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Phenotypic Variation in Body Measurements and Their Associations with Body Condition Score in Bali Cattle

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Abstract. *Body condition score (BCS) and linear body measurements are the two records most often collected at Indonesian cattle breeding stations, yet they are seldom analysed together. This study described the phenotypic variation of chest circumference (CC), body length (BL), body height (BH) and BCS, and quantified the association between BCS and each body measurement in Bali cattle (Bos javanicus) aged 1-2 years at UPTD PTHPT Api-Api, East Kalimantan, Indonesia. Fifty-five animals were measured once, and BCS was assessed visually and by palpation on a 1-5 scale. Means, standard deviations, coefficients of variation (CV) with 95% confidence intervals (CI), Pearson correlation coefficients and simple linear regressions were computed. Mean CC, BL, BH and BCS were 134.54 ± 19.86 cm, 101.72 ± 15.14 cm, 103.22 ± 10.22 cm and 3.51 ± 0.72, respectively. BCS was the most variable trait (CV 20.61%), CC and BL were intermediate (14.76% and 14.88%), and BH was the most uniform (9.90%). BCS correlated positively with CC (r = 0.73; 95% CI 0.58-0.83), BL (r = 0.77; 0.63-0.86) and BH (r = 0.78; 0.65-0.87), all at P < 0.001. A single body measurement explained 53-61% of the variance in BCS, but the standard error of estimate (0.45-0.50 score units) was close to half a scoring step. Larger heifers in this herd also carried more body reserves, and tape and stick measurements can support, but not replace, direct condition scoring. Individual age, physiological status and repeated records are needed before these relationships are used for selection or built into automated monitoring tools.*

Keywords: *Bali cattle, Body condition score, Coefficient of variation, Morphometry, Precision livestock farming*

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INTRODUCTION

Bali cattle (*Bos javanicus*) are the domesticated form of the banteng and the most widely kept indigenous beef breed in Indonesia. They are valued by smallholders for high fertility, tolerance of heat and poor-quality forage, and lean carcasses, and they form the backbone of government breeding programmes outside Bali Island (Widyas et al., 2022). East Kalimantan has expanded its Bali cattle population through provincial breeding centers that distribute heifers and bulls to farmer groups, often on land shared with oil palm plantations or reclaimed coal-mine areas. The quality of the heifers leaving these centers shapes the reproductive performance of village herds for years afterwards, so the centers need simple and reliable ways to describe and rank young females.

Two kinds of records are available almost everywhere. Linear body measurements, such as chest circumference, body length and body height, describe the skeletal frame and overall size of an animal; they are cheap to take with a tape and a measuring stick and are widely used to predict live weight in Bali cattle (Azis et al., 2023; Widyas et al., 2021). Body condition score (BCS) is a subjective rating of fat and muscle cover over defined anatomical points. It responds to feed supply within weeks and is closely tied to fertility, because both thin and over-conditioned females show poorer ovarian function and embryo quality (Bezdíček et al., 2020). Body measurements therefore describe how big an animal is, while BCS describes how well covered it is. In growing heifers the two are expected to be related, since well-fed animals grow faster and also deposit more reserves, but the strength of that relationship in Bali cattle under station management is poorly documented.

Most morphometric studies of Bali cattle have focused on body weight prediction, zoometric indices or breed-standard conformity (Nasihin et al., 2025; Rahmi et al., 2025; Warman et al., 2023), and BCS is usually reported only as a mean value. Where BCS and body measurements have been examined together, the work has concerned mature cows or other breeds (Kojima et al., 2022; Vanvanhossou et al., 2018). Two practical questions remain open for young Bali females. The first is how much of the variation among animals of similar age lies in frame size and how much in condition; the coefficient of variation (CV) allows these traits, recorded on different scales, to be compared directly. The second is whether a tape or stick measurement carries enough information about condition to be useful in the field, or in image-based and sensor-based monitoring systems

that estimate body dimensions automatically (Aquilani et al., 2022; Xiong et al., 2023). Unlike body weight prediction, which estimates total live body mass from morphometric traits, BCS estimation assesses body fat and muscle reserves. Therefore, the relationships between body measurements and BCS should be interpreted as phenotypic associations rather than direct evidence of predictive accuracy or genetic relationships, since the present study describes phenotypic variation and correlations without estimating genetic parameters such as heritability, genetic correlations, or breeding values.

