



RESEARCH

Classification of Milking Animals Based on Production and Reproductive Performance for Effective Management Decisions: An Approach Using K-Means Clustering

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ABSTRACT

This study was conducted to determine the feasibility of implementing principal component analysis (PCA) and K-means clustering method for grouping cows in a dairy herd based on their performance on multiple traits related to milk production and reproduction, for implementing need based, group specific management practices. The proposed method was tested on two different management systems, namely System A (Friesian x Jersey crossbreds managed intensively under Low Country Dry Zone) and System B (Sahiwal crossbreds managed semi intensively under Low Country Intermediate Zone). Six large scale state dairy farms were grouped into the two systems with 1507 lactation records of 643 cows belonging to System A and 552 lactation records of 185 cows in System B. Means of calf birth weight, age at first calving, lactation length (LL), total milk production (MP), average daily yield, and calving interval (CI) of System A were significantly superior to the respective means of System B ($p < 0.05$). The PCA used MP, LL and CI traits where all three traits exhibited significant positive pairwise correlations ($p < 0.05$). For both systems, the first two PCs explained over 85% of the total variation of traits. Traits MP and LL played a major component in PC1 (production component) and CI was loaded heavily for PC2 (reproduction component). For both systems, the K-means clustering approach was effective with the three clusters of cows formed within a system showing significant differences for MP, LL and CI ($p < 0.05$).

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INTRODUCTION

With production-oriented breeding, native Sri Lankan cattle have been subjected to numerous genetic improvement programs over many decades in the past (Silva, 2010). There have been several initiatives taken by the government of Sri Lanka to provide quality breeding materials to dairy farmers. Under the breed improvement initiatives, live cattle and semen have been regularly imported to Sri Lanka aiming at government-owned cattle farms to establish nucleus/foundation stocks. Historically, those state farms were managed by the Department of Agriculture, which was the implementation arm of both crop and animal agriculture development of the country. The animal farms were then handed over to the Department of Animal Production and Health (DAPH) which was established in 1978. Later, in the early 1990s, some of those farms were transferred to the National Livestock Development Board (NLDB). The foundation

stocks of those farms were also subjected to improvement through several breed improvement programs time to time. Present herds in the NLDB farms around the country are thus having varying genotypes (DAPH, 2010).

The National Livestock Breeding Policy has recognized seven major agro-climatic zones in Sri Lanka for breed improvement purposes (DAPH, 2010). Apart from the low producing dairy herds (pure and crossbred local cattle) reared extensively in the Dry zone, most of the commercial dairy production systems in Sri Lanka are comprised of extensively, semi-intensively or intensively managed indicine and taurine crossbreds (Table 1). Production levels of those commercial herds depend heavily on the agroclimatic zone where they are located, breed composition and management systems practiced. As such, different improvement strategies have to be adopted for different categories of herds based on their production status.

Table1. Major cattle genotypes present in commercial dairy production systems in different agro-climatic zones in Sri Lanka (Rathnasingham *et al.*, 2018; Mohottala and Dematawewa, 2020; Senarathna and Dematawewa, 2020; Jayasinghe *et al.*, 2021; Manojan *et al.*, 2021; Sanjeewa *et al.*, 2021)

Agro-climatic zone	Dominant/ commonly available genotypes*
Low country Dry zone	Sahiwal crosses and Jersey crosses
Low country Wet Zone	Sahiwal crosses, Jersey crosses and Friesian crosses
Low Country Intermediate zone	Sahiwal crosses, Jersey crosses and Friesian crosses
Mid Country Intermediate zone	Jersey crosses and Friesian crosses
Mid Country Wet zone	Jersey crosses and Friesian crosses
Up-Country Intermediate zone	Jersey crosses and Friesian crosses
Up-Country Wet zone	Jersey crosses and Friesian crosses

* Exact genotypes mostly unknown; Sahiwal crosses = $\geq 50\%$ Sahiwal, Jersey crosses = $\geq 50\%$ Jersey, and Friesian crosses = $\geq 50\%$ Friesian genetic compositions.

The economic returns of commercial dairy farming depend mainly on milk production and the reproductive efficiency (Age at First calving and the subsequent calving intervals) of animals (Ramos *et al.*, 2006). Milk production of a herd is determined by the lactation length of the animals and the milk yield per cow per day in each parity. Lactation length has also been identified as a factor which subsequently affecting on the

calving interval, a primary indicator of reproductive efficiency (Van Knegsel *et al.*, 2022). The return on investment of a farm depends on the systematic and frequent scrutiny of the existing herds on the major economic traits. Absence of systematic assessment deprives the opportunities for implementation of selection programs, which is essential for achieving greater economic return through genetic improvement.

Data collected on various economic traits of farm animals can be evaluated using univariate and multivariate techniques. However, there are many important traits associated with growth, production, reproduction and fitness aspects that have an economic impact on a dairy enterprise. Having to consider a large group of economic traits together poses challenges in the genetic selection of superior animals (as individual animals are often ranked differently for different traits) and in classifying them into contemporary performance groups for need based management. The univariate analysis approach that deals with one trait at a time is simple but has a limited scope since it does not consider possible correlations between multiple traits (Fraga *et al.*, 2016). However, from a multivariate analysis, individuals' multiple traits are cumulatively taken into consideration to analyze the production and reproduction potential. Well established multiple trait selection methodologies such as Index Selection (Hazel, 1943) and Best Linear Unbiased Prediction (BLUP) method (Henderson, 1975) have the ability to rank the animals according to their true genetic potential (predicted breeding values) on many economic traits and analyze genetic correlations. However, those methods demand information on genetic and phenotypic variance components of the herds and genetic relationships among animals. When accurate pedigree information (at least on sires and dams) is missing (as often is the reality of livestock herds in developing countries), the applicability of such sophisticated methods become severely constrained. Alternatively, non-genetic multivariate techniques such as principal component analysis (PCA) and cluster analysis can be efficient methods for grouping animals according to productive and reproductive potential to assist in the selection of animals, and for providing need-based management (Bezerra *et al.*, 2018). Through the PCA approach, the initial economic traits can be loaded to a few major principal components (PC), which capture most of the variation in initial data. As such it reduces the dimension and the noise of the initial data, and the newly formed PCs can be analyzed on a cartesian plane. Then the two first PC values of dimension reduced data

points can be subjected to the K-means clustering which clusters the data points with minimum sums of squared variances between each other (Bezerra *et al.*, 2018). As such, the individual animals with similar economic potential can be isolated into clusters. These techniques have been used in livestock production and genetic improvement to decrease the number of individual traits considered for selection and to assemble homogeneous groups (Kadegowda *et al.*, 2008; Naser *et al.*, 2008; González *et al.*, 2011; Ventura *et al.*, 2012; Vohra *et al.*, 2015; Bezerra *et al.*, 2018). Hence, this study was carried out on a random set of state-owned commercial dairy herds that belonged to two production performance levels, to investigate the applicability of K-means clustering approach in grouping the animals successfully according to their overall production and reproduction potentials to aid in making selection and management decisions.

