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Phenotypic characterization, milk yield, udder health and heat tolerance of Saanen Crossbred, Saanen, and Etawah Crossbred dairy goats under tropical farm conditions

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(a) Abstract

Saanen Crossbred, locally known as Sapera, are derived from Saanen–Etawah Crossbred matings and increasingly kept for milk production in Indonesia. However, their breeding has remained largely uncontrolled, preventing the establishment of breed standards and evidence-based selection programmes. This study characterized the Saanen Crossbred phenotype as a tropical dairy goat and compared it with its parental breeds, using body and udder morphometry, qualitative traits, standardized milk yield, udder health and heat tolerance as components of the characterization. In total, 243 lactating does (165 Saanen Crossbred, 48 Etawah Crossbred, 30 Saanen) were recorded on eight farms in the main dairy goat production centre of Yogyakarta, Indonesia. Data were analysed using general linear model and multivariate analyses. Saanen Crossbred goats resembled Saanen in most dairy-related traits, being predominantly white (80.0%) with a globular udder (99.4%) and greater thoracic capacity and udder circumference than Etawah Crossbred, whereas residual Etawah Crossbred influence persisted in ear orientation and coat colour, indicating that a uniform dairy type is not yet established. Standardized milk yield at 100 days in milk was intermediate between the parental breeds (1676.88 mL/day). A heat tolerance coefficient (HTC) close to 2.0 denotes good heat tolerance and higher values greater heat sensitivity; noon HTC was lowest in Etawah Crossbred (2.02), highest in Saanen (2.18) and intermediate in the Saanen Crossbred (2.10). This is the first integrated phenotypic and physiological characterization of the Saanen Crossbred, and provides a phenotypic basis for breed standards and selection criteria for tropical dairy goats.

Keywords: Dairy goat performance; morphometric traits; multivariate analysis; saanen crossbred

(b) Introduction

Etawah Crossbred goats have been widely kept in Indonesia since the late 1990s because of their good adaptability to tropical conditions. Their milk yield, however, is relatively low, ranging from only 0.5 to 1 L per head per day (Nafiu *et al.* 2020). This limitation led to the introduction of Saanen goats, a specialized dairy breed with a high milk production potential, through the Baturraden National Livestock and Feed Crop

Seed Centre in Central Java in 2015. In its country of origin, Saanen milk yield can reach 4 to 4.5 L per head per day, but under Indonesian tropical conditions it is markedly lower, at only 1.14 to 2.52 L per head per day (Yudi and Atabany 2021), a limitation attributed to a comparatively poor tolerance of Saanen to tropical heat.

Crossbreeding between Saanen and Etawah Crossbred goats was subsequently carried out to combine the high milk production potential of Saanen with the tropical adaptability of Etawah Crossbred (Abdurrahman *et al.* 2023). This crossbred, locally known as Sapera; an acronym of Saanen and Peranakan Ettawa, the Indonesian name for the Etawah Crossbred and referred to here as the Saanen Crossbred, has been developed as a dairy goat in Indonesia (Anggraeni *et al.* 2020) and has shown a favourable milk production potential under smallholder conditions, with a reported yield of 1674.00 ± 122.77 mL per head per day (Suranindyah *et al.* 2018). This crossbreed is set to be one of the best dairy goats in Indonesia, due to its combination of high production and tropical climate adaptability. However, the growth of the Saanen Crossbred population has not been managed through a formal crossbreeding programme. This has resulted in significant phenotypic variation within the population. This phenotypic variation is evident in body size, udder characteristics and other qualitative traits. Furthermore, previous reports on Saanen crosses have not produced consistent results. Abdurrahman *et al.* (2023) reported that Saanen Crossbred goats were genetically closer to Saanen than to Etawah Crossbred based on body morphometric measurements and canonical analysis, whereas Ariyanto *et al.* (2021) reported that Saanen Crossbred goats had a body and head size similar to Etawah Crossbred, but with smaller and shorter ears. These contrasting findings suggest that the phenotypic identity of the Saanen Crossbred remains unclear, as a result of uncontrolled crossbreeding. This lack of breeding control has also limited the establishment of breed standards and of evidence-based selection programmes for the Saanen Crossbred, so that the population cannot yet be described, recorded or selected on an objective phenotypic basis.

Phenotypic characterization is an approach used to describe the diversity of a livestock population based on observable characteristics (FAO 2012). In crossbred populations, such characterization is especially important because crossbreeding can generate wider phenotypic variation than is present in either parental breed. Morphometric characterization, in particular, provides an objective description of body structure, allows the identification of phenotypic variation, and helps determine which characteristics may be useful for selection and breeding programmes (Purwanti *et al.* 2019). This approach has previously been used to describe body morphometric variation in local goats in Burkina Faso (Akounda *et al.* 2023) and in Kalahari Red goats (Tyasi and Tada 2023).

Beyond body conformation, udder characteristics and milk yield are central traits in the evaluation of dairy goats. Udder morphometric measurement is required because udder size and shape are related to milk storage capacity, milking efficiency, and udder health (Alcantara *et al.* 2022). Milk yield in dairy goats changes throughout the lactation period and is influenced by lactation stage and days in milk (DIM) (Suranindyah *et al.* 2018); comparisons among individuals recorded at different DIM therefore require appropriate standardization.

In Indonesia, environmental adaptability is an important factor in developing dairy goats, as they are kept in a variety of conditions. A key indicator is the temperature-humidity index (THI), which combines temperature and relative humidity to measure thermal comfort (Ali *et al.* 2023). Adaptive capacity is typically indicated by the heat tolerance coefficient (HTC). An increase in THI beyond the comfort zone can induce heat stress, characterized by an increase in rectal temperature and respiration rate as heat-dissipation mechanisms (Shirley *et al.* 2024); the greater the increase in these two parameters, the lower the ability of the animal to cope with heat stress (Danso *et al.* 2024). Environmental stress can increase udder health problems like mastitis, so it is important to evaluate heat tolerance and udder health together, in order to get comprehensive data on the biological performance of Saanen Crossed goats compared to their ancestor breed.

Characterizing the Saanen Crossbred phenotype involves a large number of interrelated quantitative and qualitative variables and therefore requires an analytical approach capable of describing population diversity comprehensively. Multivariate analysis has been widely used in livestock characterization studies because it can simplify a large number of correlated variables and identify the characteristics that contribute most to phenotypic variation within a population (de Melo *et al.* 2020; Valsalan *et al.* 2020), while qualitative traits provide complementary information for distinguishing and describing livestock populations (Budisatria *et al.* 2022). Accordingly, this study combined a general linear model with multivariate analyses of quantitative, qualitative and mixed data; the individual procedures and the reasons for selecting them are described in the materials and methods.

Characterization of the Saanen Crossbred is directly relevant to the national dairy goat breeding programme, because breed standards, selection criteria and the recording schemes needed to support them can only be defined once the phenotype of the population and the extent of its variation are known. Previous studies of this crossbred have been limited in scope, addressing body morphometry alone (Ariyanto *et al.* 2021; Abdurrahman *et al.* 2023) or milk production alone (Suranindyah *et al.* 2018), and have reached inconsistent conclusions about the phenotypic position of the crossbred relative to its parental breeds. The

novelty of the present study therefore lies in evaluating body morphometry, udder morphology, qualitative traits, standardized milk yield, udder health and heat tolerance simultaneously in the same animals, across several smallholder farms spanning a range of tropical field conditions, and in integrating quantitative and qualitative traits within a single multivariate framework. This makes it possible to establish whether the resemblance of the Saanen Crossbred to Saanen in dairy traits is matched by a comparable resemblance in external appearance and in tropical adaptability, a question that single-trait studies cannot resolve.