This study therefore aimed to describe the phenotypic variation of chest circumference, body length, body height and BCS in Bali cattle aged 1-2 years at UPTD PTHPT Api-Api, East Kalimantan, with interval estimates for both means and CVs, and (ii) quantify the correlation and linear relationship between BCS and each body measurement, including the precision with which BCS can be estimated from a single measurement. The results are intended as baseline information for heifer evaluation at the station and for the design of low-cost monitoring tools for Bali cattle breeding.

LITERATURE REVIEW

Indonesian beef cattle breeds differ clearly in body size and shape (Adinata et al., 2023). Qualitative traits such as coat color, the white rump patch and leg stockings are still used to judge breed purity and to separate populations of different origin (Hayanti et al., 2022; Maele et al., 2024). Quantitative traits complement these descriptions. Body measurements of female Bali cattle vary between regions and management systems, and indices derived from them, such as the body length index and thoracic development, have been proposed as selection criteria for breeding females (Baliarti et al., 2023; Rahmi et al., 2025; Warman et al., 2023). Studies in Samarinda and at a national testing station have described the body size variation of Bali cattle and related it to productivity and to the quantitative breed standard (Nasihin et al., 2025; Rahmatullah, 2023).

Genetic parameters have been estimated for body weight and body size of yearling Bali cattle (Chaerunissa & Nurgiartiningsih, 2022). Female Bali cattle body weight estimation method using chest girth and body length data (Erni et al., 2026). Including them in genetic evaluation improves the accuracy of selection for weight (Nurgiartiningsih et al., 2026). Their value as predictors of live weight is well established, and chest girth alone can predict weight with acceptable accuracy in native Indonesian cattle (Hartati & Putra, 2022). However, prediction equations depend on breed, sex and

age, and they lose accuracy when transferred between populations (Firdaus et al., 2023; Heinrichs et al., 2017). The same caution applies to any relationship between body measurements and BCS.

BCS summarises energy reserves and is strongly linked with reproduction. Cows scored about 3.0–3.5 on a five-point scale show the best ovarian response and embryo quality, whereas both lower and higher scores are associated with poorer results (Bezdíček et al., 2020). In Bali cattle, maternal BCS has been positively correlated with calf birth weight (Zulkharnaim et al., 2025). The main weakness of BCS is its subjectivity: agreement between trained human scorers can be modest (O'Mahony et al., 2023). This has motivated work on objective proxies, ranging from heart girth measured with a tape (Kojima et al., 2022) to depth cameras and machine-learning models that estimate BCS and body weight from images (O'Mahony et al., 2023; Xiong et al., 2023). Such tools are being adapted to pasture-based systems (Aquilani et al., 2022), but they need reference data from the breeds and production settings where they will be used.

RESEARCH METHODS

Study site and animals

The study was carried out at the Technical Implementation Unit for Livestock Breeding and Forage Feed (UPTD PTHPT) Api-Api, East Kalimantan Province, Indonesia, a government breeding center for Bali cattle. The study population consisted of 55 Bali cattle aged 1-2 years, identified from station records. All animals were kept under the routine station management of grazing on improved pasture supplemented with cut and carry forage an intensive feeding system. The study was observational; no treatment was applied, and handling was limited to restraint in a crush for measurement. Primary data (body measurements and BCS) were collected directly, and age and identity were taken from station records (secondary data).

Body measurements

Each animal was measured once while standing squarely on level ground with the head in a natural position. Chest circumference (CC) was measured with a flexible measuring tape around the thorax immediately behind the forelimbs. Body length (BL) was measured as the straight distance from the point of the shoulder (tuberculum humeri) to the pin bone (tuber ischii). Body height (BH) was measured as the vertical distance

from the ground to the highest point of the withers. BL and BH were taken with a measuring stick (hipometer). All measurements were recorded to the nearest 0.5 cm.

