing, draught and as a companion animal. Some goat breeds have evolved and are kept for single purposes, such as the Angora for the fine mohair wool, other breeds for the precious cashmere and pashmina fibre, and the Boer goat for meat, but the majority of goats are dual-purpose breeds kept mainly for meat production plus milk at a medium or low level of production. No more than 20% of all estimated 350 goat breeds are of single-purpose dairy type. More than half of these originated in central Europe, while less than half evolved in central Asia and about 10% in Africa. Descriptions of indigenous goat breeds outside of Europe and their potential are extensive are nor they based on organized breed registries. However, they are important because of their adaptation to difficult climate, poor or sparse feeds and water, and various diseases. Goats in temperate climate regions exceed most others in productivity, especially in milk and dairy products,