This study therefore aimed to characterize the phenotype of the Saanen Crossbred as a tropical dairy goat and to compare it with that of its parental breeds, Saanen and Etawah Crossbred, under Indonesian tropical smallholder conditions. Body and udder morphometry, qualitative traits, standardized milk yield, udder health and heat tolerance were evaluated as components of this characterization rather than as separate objectives.

(c) Materials and Methods

Study area and farm conditions

The study was conducted from 1 February to 3 May 2026 on eight dairy goat farms in the Special Region of Yogyakarta, Indonesia. The study area is shown in Figure 1. The study area is a dairy goat production centre comprising Saanen, Saanen Crossbred and Etawah Crossbred farms, and the farms were selected on the basis of the availability of lactating does. The farms were located at altitudes ranging from 139.82 to 676.42 m above sea level. This altitudinal range was not imposed as an experimental treatment but was retained deliberately, because dairy goat farming in the region extends from the lowlands to the slopes of Mount Merapi and the Menoreh hills, and because altitude is the main source of variation in ambient temperature and relative humidity, and therefore in the temperature-humidity index (THI), among farms in this region. Sampling across this range therefore reproduces the range of thermal conditions to which dairy goats are actually exposed under Indonesian smallholder conditions, so that the comparison among breeds is not restricted to a single microclimate. Temperature and relative humidity were recorded in the morning (06:00-07:00), at noon (12:00-13:00) and in the afternoon (16:00-17:00) using a thermohygrometer. The THI ranged from 75.48 to 81.70 in the morning, 78.47 to 84.13 at noon and 76.96 to 81.82 in the afternoon, indicating that all farms exposed the animals to warm to hot tropical conditions. Goats were managed under practical dairy-goat farm systems. Diets consisted mainly of fresh forage, browse, corn silage, dry water spinach, commercial pellets and concentrates, depending on farm resources. Milking was performed manually on most farms, whereas two farms used portable or parlour milking machines. Animals were housed in raised slatted-floor pens, either individually or in groups.

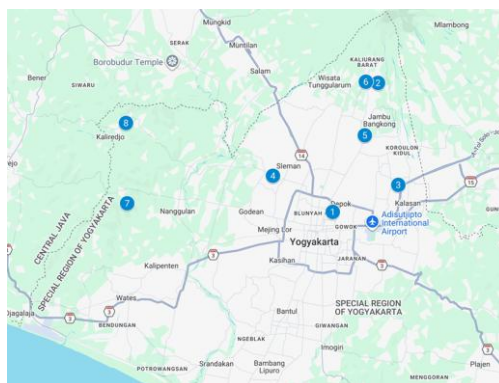


Fig. 1. Location of the eight dairy goat farms in Yogyakarta, Indonesia.

Animals and sampling

The study used 243 lactating does consisting of 165 Saanen Crossbred, 48 Etawah Crossbred and 30 Saanen goats. Animals were selected by purposive sampling with breed and lactation status as the primary criteria. Location, feeding system, milking method, age, lactation number and days in milk (DIM) were not used as exclusion criteria; these variables were recorded as supporting information and were included as non-genetic corrections in the statistical models when relevant. The description of the study locations, sample composition, altitude, and temperature-humidity index are include on Table 1.

The number of animals per breed was unbalanced because it reflects the actual composition of the lactating dairy goat population in the study area, in which the Saanen Crossbred predominates while purebred Saanen are kept only in small numbers. This unbalanced structure was addressed in the statistical analysis rather than by discarding records. Breed means were estimated as least-squares means from general linear models that also contained the relevant non-genetic effects, so that each mean is adjusted for the composition of its own subclass, and Duncan's multiple range test was applied to these adjusted means using the harmonic mean of the subclass sizes, which is the standard adjustment for unequal replication. Because the smallest group (Saanen, $n = 30$) determines the precision of the comparisons, breed differences were interpreted together with their standard deviations, and the multivariate analyses were performed on individual records rather than on group means, so that the dispersion within each breed, and not only the difference between breed means, could be evaluated.

The materials consisted of lactating does from the three breed, milk samples from the right and left teats and California Mastitis Test (CMT) reagent. Body and udder measurements were taken using a measuring stick and measuring tape. Rectal temperature was measured using a digital thermometer, respiratory rate using a stopwatch, environmental variables using a thermos-hygrometer and milk yield using a graduated milk container.

Table 1. Description of the study locations, sample composition, altitude, and temperature-humidity index (THI)

Farm	Breed composition (n)	Altitude (m a.s.l.)	THI		
			Morning	Noon	Afternoon
1	15 Saanen	139.82	79.42	84.13	81.35
2	7 Saanen, 45 Saanen Crossbred	676.42	77.89	81.65	79.01
3	5 Saanen, 31 Saanen Crossbred	184.78	75.95	81.91	79.52
4	34 Saanen Crossbred	171.03	81.70	81.95	81.82
5	3 Saanen, 31 Saanen Crossbred	351.68	75.90	81.90	79.50
6	2 Etawah Crossbred, 24 Saanen Crossbred	670.38	76.14	78.47	76.96
7	24 Etawah Crossbred	480.64	75.48	83.77	80.12
8	22 Etawah Crossbred	523.64	80.01	83.60	80.74

Qualitative trait observation

Qualitative characters were observed visually once for each animal while the goat was standing in a normal position. The recorded characters were coat pattern, body coat color, head coat color, head profile, ear orientation, udder shape, udder attachment, udder depth, wattles and teat shape. These descriptors were selected to characterize external appearance and udder conformation as elements of breed identity, following the phenotypic characterization principles of FAO (2012) and the qualitative categories used in previous goat characterization studies (Ilham *et al.* 2023; Mathapo *et al.* 2024), with modification to match the traits observed in the present population. The categories and definitions used for each qualitative trait are summarized in Table 2.

Table 2. Qualitative traits, categories, and definitions used for phenotypic characterization

Trait	Category	Definition
Body coat pattern	Solid	Whole body has one uniform dominant colour, without patches
	Patchy	Body has two or more colours forming patches, stripes, or an uneven distribution
Body / head coat colour	White, cream, brown, black, or mixed	Body or head dominated (>80%) by the stated colour, or a visible mixture of two or more colours

Head profile	Straight	Head profile appears flat/straight from forehead to nose
	Convex	Head profile is convexly curved
Ear orientation	Erect	Ears point upward or horizontally
	Semi-drooping	Ears partly hang downward at a moderate angle
	Drooping	Ears hang fully downward along the side of the head
Udder shape	Globular	Udder is round and symmetrical
	Bottle-shaped	Udder is elongated downward, resembling a bottle
Udder attachment	Strong / Moderate / Weak	Udder is tightly and highly attached with a clear suspensory ligament / moderately attached / loosely attached with an indistinct boundary and a pendulous appearance
Udder depth	Deep / Moderate / Shallow	Udder floor hangs close to or below the hock / midway between the abdomen and the hock / high, well above the hock
Wattles	Present / Absent	One or two wattles found, or not found, on the neck
Teat shape	Ideal	Cylindrical, normally proportioned, and well-separated teats
	Bottle-shaped	Teat enlarged, resembling a bottle
	Funnel-shaped	Teat wide at the base and narrowing toward the tip, like a funnel
	Pointed	Teat tapering to a point at the tip
	Not separated	The two teats are very close together or not clearly separated
	Pencil-shaped	Teat small and long, resembling a pencil
	Bulbous	Teat rounded and enlarged at the tip
	Large and thick	Teat large and thick in diameter
	Very small	Teat markedly smaller than normal
	Too close	Distance between the two teats is too narrow
	Sideways	Teat oriented laterally rather than vertically
	Uneven	The two teats differ in shape or size

Body morphometric measurements

Thirteen body traits were measured while goats stood normally on a flat surface, positioned squarely with all four feet bearing weight evenly, following the methods used by Husen *et al.* (2025) and Ilham *et al.* (2023) (Fig. 2). Measurements were recorded in centimetres and comprised: body length (BL; from the point of the shoulder [*tuberositas humeri*] to the pin bone [*tuber ischii*]), withers height (WH; vertical distance from the ground to the highest point of the withers, in line with the front leg), rump height (RH; from the ground to the top of the hip bone [*tuber coxae*]), chest width (CW; horizontal width of the chest immediately behind the shoulder), chest depth (CD; vertical depth of the chest immediately behind the shoulder), chest girth (CG; circumference of the chest immediately behind the *scapula*), rump depth (RD; vertical distance from the back line at the rump to the *ventral abdomen* in front of the hind leg), head length (HL; from the *anterior* point of the head to the *posterior* point of the skull), head width (HW; between the left and right lateral prominences of the skull), head height (HH; from the *dorsal* point of the skull to the lowest lateral point of the jaw), ear length (EL; from the base to the tip of the ear), ear width (EW; at the widest part of the ear), and cannon circumference (CC; at the mid-shaft of the left fore-cannon bone).