Body condition score

BCS was assessed by visual appraisal and palpation of the ribs, spine, hooks, pin bones, tailhead, brisket and flank, using the five-point scale described in Table 1. All animals were scored by number of trained assessor(s) on the same day as the body measurements.

Table 1. Body condition score (BCS) scale used in this study

Score	Class	Description
1	Very thin	Hips narrow and angular; pin bones, ribs and backbone very prominent; no visible fat over brisket, flank or twist
2	Thin	Hips, pin bones and ribs clearly visible but not prominent; slight fat development in flank and twist
3	Moderate	Body appears fairly rounded; hips, pin bones, ribs and backbone covered by a thin fat layer; fat beginning to develop in flank, brisket and twist
4	Fat	Fat over hips, pin bones, backbone and ribs gives a well-rounded appearance; fat evident around the tailhead; flank, brisket and twist filled
5	Very fat	Heavy fat cover over hips, pin bones, ribs and backbone; excessive fat around the tailhead; brisket, flank and twist heavily filled

Statistical analysis

Descriptive statistics, namely the mean (Equation 1), standard deviation (SD; Equation 2), standard error of the mean and the 95% confidence interval (CI) of the mean, were calculated for each trait. Relative variability was expressed as the coefficient of variation (Equation 3):

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (1)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \qquad (2)$$

$$CV\ (\%) = \frac{SD}{\bar{x}} \times 100 \qquad (3)$$

where x_i is the observation on the i-th animal, $\bar{x}$ is the trait mean and n = 55. The 95% CI of each CV was obtained with McKay's approximation as modified by Vangel (1996), so that the relative variability of traits recorded on different scales could be compared with an interval estimate rather than a single value. The range expected to contain about 95% of animals in a normally distributed population was approximated as mean ± 2 SD.

The association between BCS and each body measurement was measured with the Pearson product-moment correlation coefficient (Equation 4). Its significance was tested with a *t*-statistic on $n - 2$ degrees of freedom (Equation 5), and its 95% CI was obtained through Fisher's *z* transformation (Equation 6). Coefficients of 0.40–0.69 were described as moderate and 0.70–0.89 as strong (Schober et al., 2018). Because BCS is recorded on an ordinal scale, the coefficients were interpreted as measures of monotonic association, not as evidence of a linear causal relationship.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\,(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (4)$$

$$t = \frac{r\sqrt{n-2}}{\sqrt{1 - r^2}} \qquad (5)$$

$$z_r = \frac{1}{2}\ln\left(\frac{1+r}{1-r}\right), \quad SE_z = \frac{1}{\sqrt{n-3}} \qquad (6)$$

To express the relationships in practical units, simple linear regressions of BCS on each body measurement (X) were fitted (Equation 7). The coefficient of determination ($R^2 = r^2$), the standard error of estimate (SEE; Equation 8), the *F*-test of the regression and the 95% prediction interval for an individual animal were reported.

$$\widehat{BCS} = a + bX, \quad b = r\frac{SD_{BCS}}{SD_X}, \quad a = \overline{BCS} - b\bar{X} \qquad (7)$$

$$SEE = SD_{BCS}\sqrt{(1 - r^2)\frac{n-1}{n-2}} \qquad (8)$$

The minimum correlation that could be detected with 80% power at $\alpha = 0.05$ (two-tailed) with 55 animals was $r = 0.37$. Means, SDs and correlation coefficients were calculated in Microsoft Excel. Confidence intervals, regression parameters, prediction intervals and power were derived from these sample statistics with Python 3 (SciPy library). Statistical significance was declared at $P < 0.05$.

RESULTS AND DISCUSSION

Body size and condition

Descriptive statistics are presented in Table 2. Bali cattle had a mean chest circumference of 134.54 cm, a mean body length of 101.72 cm and a mean body height of 103.22 cm. Mean BCS was 3.51, which places the group at the upper end of the moderate class of the scale used (Table 1). The 95% CIs of the means were narrow, about

±4% of the mean for CC and BL and ±3% for BH, so the herd averages were estimated with good precision despite the modest sample.