MATERIALS AND METHODS

Management systems and genetic makeup of animals

This study considered six different randomly selected commercial milking herds of crossbred cattle with varying genotypes (*Taurine* and *Indicine*) maintained at the National Livestock Development Board (NLDB) in different agro-climatic zones of Sri Lanka (Table 2). Farms were initially clustered into two management groups (System A and System B) considering the differences and similarities in the farming systems, standard of operations, climatic conditions and performance levels of the herds so that the robustness of the proposed clustering system could be tested under different non genetic conditions. *Taurine* crosses were reared intensively in System A and *indicine* crosses were reared semi-intensively in System B herds (Jayasinghe *et al.*, 2021; Manojan *et al.*, 2021; Mohottala and Dematawewa, 2020; Rathnasingham *et al.*, 2018; Senarathna and Dematawewa, 2020). Even though System A farm was situated in Low country Dry zone, the temperature and the humidity inside the sheds have been controlled to some extent for *taurine* crossbreds with stir fans and sprinklers.

Table 2. Description of the study samples

System classification	Farm	Cattle breed	Agro-climatic zone	Geographical coordinates
System A	Ridiyagama farm	Jersey × Friesian	Low country Dry zone	6°13'41.9"N 80°57'09.3"E
System B	Andigama farm			7°23'18.0"N 80°06'05.6"E
	Koulwewa farm	Crossbreds with predominantly Sahiwal genes	Low country Intermediate zone	7°26'40.3"N 80°11'04.9"E
	Narangalla farm			7°27'36.7"N 80°05'51.7"E
	Nikaweratiya farm			7°44'10.8"N 80°07'49.0"E
	Rukkattana farm			7°34'10.4"N 79°57'21.9"E

The herd of cattle in the System A farm was descending from a foundation stock of Jersey × Friesian crossbreds imported from Australia in 2015 (Samaraweera *et al.*, 2020). The present herd, being the F₁ and F₂ generations of the imported stocks, consisted of 50% - 75% Jersey genes due to the artificial inseminations (AI) with Jersey semen. In the case of System B herds, the cattle were originally descending from the Sahiwal foundation stocks which were established in the early 1990s. With the prominent use of Sahiwal stud bulls, semen of Sahiwal and the minor usage of the semen of Jersey, Friesian and Australian Friesian Sahiwal (AFS), the current genetic composition of System B herds was more towards the Sahiwal breed. Morphological

features also suggested that the population was predominantly towards Sahiwal phenotypes (wider forehead, prominent dewlap and reddish dun coat colour).

Feeding and milking

In both systems A and B, calves were separated from cows after calving and reared in calf pens. After weaning at 90 days of age, calves were moved to growing calf pens and reared until one year of age (Plate 1), after which animals were transferred into the heifer sheds in the case of System A herd and released for free grazing in the case of System B herds. The feeding schedule of the two herd classes is given in Table 3; although feeding practices among System B farms may vary slightly from the given schedule.

Table 3 . Feeding schedule of systems A and B herds

Age	System A	System B
0 – 3 days	Colostrum	Colostrum
4 – 30 days	Whole milk: 4 L/day	Whole milk: 4 L/day
31 – 59 days	Whole milk: 3 L/day Concentrates: 250 g/day	Whole milk: 3 L/day Concentrates: 250 g/day
60 – 74 days	Whole milk: 2 L/day Concentrates: 350 g/day Hay: Small quantity	Whole milk: 2 L/day Concentrates: 350 g/day Hay: Small quantity
75 – 90 days	Whole milk: 1 L/day Concentrates: 500 g/day	Whole milk: 1 L/day Concentrates: 500 g/day

91 days – 1 year	TMR: 1 kg/day Concentrates: 500 g/day	Forage (Cut and fed): 1 kg/day Concentrates: 500 g/day
Over 1 Year	TMR: 10% Body weight TMR: 10% Body weight	Forage (Cut and fed): 10% Body weight Free grazing

In System A herd, mature animals were kept in loose stall barns and scheduled to be fed with a total mixed ration (10% of body weight/day) mainly containing hybrid Napier variety CO-3, CO-4, mineral supplements and balanced concentrates (Green fodder 7 kg, Concentrates 1 kg). In addition, urea-enriched silage was provided. In System B herds, mature animals were kept under free grazing in lands consisting of pasture *Brachiaria brizantha* and fodder *Megathyrus maximus* (Guinea grass) under the coconut shading (Plate 2). Cows were milked twice a day in System A herd with a parlor milker using a piped vacuum line and cows in system B were hand milked twice a day.

Data collection

Data on birth weight (BW, in kg), total milk production per lactation (MP, in L), average milk production per day (L/day), lactation length (LL, in days), calving interval (CI, in days) and age at respective calving (in years) were collected from farm records. Finally, records were obtained for 1507 lactations of 643 animals from System A for the period of 2015-2023, and for 552 lactations of 185 milking animals from System B herds for the period of 2009-2023. Parity wise detailed records of each measure at each system is listed in Table 4 and 5.

Comparison of performance between parities

Performance variation between parities was initially tested by statistical comparison of the parity groups with respect to MP, LL, CI and average MP per day using ANOVA procedure. Significant differences among parity groups were determined by mean comparison using the Tukey's Honestly Significant Difference test (Tukey, 1953).

Principal component analysis

Grouping of individual animals into clusters (within the system) was carried out using Principal Component Analysis considering

MP, LL and CI variables. Initially, phenotypic values of production variables were standardized to exclude the effect from the scale of measurement in different variables (production traits) and convert the mean and the standard deviation of the variables into 0.00 and 1.00, respectively.

Standardization of the phenotypic values:

$$Z_i = \frac{X_i - \mu_X}{\sigma_X}$$

The standardized value for the i^{th} observation where Z_i , X_i is the original value of the i^{th} observation, μ_X is the mean of the trait X, and σ_X is the standard deviation of the trait X.

Next, a phenotypic correlation matrix (R) for standardized data was generated to quantify the linear relationships between pairs of variables (traits) in the dataset. The correlation matrix provided a measure of how each variable is related to every other variable (strength and direction of the linear relationships between variables). PCA relied on the correlations between variables to derive the orthogonal (uncorrelated) principal components.