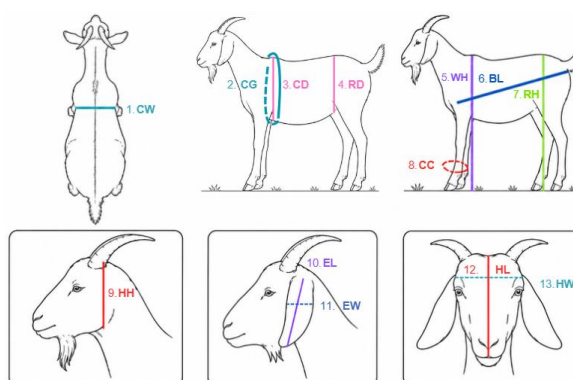


Fig. 2 Body morphometric measurements recorded in this study. 1 = chest width (CW); 2 = chest girth (CG); 3 = chest depth (CD); 4 = rump depth (RD); 5 = withers height (WH); 6 = body length (BL); 7 = rump height (RH); 8 = cannon circumference (CC); 9 = head height (HH); 10 = ear length (EL); 11 = ear width (EW); 12 = head length (HL); 13 = head width (HW).

Udder morphometric measurements

Udder morphometric measurements were taken before and after milking, following the method of Bekele *et al.* (2025) (Fig. 3). Seven udder and teat traits were recorded in centimeters using a measuring tape. First, the main udder-size traits: udder depth (UD; vertical distance from the rear udder attachment to the udder floor, midway between the two teats), udder width (UW; at the widest part of the udder), and udder circumference (UC;

measured around the mid-udder). Second, the teat-size traits: teat length (TL; from the base of teat attachment to the teat tip), teat width (TW; at the mid-point of each teat), and teat circumference (TC; measured at the mid-point of each teat). And finally, teat-floor distance (TFD; vertical distance from the tip of the lowest teat to the pen floor).

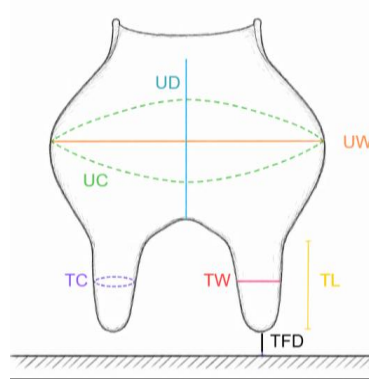


Fig. 3 Udder morphometric measurements recorded in this study. UD, udder depth; UC, udder circumference; UW, udder width; TC, teat circumference; TL, teat length; TW, teat width; TFD, teat-floor distance

Milk yield and udder health

Individual milk yield was recorded using a graduated milk measuring cup at each milking throughout the observation period, and the corresponding days in milk (DIM) were recorded for each observation. Because milk yield changes throughout lactation, individual yields recorded at different DIM cannot be compared directly. Milk yield was therefore standardized to 100 days in milk (DIM 100) using the Wood (1967) lactation curve model, $Y_t = a \times t^b \times e^{-ct}$, where Y_t is the milk yield on day t , and a , b , and c are the initial-yield, ascending, and declining lactation-curve parameters, respectively. The parameters used ($a = 1301$, $b = 0.33$, $c = 0.008$) were obtained from Saanen dairy goats reported by He *et al.* (2025); this parameter set was selected because its low c value corresponds to a persistent lactation curve after peak yield, a pattern that approximates the lactation pattern of the Saanen Crossbred under tropical conditions, in which milk yield remains relatively stable for several weeks after the lactation peak before declining (Suranindyah *et al.* 2020). DIM 100 was chosen as the standardization point because it falls within the persistency phase of lactation, after the peak yield but before a marked decline, which in Etawah Crossbred goats has been reported to begin at approximately week 16 of lactation, while DIM 100 corresponds to approximately week 14 (Suranindyah *et al.* 2018). Standardized yield was calculated as $Y_{100} = Y_{obs} \times [f(100) / f(DIM)]$, where Y_{100} is the standardized yield at DIM 100, Y_{obs} is the observed daily yield of the individual, and $f(100)$ and $f(DIM)$ are the Wood-model predictions at DIM 100 and at the individual's actual DIM, respectively. Standardized milk yield at DIM 100 was subsequently used in the statistical analysis to reduce

the confounding effect of lactation stage on the comparison of milk yield among breeds. It should be stated at this point that a single set of Saanen-derived curve parameters was applied to all three breeds because breed-specific Wood-curve parameters are not yet available for the Etawah Crossbred or the Saanen Crossbred. This is a recognized limitation of the standardization: it assumes a comparable curve shape across breeds and may therefore slightly over-correct or under-correct individual yields in the two crossbred groups, although it removes the much larger confounding effect of differences in DIM at the time of recording. The standardized values should accordingly be interpreted as comparable estimates of yield at a common lactation stage rather than as absolute breed potentials.

Udder health was assessed using the California Mastitis Test (CMT). Milk from the right and left teats was collected after discarding the first streams, and 2 mL of milk from each teat was dispensed into a CMT paddle and mixed with the CMT reagent at a 1:1 ratio. The paddle was gently rotated horizontally for 10-15 s, and the resulting change in viscosity or gel formation was scored visually as negative, trace, positive 1, or positive 2 (Fatonah *et al.* 2020).

Environmental temperature-humidity index

Environmental temperature and relative humidity were measured using a thermos-hygrometer in the morning (06:00-07:00), at noon (12:00-13:00), and in the afternoon (16:00-17:00). The temperature-humidity index (THI) was calculated as $THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$, where T is environmental temperature (°C) and RH is relative humidity (%) (NRC, 1971).

Physiological response and heat tolerance coefficient

Respiration rate and rectal temperature were recorded at the same time as the THI measurements. Respiration rate was determined by counting flank movements over 1 minute using a stopwatch and rectal temperature was measured using a digital thermometer inserted into the rectum. These physiological responses were used to calculate the heat tolerance coefficient (HTC) following the approach of Benezra (1954), which combines the two variables that reflect, respectively, heat storage and heat dissipation. In the original index each observed value is divided by the corresponding species-normal reference value, so that an animal at its normal physiological values obtains a coefficient of exactly 2.0, and coefficients above 2.0 indicate progressively poorer adaptation (Benezra 1954; Pribadi *et al.* 2021). The formula was modified here by replacing the fixed species-normal values with the mean rectal temperature and mean respiration rate recorded at each study location: $HTC = (T_b / X) + (Fr / Y)$, where T_b is the individual's rectal temperature (°C), Fr is the individual's respiration rate

(breaths/min), and X and Y are the mean rectal temperature and mean respiration rate, respectively, recorded at that location. This modification was adopted for two reasons. First, no single set of normal reference values for rectal temperature and respiration rate has been established for lactating dairy goats under Indonesian tropical conditions, whereas the reference values in the original index were derived for cattle. Second, the eight farms differed in altitude and THI, so that expressing each individual response relative to the animals exposed to the same thermal environment allows the index to compare breeds rather than farm microclimates. The interpretation of the index is unchanged: an HTC close to 2.0 indicates good heat tolerance, whereas values increasingly above 2.0 indicate greater sensitivity to heat, so that the higher the HTC, the lower the heat tolerance of the animal (Pribadi *et al.* 2021).