Table 2. Descriptive statistics and phenotypic variation of body measurements and body condition score in Bali cattle aged 1-2 years (n = 55)

Trait	Mean ± SD	SE	95% CI of mean	Mean ± 2 SD	CV (%)	95% CI of CV (%)
Chest circumference (cm)	134.54 ± 19.86	2.68	129.17–139.91	94.8–174.3	14.76	12.39–18.28
Body length (cm)	101.72 ± 15.14	2.04	97.63–105.81	71.4–132.0	14.88	12.49–18.43
Body height (cm)	103.22 ± 10.22	1.38	100.46–105.98	82.8–123.7	9.90	8.32–12.23
Body condition score (1–5)	3.51 ± 0.72	0.10	3.32–3.71	2.07–4.95	20.61	17.24–25.65

SD = standard deviation; SE = standard error of the mean; CI = confidence interval; CV = coefficient of variation. CVs were computed from unrounded data; CIs of CV by Vangel's (1996) modified McKay method. Mean ± 2 SD approximates the range containing about 95% of animals.

Body height was slightly greater than body length, which gives a body length index (BL/BH × 100, calculated from the group means) of about 98.5. A ratio below 100 means that the animals were as tall as they were long. This pattern is typical of growing cattle, because the long bones of the limbs approach mature length earlier than the trunk, which keeps lengthening into the third year, so the index is expected to rise as the heifers mature. The ratio of chest circumference to body height (about 1.30) indicates moderate thoracic development for animals of this age. Because these indices were calculated from group means and not from individual animals, they describe the herd profile only.

Relative variability of the traits

The CVs and their 95% CIs are shown in Figure 1. Body height was the most uniform trait (CV 9.90%; 95% CI 8.32–12.23%). Chest circumference (14.76%) and body length (14.88%) were intermediate and almost identical, and BCS was the most variable (20.61%; 95% CI 17.24–25.65%). The interval for BH did not overlap with those of the other three traits, so the greater uniformity of body height is a robust feature of these data. The intervals for CC, BL and BCS overlapped, and their ranking should be treated as indicative.

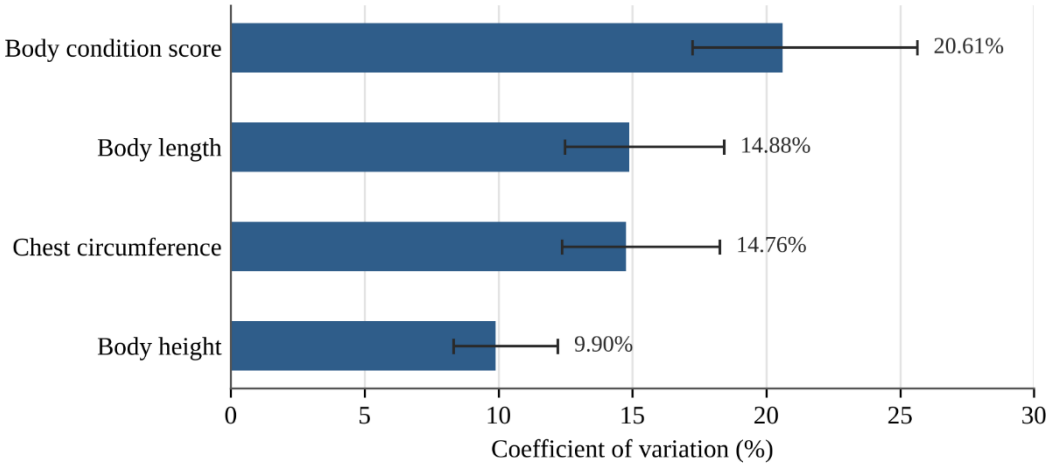


Figure 1. Coefficients of variation (CV) of body measurements and body condition score in Bali cattle aged 1–2 years (n = 55). Error bars show 95% confidence intervals (Vangel's modified McKay method).