Generation of the correlation Matrix:

$$R = \frac{1}{n-1} Z^T Z$$

R denoted the correlation matrix, Z is the matrix of standardized variables and n is the number of observations. Then each eigenvector (principal component) and the associated eigenvalue (Principal component score) was derived from the correlation matrix of the standardized data (Z_i).

The i^{th} principal component was derived by:

$$PC_i = e_{i1}x_1 + e_{i2}x_2 + \dots + e_{ip}x_p$$

The loading of the j^{th} trait (ex-MP) in the i^{th} principal component is e_{ij} and x_j is the



Calves in System A



Calves in System B



Growing calves' pens in System B

Plate A. Feeding and housing conditions of calves in systems A and B



TMR feeding in free stall barns - system A



Free grazing - system B

Plate B. Feeding practices of the mature animals in systems A and B

standardized value of the j^{th} trait. The loadings of each trait in a principal component determine the relative importance of that trait in the component. Eigenvalues (λ_i) represent the amount of variance explained by each principal component (Rencher, 2002). The first principal component covers the highest percentage of total variance, and the second component handles the second highest percentage of total variance and so on sequentially until all variances are explained as follows:

$$\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \dots \geq \lambda_p \geq 0$$

Within group sum of squares (WSS) of variation of the major two principal components of the individuals, calculated through the K-means algorithm was used to determine the optimum number of clusters (K).

$$WSS_K = \sum_{j=1}^K \sum_{x_i \in C_j} \|x_i - c_j\|^2$$

WSS_K is the total within-cluster sum of squares for K clusters, x_i is a data point in cluster j and c_j is the centroid of cluster j . The optimal number of clusters was formed to maximize the similarity within clusters and differences between the clusters (Rencher, 2002). As such, within those clusters included cows with similar performance levels and management needs. All the analyses were carried out with computational algorithms and packages available in the R software 4.2.3 (R core team, 2023).

RESULTS AND DISCUSSION

Comparative performance of different systems

Birth weight

The mean birth weight ($\pm$ SE) of a heifer calf in System A (24.52 ± 0.19 kg) was significantly greater ($p < 0.05$) than that of System B herds (19.80 ± 0.17 kg). The mean BW of Jersey $\times$ Friesian crossbreds in System A was found to be lower than those reported for Friesian purebred animals reported in the literature. For instance, a mean BW of $32.5 \pm$

0.8 kg was reported for pure Friesian heifers in temperate regions (Hickson *et al.*, 2015), and a value of 32 ± 4 kg was reported from Upcountry intensive farming system in Sri Lanka (Kollalpitiya *et al.*, 2012). However, the above performance level of System A crossbred heifers is superior to the mean performance value of 21 ± 2 kg reported by Kollalpitiya *et al.* (2012) for pure Jersey herds in the Up-Country large scale intensive farming system, showing that crossbreds could perform better than some pure breeds. Meanwhile, the mean BW of Sahiwal crossbred heifers of System B was comparable to the previously reported value of 19.03 kg for the Sahiwal crossbred cattle under extensively managed farming systems in the Dry zone of Sri Lanka (Spoelstra *et al.*, 2022).

Milk production and reproductive performances

Herd groups A and B were on different breeding management conditions resulting in a significant difference in reproductive performance between the two systems ($p < 0.05$). In System A, where animals were bred by AI, the age at first successful conception was 18.4 ± 0.1 months while in System B herds, where animals were bred through natural service and AI was practiced occasionally, the age at the first successful conception was 40.1 ± 1.0 months. Age at first successful conception directly determines the age at first calving (AFC) and in turn, influences the duration of the productive life of a cow. The present study records 27.5 ± 0.1 months and 49.5 ± 0.9 months of age at first calving (AFC) in Systems A and B ($p < 0.05$), respectively with 15-18 and 11-16 months of CI ($p < 0.05$) as shown in Tables 4 and 5. The results in Tables 4 and 5 are comparable with the findings of similar studies conducted on those systems previously (Jayasinghe *et al.*, 2021; Manojan *et al.*, 2021; Mohottala and Dematawewa, 2020; Rathnasingham *et al.*, 2018; Senarathna and Dematawewa, 2020). In India, long AFC values have been recorded for Sahiwal crossbreds (32-36 months) compared with Jersey purebreds (26-30 months) with 15 months and 13-14 months of CI, respectively under commercial farming conditions (TNAU, 2008). However, in commercial dairy farming, when a heifer

passes more than 30 months for the first calving, it is generally considered as unprofitable (Nilforooshan and Edriss, 2004).

Table 4. Parity wise means ($\pm$ SE) of production and reproductive traits of System A*

Parity	Number of records	MP (L)	LL (days)	CI (days)	Average MP (L/day)	Age at calving (Years)
1	643	2522 $\pm$ 660 ^a	361 $\pm$ 60 ^a	525 $\pm$ 60 ^a	6.71 $\pm$ 0.13 ^b	2.29 $\pm$ 0.01 ^a
2	377	3660 $\pm$ 108 ^b	353 $\pm$ 60 ^b	495 $\pm$ 60 ^b	10.15 $\pm$ 0.24 ^c	3.73 $\pm$ 0.01 ^b
3	241	4011 $\pm$ 128 ^c	404 $\pm$ 10 ^c	538 $\pm$ 11 ^c	10.21 $\pm$ 0.28 ^c	5.02 $\pm$ 0.02 ^c
4	159	3384 $\pm$ 143 ^b	376 $\pm$ 12 ^d	509 $\pm$ 11 ^c	9.03 $\pm$ 0.29 ^c	6.47 $\pm$ 0.05 ^d
5	72	2173 $\pm$ 155 ^a	332 $\pm$ 16 ^a	465 $\pm$ 11 ^d	6.29 $\pm$ 0.36 ^a	7.75 $\pm$ 0.06 ^e
6	15	1688 $\pm$ 208 ^a	321 $\pm$ 23 ^a	-	5.49 $\pm$ 0.65 ^a	8.79 $\pm$ 0.06 ^f

*MP: Milk production, LL: Lactation length, CI: Calving Interval.

^{a, b, ..., f} Means with different superscripts in a column are significantly different at $p < 0.05$.