Statistical analysis

Data were tabulated for each individual. Quantitative data were summarized as means $\pm$ standard deviation, and qualitative data and CMT results were summarized as frequencies and percentages, using Microsoft Excel 2021 and R version 4.5.2 (R Core Team 2025) implemented through RStudio (Posit Software, PBC, Boston, MA, USA). Body and udder morphometric traits were analysed using a general linear model (GLM) fitted with the `lm()` function in R. The body morphometric model included breed and age category as fixed effects: $Y_{ij} = \mu + B_i + A_j + \epsilon_{ij}$, where Y_{ij} is the observed value of the body morphometric trait, μ is the overall mean, B_i is the effect of breed i , A_j is the effect of age category j , and ϵ_{ij} is the random residual error. The udder morphometric model included breed and lactation stage as fixed effects and days in milk (DIM) as a covariate: $Y_{ijk} = \mu + B_i + L_j + \beta(X_{ijk} - \bar{X}) + \epsilon_{ijk}$, where L_j is the effect of lactation stage j , β is the regression coefficient of the trait on DIM, X_{ijk} is the DIM at the time of measurement, and $\bar{X}$ is the mean DIM across the sampled population. Standardized milk yield at DIM 100 was analysed using a GLM with breed and lactation stage as fixed effects. Differences among breeds were tested using Duncan's multiple range test through the *agricolae* package (de Mendiburu 2023). Results are presented as means $\pm$ standard deviation, with different superscripts within a row indicating a significant difference at $P < 0.05$.

Principal component analysis (PCA) was applied separately to the body and udder morphometric traits to reduce data dimensionality and identify the variables contributing most to phenotypic variation, using the function of the *FactoMineR* package (Husson *et al.* 2023) and visualized with *factoextra* (Kassambara and Mundt 2020). Sampling adequacy was assessed using the Kaiser-Meyer-Olkin (KMO) statistic and Bartlett's test of sphericity, computed with the *psych* package (Revelle 2024); components with an eigenvalue greater than 1 were retained (Kaiser criterion). Multiple correspondence analysis was applied to the qualitative traits using the

function of FactoMineR (Lê *et al.* 2008; Abdi and Valentin 2007) to evaluate relationships among qualitative categories. Factor analysis of mixed data applied using the function of FactoMineR, was used to analyse the quantitative and qualitative variables simultaneously by combining the principles of PCA and MCA. Individual and variable plots for all multivariate analyses were produced using the fviz* functions of the factoextra package, with individuals coloured by breed group.

(d) Results and discussions

Qualitative traits and multivariate phenotypic structure

Qualitative traits showed clear differences among the three breeds (Table A5). Etawah Crossbred goats were fixed for a bottle-shaped udder (100%), a drooping ear (100%), a convex head profile (100%), and the absence of wattles (100%), whereas Saanen goats were fixed for a globular udder (100%), an erect ear (100%), a straight head profile (100%), a solid white coat (100%), and a white head colour (100%). Saanen Crossbred goats were considerably more heterogeneous: most individuals had a globular udder (99.4%), a solid coat pattern (80.0%), a straight head profile (57.6%), and a white body coat (63.6%), indicating that the Saanen Crossbred phenotype for these traits resembles Saanen more closely than Etawah Crossbred. However, residual Etawah Crossbred-type traits remained evident in the Saanen Crossbred population, particularly for ear orientation, where only 43.6% of individuals had fully erect ears, while 33.9% had semi-drooping and 22.4% had fully drooping ears, and for head profile, where 42.4% retained a convex profile characteristic of Etawah Crossbred. Coat colour was also more variable in the Saanen Crossbred than in either parental breed, including cream (12.7%), brown (3.0%), black (3.6%), and mixed (17.0%) body-coat colours that were largely or entirely absent in Saanen and much less frequent, for most categories, than in Etawah Crossbred. Etawah Crossbred goats had a distinctive drooping ear and convex head profile, consistent with its established visual identity as an Indonesian tropical goat type, whereas Saanen goats had a uniformly erect ear, straight head profile, and white coat, consistent with its identity as a specialized temperate dairy breed. This heterogeneity within the Saanen Crossbred population is consistent with the largely uncontrolled mating that has characterized its expansion in Indonesia, which has meant that a stable, uniform qualitative phenotype has not yet been established for this crossbred.

Multiple correspondence analysis (MCA) of the qualitative traits (Fig. 4) showed that the first two dimensions explained a limited proportion of total variance (Dim1 = 14.8%, Dim2 = 8.3%; cumulative 23.1%), indicating that qualitative variation in this population was not dominated by one or two simple patterns. Etawah Crossbred goats were clearly separated from Saanen and most Saanen Crossbred individuals along Dim1, consistent with their distinctive combination of drooping ears, a convex head profile, a black head colour, the absence of wattles, and

a weaker udder attachment. Saanen goats formed a comparatively tight cluster, reflecting the fixed expression of several qualitative traits in this breed, whereas Saanen Crossbred goats showed the widest dispersion of all three breeds: although a large proportion of Saanen Crossbred individuals overlapped with Saanen, a distinct subgroup was positioned separately, indicating internal qualitative heterogeneity within the Saanen Crossbred population. A similarly broad dispersion of qualitative traits within a crossbred or composite goat population has been reported using MCA for Bligon goats in different agroecological zones (Budisatria *et al.* 2022).

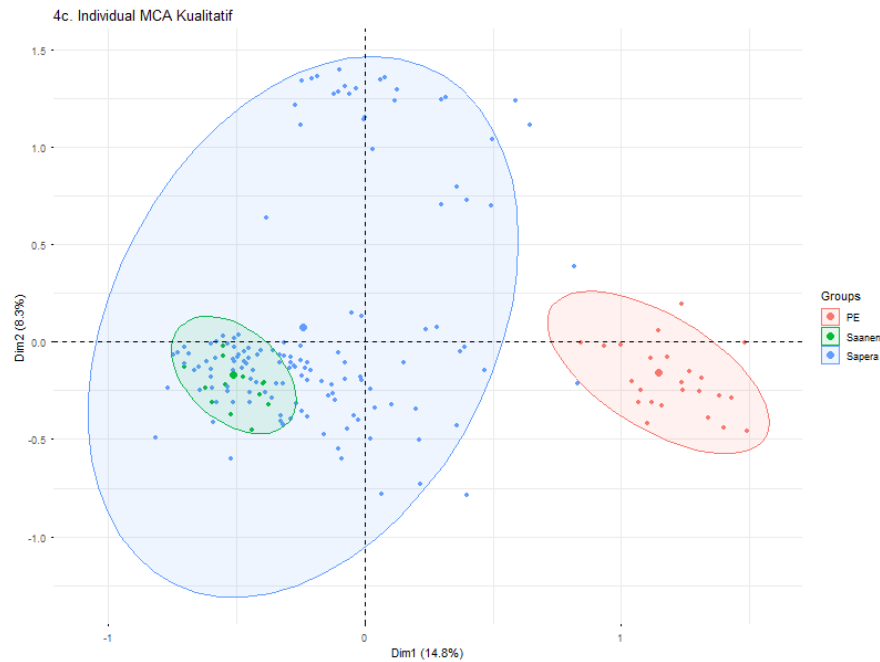


Fig. 4 Multiple correspondence analysis (MCA) of qualitative traits, showing the distribution of Etawah Crossbred, Saanen, and Saanen Crossbred individuals based on qualitative trait categories