The low CV for body height is consistent with what is known about frame traits. Withers height is largely skeletal, it changes slowly once the growth spurt slows, and it is less sensitive to short periods of under- or over-feeding than girth or condition. Body size in Bali cattle also has a genetic component (Chaerunissa & Nurgiartiningsih, 2022). Chest circumference combines a skeletal component with muscle, gut fill and subcutaneous tissue, and body length continues to increase between one and two years of age. The 12-month age span of the sample therefore inflates the CVs of CC and BL. If animals had been grouped in narrower age classes, the variation within each class would probably have been smaller.

BCS was the least uniform trait, and the expected range of mean ± 2 SD extended from about 2.1 to 4.9. In practical terms, the herd contained thin heifers close to score 2 alongside fat heifers close to score 5, even though all animals were managed in the same station system. Such spread in condition under common management usually reflects differences in feed intake within groups (competition at the feed trough or on pasture), parasite burden, previous growth history and the age span of the sample. The present design cannot separate these causes. The spread matters for reproductive management, because the optimal range for ovarian activity and embryo quality is about 3.0–3.5 and both tails of the distribution carry a reproductive cost (Bezdíček et al., 2020). A mean of 3.51 is acceptable, but the width of the distribution suggests that grouping heifers by

condition and adjusting supplementation would bring more animals into the target range before mating.

The variation reported here is phenotypic. It includes genetic differences, age effects, health and measurement error, and a CV from a single cross-sectional sample does not partition these sources. A high CV for BCS therefore does not mean that the trait is genetically more variable. Estimating genetic parameters requires pedigree or genomic relationships, repeated records and models that account for systematic environmental effects (Nurgiartiningsih et al., 2026).

Correlations between BCS and body measurements

BCS was positively and strongly correlated with all three body measurements (Table 3; Figure 2). The coefficients were 0.73 for chest circumference, 0.77 for body length and 0.78 for body height (all $P < 0.001$). The lower limit of every 95% CI (0.58–0.65) was well above the minimum detectable correlation of 0.37, so the associations are not artefacts of sample size. The CIs overlapped almost completely, however. The data do not show that BCS is more closely related to height than to girth, and the small numerical differences among the three coefficients should not be over-interpreted. A formal comparison of dependent correlations would require the correlations among the body measurements themselves, which were not available for this analysis.

Table 3. Pearson correlation coefficients between body condition score (BCS) and body measurements in Bali cattle (n = 55)

Trait pair	r	95% CI	t (df = 53)	P	r^2	Strength
BCS – chest circumference	0.73	0.58–0.83	7.78	<0.001	0.53	Strong
BCS – body length	0.77	0.63–0.86	8.79	<0.001	0.59	Strong
BCS – body height	0.78	0.65–0.87	9.07	<0.001	0.61	Strong

CI = confidence interval obtained by Fisher's z transformation; strength classified after Schober et al. (2018).

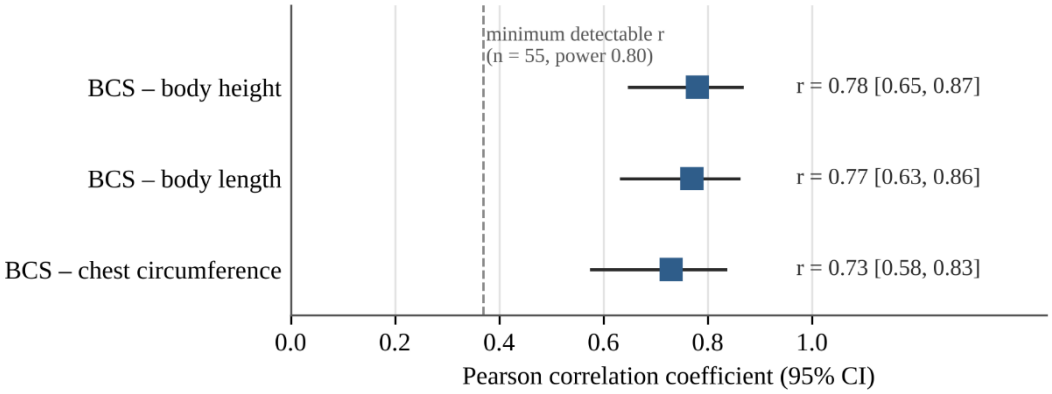


Figure 2. Pearson correlation coefficients between body condition score (BCS) and body measurements with 95% confidence intervals (Fisher's z). The dashed line marks the smallest correlation detectable with 80% power at n = 55.