Table 5. Parity wise means ($\pm$ SE) of production and reproductive traits of System B*

Parity	Number of records	MP (L)	LL (days)	CI (days)	Average MP per day (L)	Age at calving (Years)
1	185	1169 $\pm$ 610	252 $\pm$ 90	473 $\pm$ 17	4.49 $\pm$ 0.16	4.13 $\pm$ 0.08 ^a
2	129	1253 $\pm$ 730	244 $\pm$ 10	470 $\pm$ 21	4.87 $\pm$ 0.19	5.48 $\pm$ 0.12 ^b
3	86	1296 $\pm$ 990	244 $\pm$ 11	421 $\pm$ 17	5.26 $\pm$ 0.53	6.63 $\pm$ 0.16 ^c
4	61	1273 $\pm$ 103	259 $\pm$ 11	377 $\pm$ 13	4.74 $\pm$ 0.29	7.99 $\pm$ 0.22 ^d
5	44	1318 $\pm$ 130	262 $\pm$ 13	412 $\pm$ 25	4.91 $\pm$ 0.38	9.10 $\pm$ 0.28 ^e
6	24	1223 $\pm$ 188	265 $\pm$ 14	476 $\pm$ 99	4.44 $\pm$ 0.60	10.56 $\pm$ 0.43 ^f
7	11	1513 $\pm$ 255	257 $\pm$ 19	352 $\pm$ 13	5.78 $\pm$ 0.79	12.24 $\pm$ 0.70 ^g
8	06	1546 $\pm$ 403	266 $\pm$ 39	416 $\pm$ 59	5.43 $\pm$ 0.82	12.83 $\pm$ 0.65 ^g
9	05	1664 $\pm$ 417	275 $\pm$ 18		5.86 $\pm$ 1.20	14.12 $\pm$ 0.70 ^g

*MP: Milk production, LL: Lactation length, CI: Calving Interval.

^{a, b, ..., g} Means with different superscripts in a column are significantly different at $p < 0.05$.

Patten of variation of milk production per lactation over the parities under the two systems are shown in Figures 1 and 2. Mean milk yield of the system A increased with the parity until third lactation significantly and decreased thereafter ($p < 0.05$). The variation of MP among cows within the parity showed an increasing trend with the increase of parity, thus showing the least variation in the first parity due to its lower milk yield (Table 4). Both lactation length and average milk production per day in System A also increased significantly for several parities until cows reaching maturity and declined thereafter (Table 4).

A similar pattern of variation has been reported previously in many different production scenarios (Ray *et al.*, 1992; Cilek, 2009; Kollalpitiya *et al.*, 2012; Vijayakumar *et al.*, 2017; Alqaisi *et al.*, 2020; Habibi *et al.*, 2021). Describing the physiological aspects behind this trend, Vijayakumar *et al.* (2017) stated that first lactation cows typically exhibit lower milk yields, possibly due to the continuation of their growth phase, where their mammary glands and mammary veins are still not fully developed. Sorensen *et al.* (2006) stated that the gradual development and enlargement of the udder of a heifer leads to an increase in milk secretory cells until maturity. Additionally, Wathes *et al.* (2007) elaborated that increased parity could be a

significant factor contributing to higher milk yields, as it influences the regulation of tissue mobilization. The increase of within parity variation with the advancement of the lactation number until maturity might also be

due to the variations in the physical conditions specific to the individual in later lactations.

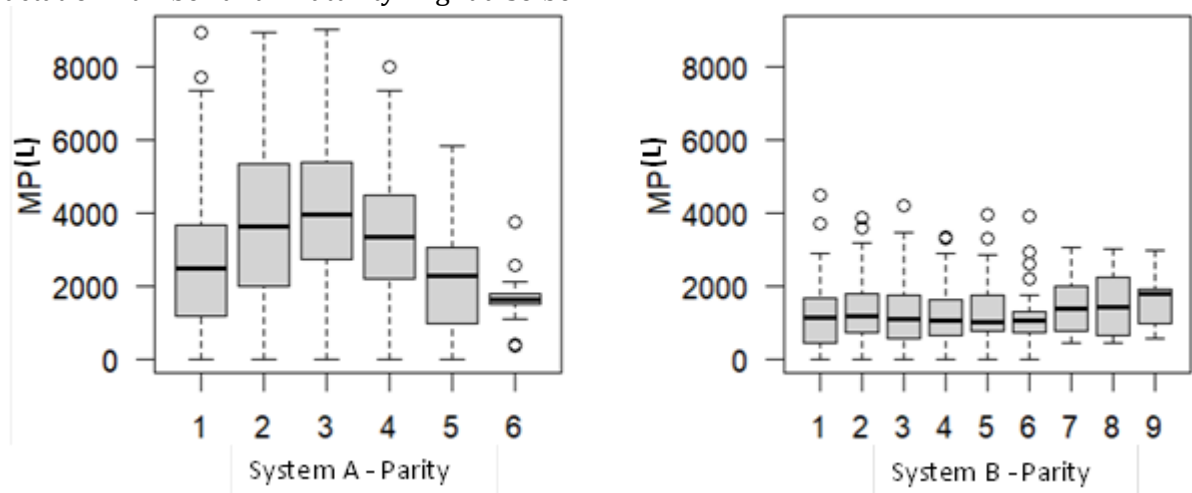


Figure1. Parity wise milk production (MP) per lactation in systems A and B

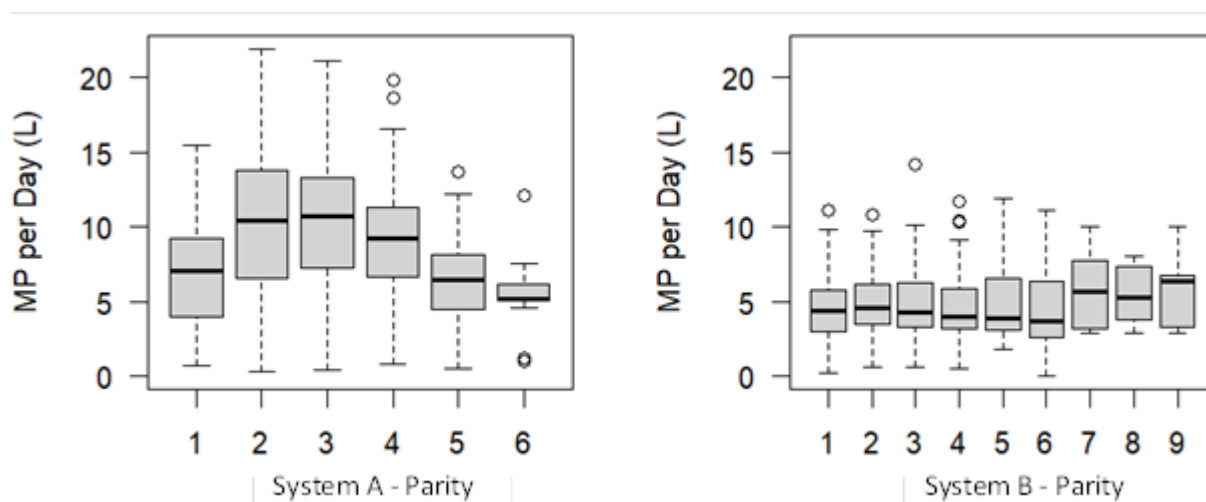


Figure 2. Parity wise average milk production (MP) per day in respective lactations in systems A and B