Body morphometry

Breed significantly affected all body morphometric traits ($P < 0.01$), except rump depth, which did not differ significantly among breeds ($P = 0.14$) (Table A1). Age category also affected several traits, including ear length, head width, withers height, body length, chest depth, chest girth, and rump height ($P < 0.05$)

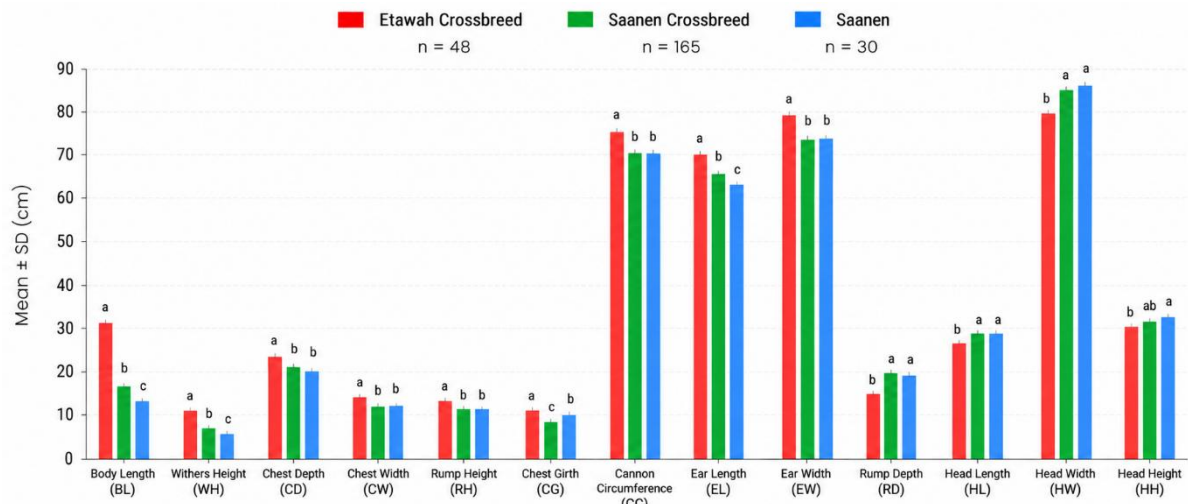


Fig. 5 Body morphometric traits of Etawah Crossbred, Saanen Crossbred, and Saanen goats. Bars sharing no common letter differ significantly ($P < 0.05$).

Etawah Crossbred goats were the largest of the three breeds for frame, head and ear dimensions, whereas Saanen Crossbred and Saanen goats exceeded them in chest width, chest depth and chest girth (Table A1; Fig. 5). Biologically, these two patterns describe two different body plans: a taller, longer and comparatively leaner frame in Etawah Crossbred, consistent with a dual-purpose goat in which body size contributes to both meat and milk output, and a more developed thoracic capacity in the two dairy-type groups, which provides greater space for the heart, lungs and digestive tract and is therefore associated with the capacity to sustain the feed intake and metabolic load of higher milk production (Assefa *et al.* 2023). The large frame, head and ear dimensions of Etawah Crossbred are consistent with its established phenotypic identity as a large-bodied, long-eared Indonesian goat (Ilham *et al.* 2023; Azizah *et al.* 2024). The position of the Saanen Crossbred differed between the two trait groups: it was intermediate between its parental breeds for ear size, indicating that ear conformation still carries a detectable Etawah Crossbred influence, but was close to Saanen for head dimensions, withers height, rump height and all chest measurements (Table A1). The biological implication is that the traits governing dairy function have shifted towards Saanen, while several of the traits that are most visible to farmers and used informally to identify a goat by eye have not, in agreement with Abdurrahman *et al.* (2023), who reported that the Saanen Crossbred is genetically closer to Saanen than to Etawah Crossbred on the basis of canonical analysis.

Principal component analysis of the 13 body morphometric traits was adequate for dimension reduction ($KMO = 0.57$; Bartlett's test $P < 0.05$) and extracted three components with an eigenvalue greater than 1, together explaining 66.79% of the total variance (Table A2). PC1 grouped withers height, body length, rump

height and the head and ear dimensions and can therefore be interpreted as an overall frame and head/ear size axis, indicating that these traits vary together as a single size complex rather than independently; a comparable frame-dominated first component has been reported for Ganjam goats, in which ear length loaded instead on a separate component (Karna *et al.* 2024). PC2 grouped chest depth, chest width, chest girth and rump depth, representing thoracic capacity, and separated the two dairy-type groups from Etawah Crossbred. PC3 was associated mainly with head height and contrasted with withers and rump height, indicating that head shape varies partly independently of overall body size. The biological implication is that body conformation in this population is organized along two largely independent axes, overall size and thoracic capacity, so that selection for a dairy-type conformation can act on thoracic development without necessarily altering frame size.

In the score plot of the body morphometric PCA (Fig. 6), Etawah Crossbred goats were positioned mainly along PC1, reflecting their larger frame and head/ear dimensions, whereas Saanen Crossbred and Saanen goats were positioned mainly along PC2, reflecting their greater thoracic capacity, and overlapped substantially with one another. This overlap indicates that, in terms of overall body conformation, the Saanen Crossbred more closely resembles Saanen than Etawah Crossbred, although some individuals occupied an intermediate position, consistent with residual Etawah Crossbred influence in a population where crossbreeding has not been fully standardized.



Fig. 6 Principal component analysis (individual score plot) of body morphometric traits, showing the distribution of Etawah Crossbred, Saanen, and Saanen Crossbred individuals along PC1 and PC2.

Udder morphometry

Breed significantly affected nearly all udder and teat traits, both before and after milking, except udder depth before milking, which did not differ significantly among breeds ($P = 0.32$) (Table A3; Fig. 7).