The pattern of the coefficients is informative. A purely mechanical link between fat cover and body dimensions would make chest circumference the trait most closely related to BCS, because girth includes subcutaneous fat and muscle over the ribs. Heart girth has been used for this reason as a simple proxy for BCS in beef cows (Kojima et al., 2022). In the present heifers, the skeletal traits BL and BH were at least as strongly correlated with BCS as CC was. The most likely explanation is a shared size-age-factor. Within a 1-2 year age range, older heifers and those that had grown well because of better feed access were both larger and better covered than younger or poorly grown animals. In other words, BCS and frame size moved together because they shared common causes, not because a larger frame produces a higher score. Partial correlations adjusted for age in days, or analyses within narrow age classes, would be needed to establish how much of the association remains once age is accounted for.

A similar positive link between condition and size has been reported for other indigenous breeds, where adding BCS to linear body measurements improved live-weight prediction (Vanvanhossou et al., 2018). In Bali cattle, maternal BCS and withers height are both positively related to calf birth weight, although the correlations were weaker (0.35 and 0.19, respectively) than those found here between traits measured on the same animal (Zulkharnaim et al., 2025). For a breeding center, the practical message is that selecting heifers for larger frame size at a given age is unlikely to lead to thinner animals under the current management. Because phenotypic and genetic correlations can differ in sign and size, this conclusion holds only at the phenotypic level.

Estimating BCS from a single body measurement

The regression equations derived from the sample statistics are given in Table 4 and illustrated in Figure 3. Each additional 10 cm of chest circumference, body length or body height was associated with an increase in BCS of 0.26, 0.37 and 0.55 points, respectively. The equations explained 53% (CC), 59% (BL) and 61% (BH) of the variance in BCS.

Table 4. Simple linear regressions of body condition score (BCS) on individual body measurements in Bali cattle (n = 55)

Predictor (X, cm)	Equation	b ± SE	R^2	SEE	F (1, 53)	ΔBCS per 10 cm
Chest circumference	BCS = –0.05 + 0.0265X	0.0265 ± 0.0034	0.53	0.50	60.5	0.26
Body length	BCS = –0.21 + 0.0366X	0.0366 ± 0.0042	0.59	0.46	77.2	0.37
Body height	BCS = –2.16 + 0.0550X	0.0550 ± 0.0061	0.61	0.45	82.3	0.55

b = regression coefficient; SE = standard error; R^2 = coefficient of determination; SEE = standard error of estimate (BCS units). Parameters derived from sample means, SDs and correlation coefficients (Equations 7–8). $P < 0.001$.