Figures 1 and 2 also depict the substantial variation existing among the cows within a system with respect to milk production. As far as the best milk producers in the system A are concerned, cows with maximum production of 7000, 8500, 9000, 7000, 6000, 2000 liters per lactation and average production of 15, 22, 20, 18, 14, 12 liters/day have been recorded in the first 6 consecutive lactations, respectively. When considering the average milk production per lactation, Samaraweera *et al.* (2020) has reported an average of 4043 kg and 4277 kg of 305-day milk production in first two lactations

respectively for the foundation Jersey × Friesian crossbred herd in system A. The reported values of the foundation herd indicated fairly high average production compared to the average production of their F1 and F2 progenies where; 2522 L and 3660 L with the average lactation lengths of 361 and 353 days respectively for lactation one and two (Table 4). The considerable difference of the current average production against the maximum production and the production of the foundation herd might be associated with the reduction of the Friesian admixture level with the generation progress

and other management associated factors such like feeding and nutrition. These factors regarding the potential and the existing production signified the need of grouping (clustering) the cows within a system and managing them according to their production levels and nutritional requirements. System A animals are currently being classified as Fresh, Mid and Late lactating animals based on the daily MP. But clustering of animals by cumulatively considering other associated factors affecting for MP (LL and CI) together, will provide a comprehensive overview of the animals for a need-based management not only for the production, but also for the reproduction which ultimately effect on an efficient MP. Under tropical climatic conditions in India, an average production of 20 liters/day with total MP of 7750 liters for a Jersey cow, and 25 liters/day with total MP of 8750 liters for a Friesian cow during their 300-day lactation was reported (TNAU, 2009) due to their better management conditions, which could be used as reasonable potential targets for present commercial farms in Sri Lanka.

In system B herds (Table 5), the mean values of the total milk production among first nine lactations were not significantly different ($p>0.05$). Similarly, there were no significant differences in lactation lengths or calving intervals among parities in those herds ($p>0.05$). None of the lactations has reached standard lactation lengths (305 days). The differences in the performance levels shown in Tables 4 and 5 clearly justify the need for classification of herds into different production scenarios (systems) for the purpose of clustering in this study. In system B, animals were allowed to graze on natural pasture and fodder, leading to more variable and potentially less optimal nutritional intake. This could lead to sub optimal performance and consequently less pronounced differences in milk production across lactations, as the cows may not receive the consistent nutritional support needed to maximize their production potential as the parity increased. Additionally, animals in System B were exposed to harsh and varying environmental conditions and had to spend more energy for grazing. These factors are likely to cause low milk production across

lactations not reaching their maximum genetic potential. Consequently, these conditions contributed to stable but low peaks in milk production across successive lactations. The variation within parity after the third lactation was remarkably high (Table 5) which might be due to the variations in the physical conditions of animals as they carry a significantly high AFC and CI. Maximum milk production values in Figures 1 and 2 indicated that some cows in System B producing 3000-3500 liters of MP and 10-12 liters/day, respectively. A maximum of 2000 liters per lactation of MP also have been reported for the Sahiwal cattle under commercial farms in Tamil Nadu, India (TNAU, 2009). Sahiwal herds managed with good AI practices in India, recorded 1800-2150 liters of MP, 268-303 days of LL and 10 liters of maximum test day yield (Ratwan *et al.*, 2020). The highest producing cows in system B in the present study (Figures 1 and 2) also exhibited high production potentials similar to those reported in India, which shows the potential for further improvement in the local commercial herds and the need to cluster the present cows into performance-based groups for need based management. Table 6 shows the performance levels reached in India under similar tropical climatic conditions purely due to their adoption of appropriate technology and better management practices (TNAU, 2009; Ratwan *et al.*, 2020). Those real achievements at the field level could be used as potential (target) yields in goal setting in the efforts which are being made for improvement of the state herds in Sri Lanka.

Multivariate analysis and phenotypic correlation among traits

Phenotypic correlations among LL, MP and CI for the two systems are shown in Table 7. Previously Vijayakumar *et al.* (2017) recommended that the cows with more than three lactations are unsuitable candidates for further breeding with the target of maximizing milk yield, as the potential of milk production declines beyond the third parity and within herd variation escalates (Figures 1 and 2). Hence, animals in the initial three lactations were considered in this study as the suitable candidates to analyze the relationships among economic traits.

Consideration of consecutive lactations rather than a single lactation provided the space for analyzing the changing pattern of productive and reproductive characteristics over successive parities. Correlation between LL and MP was high and positive for both systems (Table 7) indicating cows with longer LL tend to produce higher yields. The typical lactation curve of a dairy cow also suggests

the positive correlation between LL and MP, although extending LL beyond a certain period gives rise to diminishing returns in MP (Hovey, 2018). Typically, daily milk yield rises to a peak around 4-12 weeks and declines thereafter. As a result, daily yield generally decreases towards the later part of the lactation although the total MP increases with increasing LL (Van Kneegsel *et al.*, 2022).

Table 6. Present mean performance levels and the possible potential standards to which the two systems can be upgraded

Trait	System A		System B	
	Existing	Potential*	Existing	Potential*
Age at first calving (months)	27.5	26	49.5	30-36
Milk production (liters)	1650-4000	7500	1100-1300	3500
Lactation length (days)	320-400	305	240-270	280-300
Milk Production/day (liters)	6.5-10	20-25	4.5-5.5	10-12
Calving interval (days)	460-540	390-420	370-470	390-450

*As reported under the standard conditions (Intensively managed proper nutrition with diet of 10% of the body weight [Roughages 7: Concentrates 1] during the lactation and breeding management with timely managed AI practices) in the region (TNAU, 2009; Ratwan *et al.*, 2020).