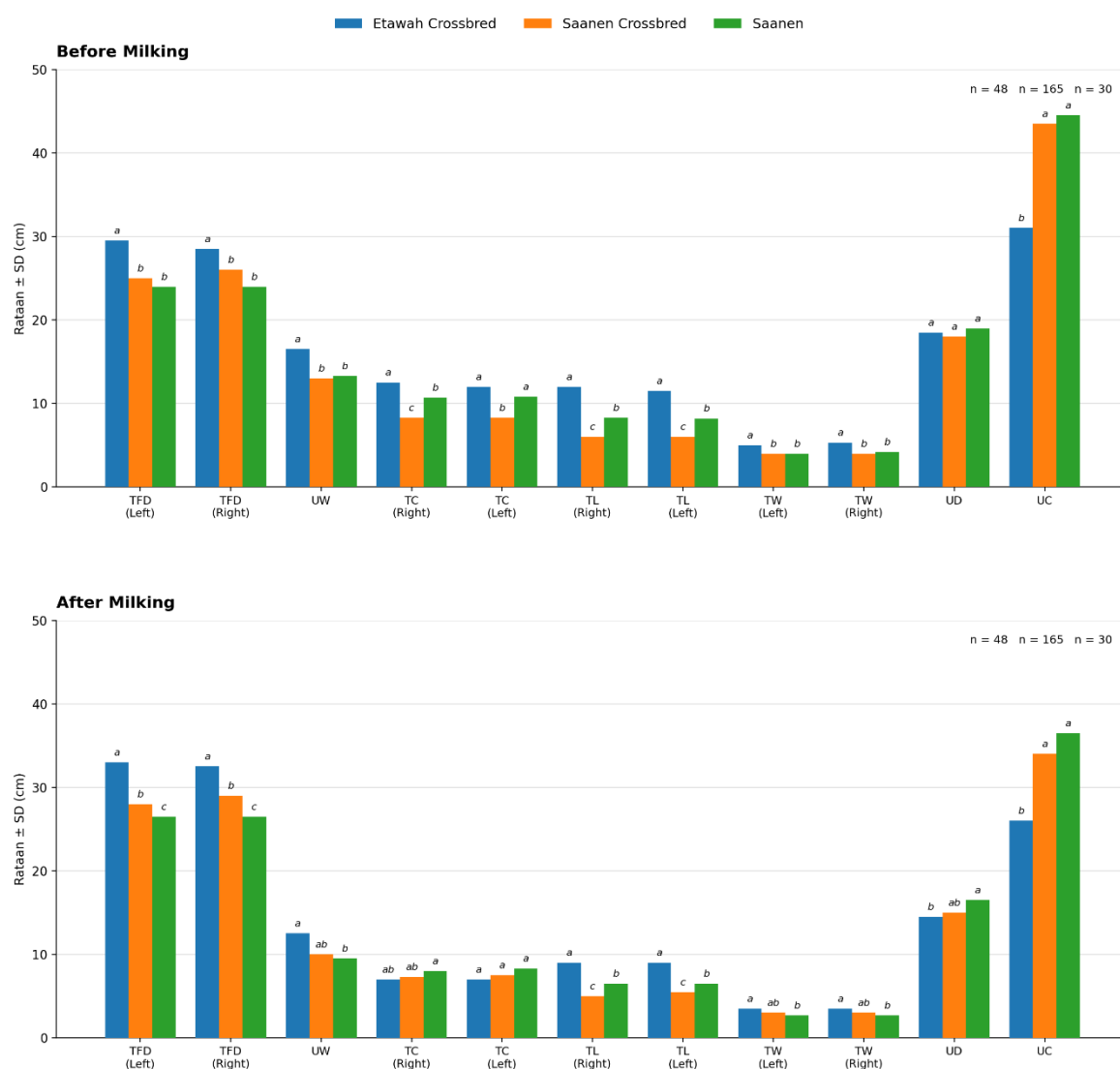


Fig. 7 Udder and teat morphometric traits of Etawah Crossbred, Saanen Crossbred, and Saanen goats, before and after milking. Bars sharing no common letter differ significantly ($P < 0.05$).

Saanen and Saanen Crossbred goats had a greater udder circumference than Etawah Crossbred goats, both before and after milking (Table A3; Fig. 7), indicating more developed secretory tissue and a greater milk storage capacity in the two dairy-type groups. This is consistent with reports that udder circumference is among the udder traits most strongly associated with milk yield in dairy goats (Bekele *et al.* 2025), and that udder and teat morphometrics can serve as simple, low-cost indicators for predicting yield and for selecting dairy does under smallholder conditions (Guyo and Tareke 2025). In practical terms, udder circumference measured before milking is therefore a candidate field indicator for the initial screening of Saanen Crossbred

does, because it can be recorded with a measuring tape during the routine milking without additional equipment.

In contrast, Etawah Crossbred goats had the largest teat dimensions, with teat length, teat width and teat circumference before milking all greater than in Saanen Crossbred and Saanen goats (Table A3). Etawah Crossbred goats also had a greater udder width than the other two breeds, indicating a more laterally expanded udder, although this does not necessarily reflect a greater udder capacity, since their udder circumference was comparatively low. Husen *et al.* (2025) noted that udder size before milking reflects milk storage capacity, whereas the change in udder dimensions after milking indicates the elasticity of udder tissue across the milking cycle. These differences in teat conformation have direct consequences for milking efficiency. Udder and teat morphology determine cluster attachment, vacuum distribution, teat-end stress, milk flow and the risk of environmental contamination during milking, and excessively long or funnel-shaped teats have been associated with incomplete milking, liner slip, teat-end irritation and elevated somatic cell counts, whereas shorter and more cylindrical teats are better suited to machine milking (Weidel *et al.* 2026). The comparatively short teats of the Saanen Crossbred, together with a high proportion of ideal, cylindrical teats and few bottle-shaped teats relative to Etawah Crossbred (Table A5), therefore represent a favourable conformation for machine milking, whereas the long, bulbous and bottle-shaped teats that were frequent in Etawah Crossbred are more suited to hand milking. The substantial proportion of funnel-shaped teats within the Saanen Crossbred (36.97%), however, is an unfavourable conformation that should be selected against if machine milking is to be adopted more widely in this population.

Teat-floor distance, both before and after milking, was greatest in Etawah Crossbred goats and lowest in Saanen goats, with Saanen Crossbred goats intermediate. The lower teat-floor distance in Saanen can be related to its larger udder circumference, since a larger and heavier udder is positioned closer to the floor. After milking, teat-floor distance increased in all breeds, reflecting the reduction in udder volume and weight following milk removal, which raises the position of the teat. Ahlem *et al.* (2023) reported a negative relationship between teat height from the floor and milk yield in Tunisian local goats, indicating that does with a greater udder capacity tend to have a lower teat position, consistent with the pattern observed here. From the perspective of selecting dairy does, this relationship implies a trade-off: the does with the greatest udder capacity also carry the udder closest to the pen floor, which increases exposure of the teat end to bedding, faeces and urine. Selection within this population should therefore combine udder circumference as an indicator of capacity with udder attachment and teat-floor distance as indicators of structural support,

rather than selecting for udder size alone; udder and teat conformation traits show moderate to high heritability in dairy goat populations and are therefore relevant as phenotypic selection criteria (Weidel *et al.* 2026).

PCA of the udder and teat traits produced a KMO value of 0.83, indicating a strong correlation structure suitable for dimension reduction. Five components with an eigenvalue greater than 1 together explained 79.81% of the total variance (Table A4). PC1 (38.82%) had high loadings for nearly all teat dimensions, most strongly right teat width before milking (0.83), right teat circumference before milking (0.82), and left teat circumference before milking (0.80), and can be interpreted as a teat-size axis; this interpretation is consistent with the GLM results showing that Etawah Crossbred had larger teat dimensions than Saanen Crossbred and Saanen goats. PC2 (19.53%) had high positive loadings for teat-floor distance (both sides, before and after milking) and high negative loadings for udder circumference (before and after milking), indicating that PC2 represents an axis contrasting udder position with udder capacity: individuals with a larger udder circumference tended to have a lower teat position, and vice versa. PC3 (10.82%) had high loadings for udder width and udder depth, representing udder dimension independent of teat size, indicating that teat size and udder dimension do not necessarily vary together: an animal may have large teats without having the largest udder width or depth. PC4 and PC5 explained comparatively small proportions of variance (5.61% and 5.03%, respectively) and were associated mainly with residual variation in teat circumference and width after milking.

In the score plot of the udder morphometric PCA (Fig. 8), Etawah Crossbred goats were separated mainly along PC1, reflecting their larger teat dimensions, whereas Saanen and Saanen Crossbred goats were separated mainly along PC2, reflecting their larger udder circumference and lower teat-floor distance. Saanen Crossbred goats overlapped with Saanen along these axes but were more widely dispersed, indicating a less uniform udder phenotype than Saanen.



Fig. 8 Principal component analysis (individual score plot) of udder and teat morphometric traits, showing the distribution of Etawah Crossbred, Saanen, and Saanen Crossbred individuals along PC1 and PC2

Factor analysis of mixed data (FAMD), which integrated the quantitative and qualitative variables from the sections above in a single analysis (Fig. 9), confirmed that Saanen Crossbred goats overlapped with Saanen for several combined quantitative-qualitative traits but did not form a fully separate, compact cluster. Because PCA alone describes only the quantitative structure and MCA describes only the qualitative structure, FAMD was necessary to show that the resemblance of the Saanen Crossbred to Saanen in body and udder conformation was accompanied by only a partial convergence of qualitative appearance, indicating that the population has not yet reached a stable, uniform dairy-type phenotype.