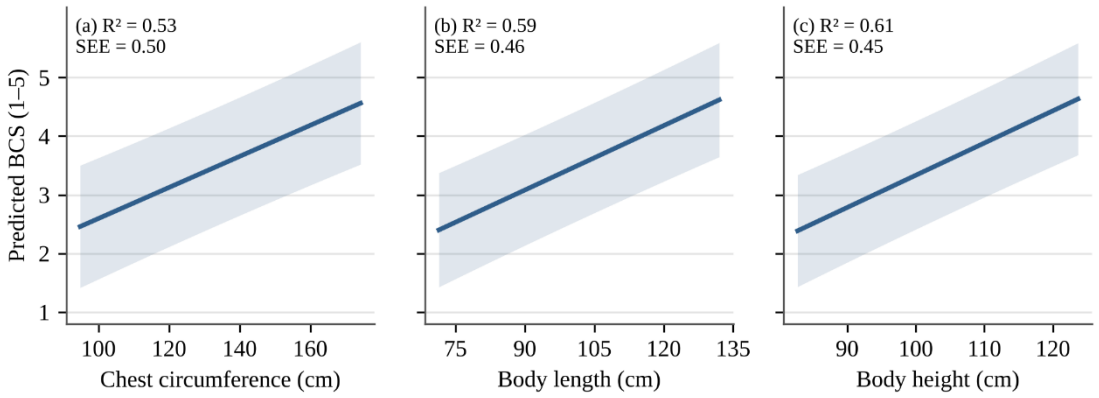


Figure 3. Predicted body condition score (BCS) as a function of (a) chest circumference, (b) body length and (c) body height over the range mean ± 2 SD. Lines are fitted regressions and shaded bands are 95% prediction intervals for an individual animal; horizontal lines mark the BCS classes.

These R^2 values are high for a subjective trait, but the precision of individual estimates is limited. The SEE ranged from 0.45 to 0.50 score units, which is only 31–37% smaller than the SD of BCS itself. The 95% prediction interval for a single animal therefore spans about ±0.9 to ±1.0 score units (Figure 3). A heifer predicted to score 3.5 from her height could, with reasonable probability, actually score anywhere from 2.6 to 4.4, a range that covers three of the five classes in Table 1. A tape or stick measurement cannot replace hands-on condition scoring when decisions concern individual animals, such as selection for mating or culling. The equations remain useful at group level, for

example to check whether a pen of heifers of known size is in poorer or better condition than expected, or to flag animals whose score departs strongly from that predicted by their frame.

Two further points limit the transfer of these equations. First, prediction equations based on body measurements are population-specific, and their accuracy falls when they are applied to other breeds, sexes or ages (Firdaus et al., 2023; Heinrichs et al., 2017; Widyas et al., 2021). Second, BCS itself contains assessor error. Agreement between trained human scorers can be modest (O'Mahony et al., 2023), and measurement error in either variable lowers the observed correlation. The true association between condition and size may therefore be somewhat stronger than reported here.

Implications for precision livestock farming and limitations

Automated systems that estimate body dimensions from two- or three-dimensional images have been used to estimate body weight and BCS in beef cows (Xiong et al., 2023), and similar approaches are being developed for pasture-based systems (Aquilani et al., 2022). The present data show what such tools would capture in Bali cattle. Frame measurements account for roughly half to three-fifths of the variation in a condition score, and the remainder must come from features that describe fat cover directly, such as the shape of the tailhead, hooks and pin bones. Reference datasets that pair manual BCS with body measurements and images in local breeds are a prerequisite for calibrating these tools for Indonesian smallholder and station herds. The present study provides a first baseline for Bali cattle in East Kalimantan.

The study has limitations that define the scope of its conclusions. It was a single cross-sectional observation of one herd, and individual ages within the 1–2-year range, physiological status and parity were not included in the analysis. BCS was recorded once on an ordinal scale, and repeatability was not assessed. The Pearson coefficient was used. A rank-based coefficient (Spearman's ρ) and a check of the normality of the residuals on the individual records would confirm that the conclusions do not depend on the linear model. The regression parameters and prediction intervals were derived from summary statistics and assume linearity and constant residual variance. Repeated measurements of the same animals across seasons, with recorded birth dates, would allow growth curves, age-adjusted correlations and individual repeatability to be estimated.

CONCLUSION

Bali cattle aged 1-2 years at UPTD PTHPT Api-Api had mean chest circumference, body length, body height and BCS of 134.54 cm, 101.72 cm, 103.22 cm and 3.51, respectively. Body height was the most uniform trait (CV 9.90%), chest circumference and body length were intermediate (14.76% and 14.88%), and BCS was the most variable (20.61%), with heifers ranging from thin to fat under the same management. BCS was strongly and positively correlated with chest circumference (r = 0.73), body length (r = 0.77) and body height (r = 0.78). A single body measurement explained 53–61% of the variation in BCS, but individual estimates carried an error of about half a score, so measurements are best used alongside, not instead of, direct condition scoring. Grouping heifers by condition before mating, and recording birth dates and repeated measurements, would improve both herd management and the calibration of future automated monitoring tools.

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