Table 7. Linear correlation estimates between milk production (MP), lactation length (LL) and calving interval (CI) in initial three lactations

Management system	Number of Animals	LL and MP	CI and MP	LL and CI
System A	241	0.59 (p < 0.05)	0.21 (p < 0.05)	0.48 (p < 0.05)
System B	86	0.68 (p < 0.05)	0.18 (p < 0.05)	0.35 (p < 0.05)

*MP: milk production/lactation, LL: lactation length, CI: calving interval

When considering the initial three lactations, correlation between LL and CI was found to be moderately high, however, CI and MP were not strongly related (Table 7). The absence or low correlation between MP and CI for lactating ruminants was also reported by several authors (Ramos *et al.* 2006; Malhado *et al.* 2009; Bezerra *et al.* 2018, and Van Kneegsel *et al.* 2022). The calving interval is a function of lactation length and voluntary or involuntary dry period at the end of the lactation. It could be expressed as the sum of the pregnancy period and no. of days open (the period between the previous calving date and date of conception for the current pregnancy). No. of days open can get extended beyond the recommended length due to inefficiencies in heat detection, insemination practices and stud bull use. Such increases of no. of days open delays

subsequent calving and inadvertently increases CI of a cow. When the next calving of a lactating cow is delayed, the herdsmen tend to extend the current lactation of a cow increasing the LL. This causes a significant positive relationship between CI and LL. According to Van Kneegsel *et al.* (2022), the extension of the postpartum voluntary waiting period of a cow is the main causative factor for the extension of the LL and the subsequent expansion of the CI. However, longer lactations of unproductive cows only prolong the LL where the milk production remains generally low and does not provide additional milk to the total MP. Hence, the extended CI does not greatly contribute to the increase of MP (Rehn *et al.* 2000; Arbel *et al.* 2001; Österman and Bertilsson 2003).

Contrary to the fact that extended CI does not affect largely on the MP of the current lactation, Arbel *et al.* (2001) and Lehmann *et al.* (2016) have indicated that increased CI could affect positively for the MP in the subsequent lactation. However, the economic efficiency of having extended lactations (thereby increasing CI), instead of maintaining a standard lactation of 305 days is yet to be discovered. In some cases, an extended lactation strategy has been proposed as a solution to the increasing problems with infertility and to curb the waste of resources by cows being dried off with high milk yields (Schindler *et al.* 1991; Knight, 2008). However, in our study, the issue of extended lactations does not arise

particularly in System B herds as they are far from reaching the standard 305-day LL.

Principal component analysis

The results of the PCA carried out based on LL, MP and CI variables are in Table 8. Essentially three PCs were derived from the three traits and the variation captured by the first two PCs were much similar between the two management systems. According to Rencher (2002), the first two principal components must account for at least 70% of the overall variation. In the analysis, the first two principal components have effectively summarized total variation covering more than 70% of the overall variation in the three traits.

Table 8. Variation captured by the first two principal components (PC1 and PC2) under different management systems

Management system	Variation captured (%)		Total variation captured by PC1 and PC2 (%)
	PC1	PC2	
System A	62.7	26.2	88.9
System B	61.8	28.4	90.2

Table 9 shows that most of the variation in MP and LL was captured by the first principal component (PC1) and the variation of CI was covered mostly by the second component (PC2). Therefore, PC1 can be used to evaluate

the variation in MP and LL (i.e., production component) while PC2 can be used to evaluate the CI (i.e., reproduction component).

Table 9. Correlations and loading scores for MP, LL and CI from first two principal components (PC1 and PC2) *

Trait	System A				System B			
	Correlations		Loading scores		Correlations		Loading scores	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
MP	0.77	-0.54	0.56	-0.61	0.84	-0.39	0.62	-0.42
LL	0.89	-0.05	0.65	-0.06	0.90	-0.13	0.66	-0.14
CI	0.68	0.69	0.50	0.78	0.55	0.82	0.41	0.89

*MP: milk production/lactation, LL: lactation length, CI: calving interval

Within group sum of squares in variation (WSS) dendrogram designed based on the reduced-dimensional data points (principal component values of the individuals) of the systems A and B (Figure 3) suggested that the individuals in two systems can be optimally separated into three clusters (K=3). Cattle

were identified into clusters to minimize differences within each cluster while maximizing differences among clusters and allowing to categorize the individuals with similar production potential together. The optimum number of K was selected at the point where an elbow/kink appeared at the WSS variation graph which indicated that the

inter cluster variation between (K-1) and K cluster was greater than the variation between K and (K+1) cluster. A similar method for the clustering of bovines has been used by Bezerra *et al.* (2018) for the

classification of crossbred buffaloes in Brazil according to production and reproduction potential based on the variations in milk production, lactation length and the calving interval.

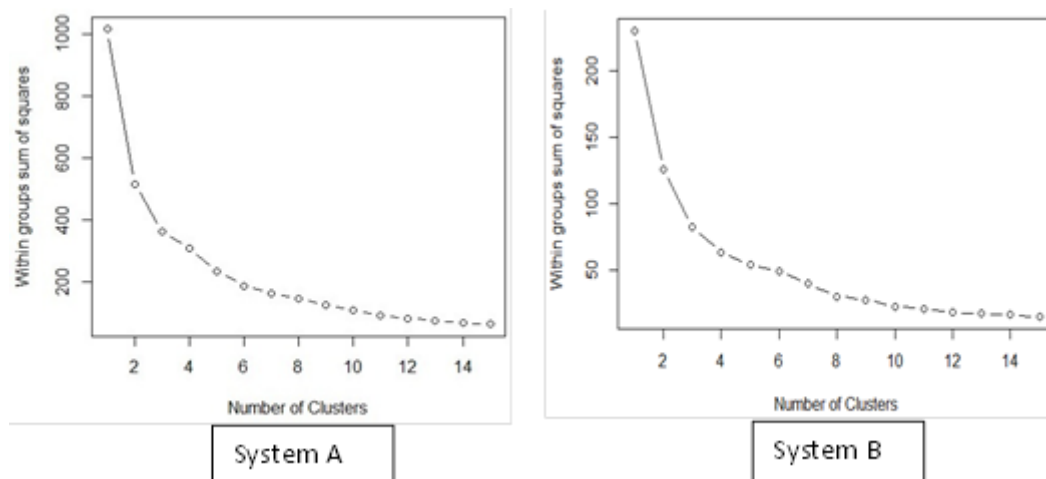


Figure 3. Within group sum of squares in variation dendrograms of the systems A and B

Distribution of the individuals among the clusters are shown in Figures 4 and 5, and the respective cluster summary statistics are presented in Tables 10 and 11. K means clustering plots presented the distribution of the individual animals according to the multivariate analysis of the MP, LL and CI which were aligned to two PCs. The K means clusters on the PCA scatterplot contained the animals with minimum variations within the groups, which were grouped based on the scaled PC values of each individual animal. Total variation captured by the two PCs have been increased in the K means clustering

plots because of the reduction of the dimension of initial data through the PCA.