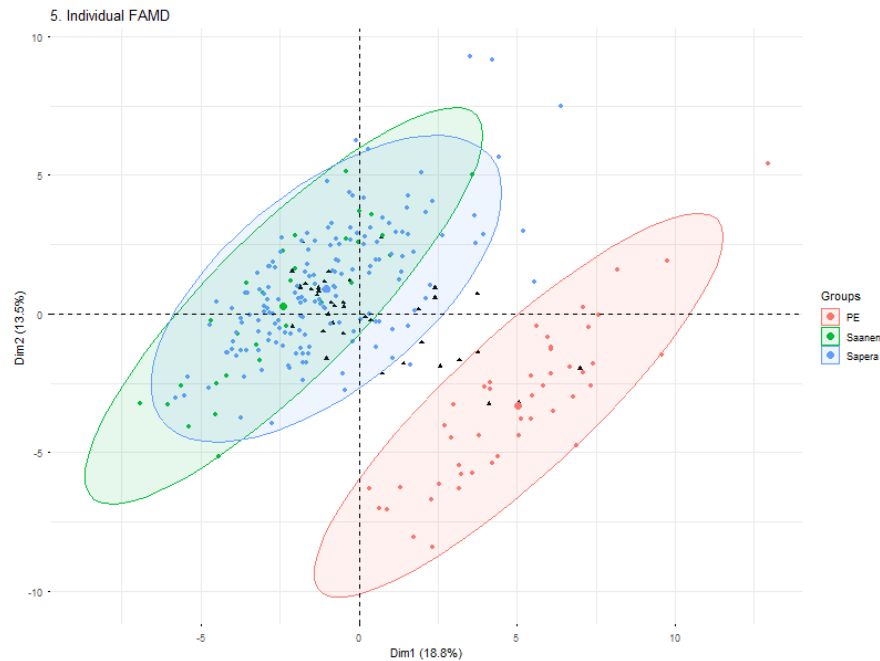


Fig. 9 Factor analysis of mixed data (FAMD) integrating quantitative and qualitative traits, showing the distribution of Etawah Crossbred, Saanen, and Saanen Crossbred individuals

The morphometric and qualitative results (Table A1, Table A3, Table A5; Fig. 4, Fig. 5) indicate that the Saanen Crossbred inherited its coat colour pattern (predominantly white), globular udder shape, larger udder circumference, greater thoracic capacity, and, in most individuals, a straight head profile from Saanen, whereas a residual influence of Etawah Crossbred was most evident in ear orientation (with a considerable proportion of semi-drooping or drooping ears), in head profile for a substantial minority of individuals, and in a wider range of coat colours than in either parental breed. This combination indicates that the Saanen Crossbred is not simply an even intermediate between its parental breeds, but rather a population in which Saanen-type traits currently predominate for most dairy-related characteristics, while several external and structural traits still carry a detectable Etawah Crossbred influence, consistent with a population still shaped by uncontrolled mating rather than a directed breeding programme.

Milk yield and udder health

Standardized milk yield at DIM 100 differed significantly among breeds ($P < 0.01$; Table A6; Fig. 10a). Saanen goats had the highest standardized yield (2411.07 ± 171.87 mL/day), Saanen Crossbred goats were intermediate (1676.88 ± 121.45 mL/day), and Etawah Crossbred goats had the lowest yield (966.87 ± 142.56 mL/day). The milk yield of Etawah Crossbred goats in this study is comparable to the 960 ± 340 mL/day previously reported for intensively managed Etawah Crossbred goats (Suranindyah *et al.* 2020); Etawah Crossbred is generally regarded as a dual-purpose goat, so its milk yield is inherently lower than that of specialized dairy

breeds, although Etawah Crossbred remains widely kept in Indonesia because of its tropical adaptability and consistent milk production (Suranindyah *et al.* 2018). The standardized yield of the Saanen Crossbred was close to the 1674.00 ± 122.77 mL/day previously reported for the breed (Suranindyah *et al.* 2018), while the yield of Saanen goats fell within the 1.14-2.52 L/day range previously reported for Saanen in Indonesia (Yudi and Atabany 2021). These comparisons support the reliability of the standardized milk yield values obtained in this study, although the use of Saanen-specific Wood-curve parameters for all three breeds remains a limitation of the standardization approach and should be refined once breed-specific lactation-curve parameters become available for Etawah Crossbred and the Saanen Crossbred. Overall, the position of the Saanen Crossbred between Etawah Crossbred and Saanen indicates that crossbreeding has increased milk yield relative to Etawah Crossbred, but production has not yet reached the level of Saanen, in line with the observation that the performance of Saanen Crossbred goats on smallholder farms remains variable because the genetic contribution of the parental sires and dams used is not always controlled (Suranindyah *et al.* 2018).

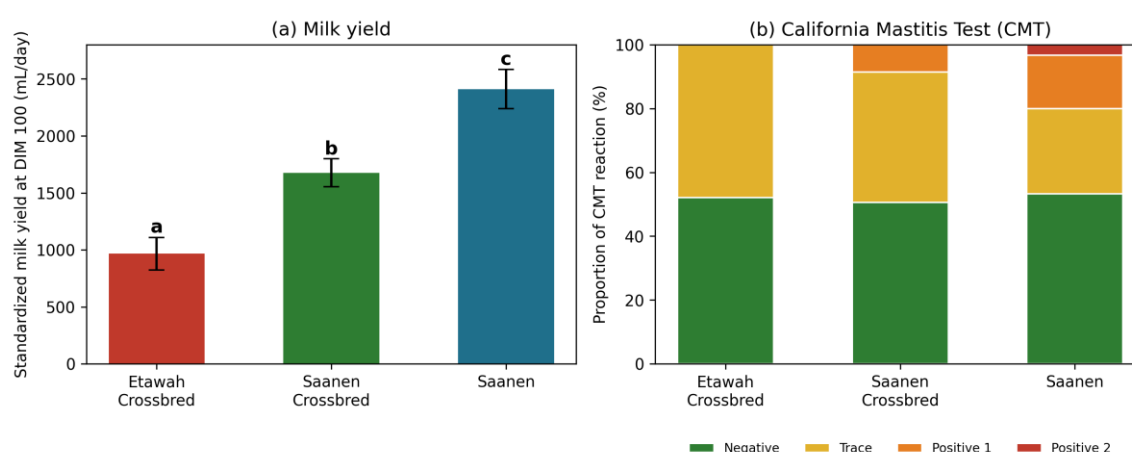


Fig. 10 (a) Standardized milk yield at 100 days in milk (DIM 100) and (b) California Mastitis Test (CMT) results of Etawah Crossbred, Saanen Crossbred, and Saanen goats. Bars sharing no common letter in (a) differ significantly ($P < 0.05$).

Udder health, assessed using the California Mastitis Test (CMT), showed the highest proportion of positive reactions in Saanen (16.67% positive 1, 3.33% positive 2), followed by the Saanen Crossbred (8.54% positive 1, no positive 2), while Etawah Crossbred goats showed no positive reaction, although a high proportion of Etawah Crossbred goats (47.92%) showed a trace reaction (Table A6; Fig. 10b). This pattern corresponds with the udder morphometric results reported above: Saanen had the largest udder circumference and the lowest teat-floor distance among the three breeds, indicating that its udder is both larger and positioned closer to the floor. A lower teat position increases the likelihood of contact with the floor, faeces, urine, or damp bedding, which may increase

the risk of bacterial contamination at the teat end and could partly explain the higher CMT-positive prevalence in Saanen, in addition to other contributing factors such as hygiene, milking practice, parity, and lactation stage. The intermediate CMT-positive prevalence in the Saanen Crossbred is consistent with its intermediate udder circumference and teat-floor distance relative to Etawah Crossbred and Saanen, while the absence of positive CMT reactions in Etawah Crossbred goats corresponds with their considerably greater teat-floor distance, which keeps the teat further from potential sources of environmental contamination.