According to the animal classification in system A, three separate clusters were identified (Figure 4.a). Table 10 shows that the three clusters are significantly different from one another with respect to means of MP, LL and CI ($p < 0.05$). This shows how effectively animals are clustered into different performance groups by the approach used in this study.

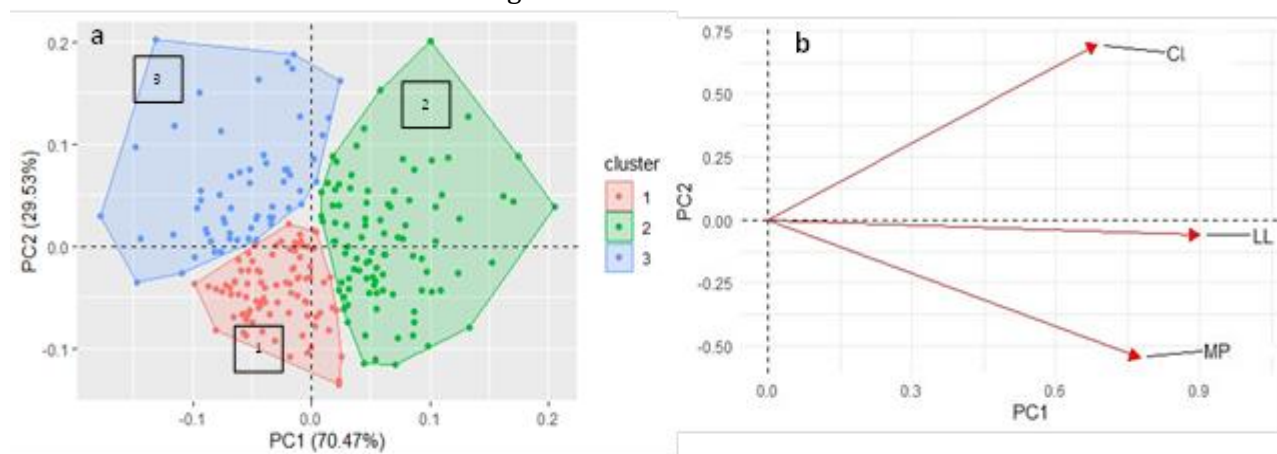


Figure 4. Distribution of animals in system A among different clusters. 4(a) PCA score plot showing three clusters (Cluster 1: red, Cluster 2: green, Cluster 3: blue) based on PC1 and PC2. 4(b) PCA correlation plot indicating the contribution of initial variables (MP, LL and CI) for the case.

A high proportion of animals in cluster 2 are in the same region where the vectors for MP and LL directed (Figure 4.b). Hence, those animals generally exhibit greater performance in MP and LL with many cows also exhibiting high CI (Table 10). Animals in cluster 1 are having moderate MP and LL

with low CI. Greater CI (beyond standard 305 days) generally indicate poor reproductive performance. Hence poor producers in cluster 3 require different management interventions than the high producing second cluster cows.

Table 10. Cluster summaries of system A*

Cluster	Count	MP (L) Average ($\pm$ SE)	LL (days) Average ($\pm$ SE)	CI (days) Average ($\pm$ SE)
1	89	4291 $\pm$ 106 ^a	350 $\pm$ 5 ^a	425 $\pm$ 6 ^a
2	94	5595 $\pm$ 132 ^b	475 $\pm$ 9 ^b	585 $\pm$ 8 ^b
3	58	2230 $\pm$ 106 ^c	293 $\pm$ 11 ^c	508 $\pm$ 12 ^c

*MP: Milk production/lactation, LL: lactation length, CI: calving interval

a, b, c Means of different superscripts in a column are significantly different at $p < 0.05$.

According to the animal classification in system B (Figure 5), animals in cluster 1 were having high MP with an acceptable LL (average of 295 days) with low CI (Table 11), hence can be identified as the most effective producers in system B. Even though the animals in cluster 2 were having MP and LL similar to cluster 1, they were recording high CI. Therefore, the animals in cluster 2 cannot be considered as exhibiting great reproduction potential. Finally, animals in

cluster 3 seem to be the lowest producers. Their moderate CI seems to be due to their unimpressively short lactations (small LL) hence cannot be considered as acceptable performance. Thus, critical decisions have to be made either to replace the cluster 3 cows due to their economic inefficiency or to improve their performance by appropriate management interventions.

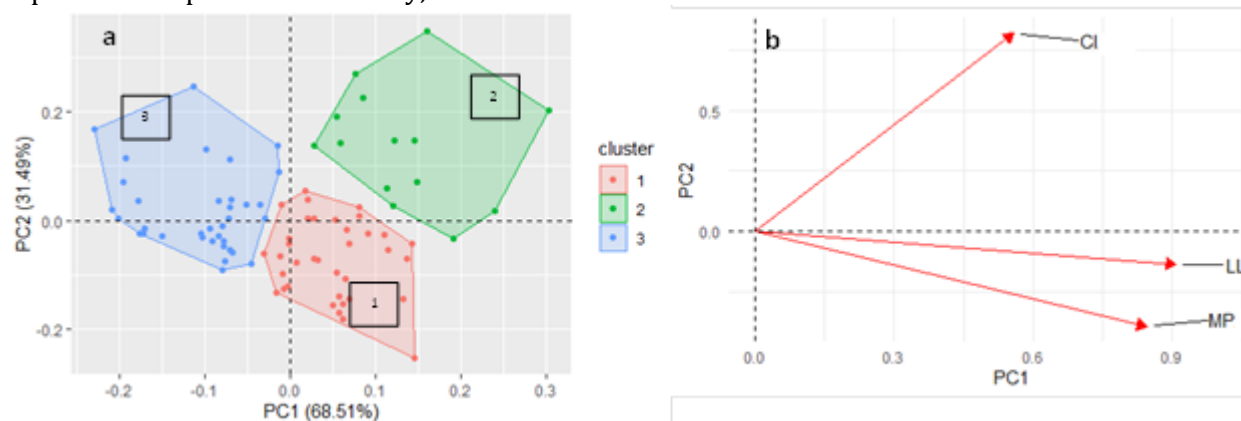


Figure 5. Distribution of animals in system B among different clusters.

5(a) PCA score plot showing three clusters (Cluster 1: red, Cluster 2: green, Cluster 3: blue) based on PC1 and PC2.

5(b) PCA correlation plot indicating the contribution of initial variables (MP, LL and CI) for the case.