Thermal adaptation: temperature-humidity index, physiological response, and heat tolerance coefficient

Environmental conditions across the eight farms were consistently warm. Morning THI ranged from 75.48 to 81.70, noon THI from 78.47 to 84.13, and afternoon THI from 76.96 to 81.82 (Table 1), which falls within the moderate-to-severe heat-stress range for dairy goats (moderate stress, $72 \leq \text{THI} < 88$; severe stress, $\text{THI} \geq 89$) (Ivanova and Hristev 2023). Even the farm with the lowest noon THI (Farm 6, $\text{THI} = 78.47$) still represented a thermally challenging environment for dairy goats. Under humid tropical conditions, an elevated THI limits sensible heat loss and can therefore increase body temperature and respiration rate (Ali *et al.* 2023).

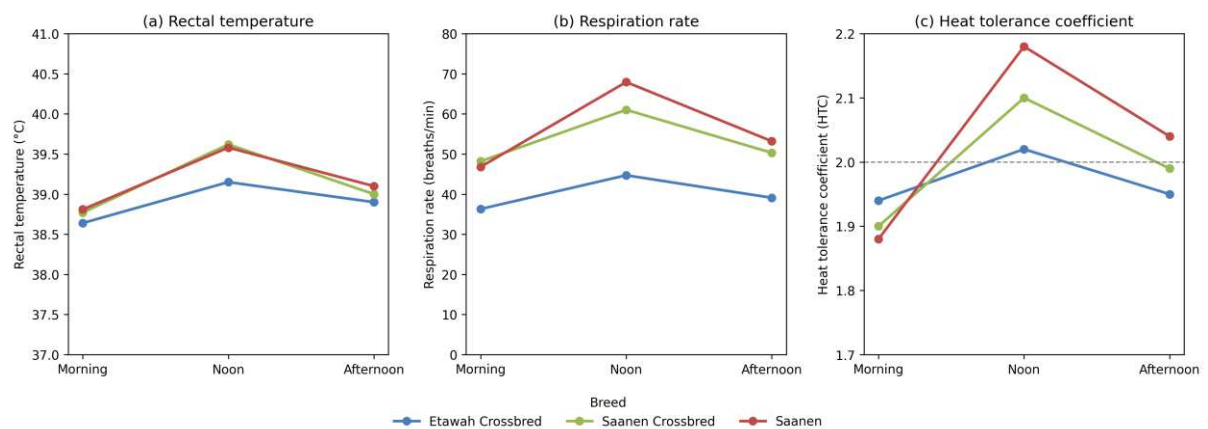


Fig. 11 (a) Mean rectal temperature, (b) mean respiration rate, and (c) mean heat tolerance coefficient (HTC), in the morning, at noon, and in the afternoon, in Etawah Crossbred, Saanen Crossbred, and Saanen goats. The dashed line in (c) marks $\text{HTC} = 2.0$, the reference value for good heat tolerance.

Rectal temperature increased from morning to noon in all three breeds: from 38.64 to 39.15 °C in Etawah Crossbred, from 38.81 to 39.58 °C in Saanen, and from 38.77 to 39.62 °C in Saanen Crossbred goats, before decreasing in the afternoon to approximately 38.9, 39.1, and 39.0 °C, respectively (Fig. 11a). Because rectal temperature reflects core body temperature, this increase indicates that the ambient heat load affected the thermal balance of all three breeds. Etawah Crossbred goats had the lowest noon rectal temperature, indicating a comparatively greater ability to maintain a stable core temperature under high THI, which may be related to the long-term adaptation of Etawah Crossbred to Indonesian tropical conditions. Saanen and Saanen Crossbred goats

showed higher noon rectal temperatures (39.58 °C and 39.62 °C, respectively), indicating greater heat accumulation in these two breeds; the marginally higher noon rectal temperature in the Saanen Crossbred compared with Saanen may reflect ambient variation among farms rather than a consistent breed effect, given the small difference between the two groups.

Respiration rate at noon was highest in Saanen (67.93 breaths/min), intermediate in Saanen Crossbred (61.02 breaths/min), and lowest in Etawah Crossbred goats (44.70 breaths/min), before decreasing in the afternoon to approximately 39, 50, and 53 breaths/min, respectively (Fig. 11b), indicating that Saanen required the greatest physiological effort to dissipate heat through panting once other avenues of heat loss, such as conduction and convection, became insufficient, consistent with the general pattern that an elevated respiration rate reflects a greater reliance on evaporative heat loss under thermal load (Shirley *et al.* 2024).

The heat tolerance coefficient (HTC) followed the same diurnal pattern, increasing at noon in all three breeds (Fig. 11c). Etawah Crossbred goats had an HTC of 1.94 in the morning, 2.02 at noon, and 1.95 in the afternoon; Saanen Crossbred goats had an HTC of 1.90, 2.10, and 1.99; and Saanen goats had an HTC of 1.88, 2.18, and 2.04, at the same respective times. Because an HTC close to 2.0 indicates good heat tolerance, Etawah Crossbred goats showed the most stable response across the day, remaining closest to this reference value at all three time points, whereas Saanen showed the greatest deviation, particularly at noon. The Saanen Crossbred was intermediate, with a noon HTC (2.10) lower than Saanen but higher than Etawah Crossbred, indicating a partial improvement in heat tolerance relative to Saanen without fully reaching the stability shown by Etawah Crossbred. This pattern is consistent with the general observation that highly productive dairy goat genotypes tend to be more physiologically sensitive to a warm environment than genotypes selected primarily for adaptability (Danso *et al.* 2024).

(e) Conclusion

This study shows that the Saanen Crossbred is phenotypically closer to Saanen than to Etawah Crossbred, particularly for the traits related to dairy function, while retaining a detectable Etawah Crossbred influence in external appearance. Standardized milk yield, heat tolerance coefficient and udder health status of the Saanen Crossbred were intermediate between the two parental breeds, indicating that crossbreeding has raised milk production above the level of Etawah Crossbred while improving thermal stability relative to Saanen. The Saanen Crossbred is therefore a promising dairy goat for tropical smallholder conditions, although the population is not yet phenotypically uniform. In practical terms, the results provide a phenotypic basis for establishing selection criteria and breeding standards for Saanen Crossbred goats in Indonesia: udder circumference, thoracic

dimensions, teat conformation and teat-floor distance can be recorded in the field with simple equipment and used to screen candidate does, while the HTC derived from rectal temperature and respiration rate provides a low-cost indicator for identifying individuals that maintain thermal stability under a high THI. A directed breeding programme supported by such recording is required to improve phenotypic uniformity and to stabilize the dairy-type characteristics of this population. Further research relating specific phenotypic markers to individual milk production and heat adaptability would allow these field indicators to be weighted objectively within selection programmes.

(f) Acknowledgements

The authors thank the dairy goat farmers in the Special Region of Yogyakarta for their cooperation during field sampling, namely the PPT Faculty of Animal Science, Universitas Gadjah Mada; Merapi Farm; Prabhu Farm; Ganesha Farm; Goatday; Satoloka; and the smallholder dairy goat farmers of Girimulyo and Samigaluh Districts, Kulon Progo Regency.

(g) Statement of Animal Rights

This research has been reviewed and approved by the Ethics Committee of Universitas Gadjah Mada and has obtained ethical clearance with reference number 38/EC-FKH/int./2026. All procedures involving animals were conducted in accordance with the ethical standards and guidelines for the care and use of animals in research, as stipulated by the committee.

(h) Conflict of Interest Statement

The authors declare that they have no conflict of interest.

(i) Data Availability

The authors declare that there are any data availability that can accessed by requirement.

(j) References

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