Table 11. Cluster summaries of system B*

Cluster	Count	MP (L) Average ($\pm$ SE)	LL (days) Average ($\pm$ SE)	CI (days) Average ($\pm$ SE)
1	37	1784 $\pm$ 105 ^a	295 $\pm$ 5 ^a	431 $\pm$ 13 ^a
2	14	1720 $\pm$ 191 ^a	328 $\pm$ 14 ^a	735 $\pm$ 35 ^b
3	35	626 $\pm$ 54 ^b	173 $\pm$ 11 ^b	413 $\pm$ 15 ^a

*MP: milk production/lactation, LL: lactation length, CI: calving interval

a, b, c Means of different superscripts in a column are significantly different at $p < 0.05$.

When animals are separated into clusters according to their production and reproductive potential based on the phenotypic evaluations, they automatically get categorized according to their nutritional and health requirements as well as the genetic potential for performance. Based on the present approach of clustering of cattle, the management of the farms can take crucial decisions on nutrition, reproductive management, health and culling. Therefore, this approach helps in need based nutritional, reproductive and health management during the implementation of the breeding strategies according to farming objectives. These clusters can be used to implement a breeding strategy with the animals which have performed well under existing conditions. This method is important to a system where the management is unable to estimate the

true breeding values of the animals due to the unavailability of the pedigree records. But management can use this method to select the animals which have performed well. The cluster formations between system A and system B (Figures 4 and 5) are found to be different, which reiterates the effectiveness of grouping the herds into performance-based groups in finding system specific solutions to their unique issues.

Combined production and reproduction performance in Systems A and B and the scope for improvement

Performance data (MP, LL and CI) of the initial three lactations of system A and B were analyzed together to identify the level of variability of those traits in the two systems (Figure 6).

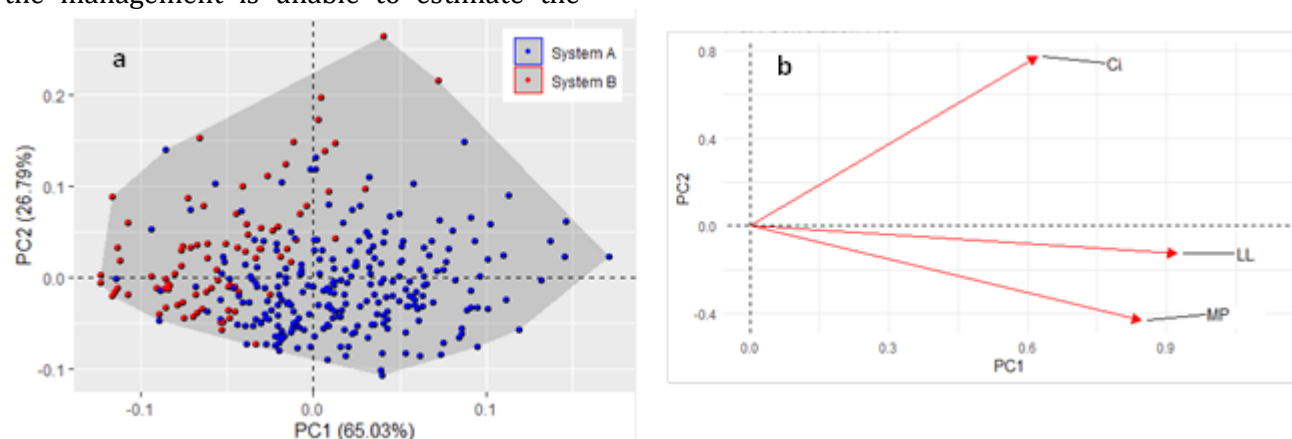


Figure 6. Distribution of animals in systems A and B according to the variation in their performance. 6(a) PCA score plot showing the difference in individual animal's production and reproduction levels among two systems (System A: blue, System B: red) based on PC1 and PC2. 6(b) PCA correlation plot indicating the contribution of initial variables (MP, LL and CI) for the case.

Table 12. Correlations and loading scores for MP, LL and CI from the first two principal components of overall data*

Trait	Correlations		Loading scores	
	PC1	PC2	PC1	PC2
MP	0.84	-0.43	0.60	-0.48
LL	0.92	-0.12	0.66	-0.14
CI	0.62	0.77	0.44	0.86

*MP: milk production/lactation, LL: lactation length (days), CI: calving interval (days)

Results of PC analysis (Figure 6.a) indicated that the individuals in the two systems have a clear demarcation in production potential and the separation of cows into two systems

is better explained along the X-axis (by PC1). As shown in Table 12, the LL was the key trait that contributed to the variability of PC1 closely followed by the MP. Thus, the two

systems are greatly demarcated by performance on production traits.

The combined analysis also indicated that the CI variable has directed more perpendicularly against the MP. It is an indication that the MP behaved more independently with respect to the CI, regardless of the management system and the genotype of cows. This observation aligns with the fact explained by Van Knegsel *et al.* (2022) implying the absence of correlation between MP and CI. Their study indicated that extended CI only prolongs the late lactation period where the milk production is generally low. Consequently, an extended LL, which subsequently results in an extended CI, does not contribute significantly to the total MP.

Conventional animal selection methods are based on the pedigree records and the offspring of the high producing lineages are classified or selected. But, more often than not, pedigree records are missing in commercial herds due to random mating using stud bulls or deficiencies in animal identification and managing breeding records. When the pedigree records are not available, it is important to characterize the animals with their existing performance records and take decisions on whether to select, upgrade or replace the individuals. Performance based clustering of the animals allows for treating and monitoring animals as groups with similar production and reproduction potential, which is important in large-scale commercial dairy management. The categorizations in this study were conducted based on the phenotypic evaluations of the animal's production and reproduction performance. However, to exploit the genetic impact of those traits, the heritability of the traits and breeding values of animals have to be evaluated within and between different crossbred populations. With the improvement of production standards and economic efficiency, the commercial herds of the country must move towards maintaining accurate pedigree records enabling classification of the animals based on routinely estimated breeding value and if successful approaches towards genomic selection, and establishing sustainable breeding populations with

greater capacity for commercial dairy production.

CONCLUSIONS

The use of existing production information in clustering animals under two commercial dairy management systems in the country was attempted. The results revealed that PCA and K means clustering could be successfully employed in classifying the animals according to their production and reproductive performance in making management decisions for herd improvements. Once these clusters are defined, animals in high-performing clusters can be prioritized for retention, breeding, or as sources of replacement stock. Conversely, animals in lower-performing clusters can be targeted for culling or other management interventions with supervised nutrition and breeding. Thus, clustering helps to identify and select superior animals systematically, especially in settings where resources for individual genetic evaluations may be limited. The success of the proposed methodology on both management scenarios (systems) indicates the robustness and applicability of the clustering method in implementing need based, group specific management strategies in the commercial dairy farms in Sri Lanka.

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