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PRINCIPAL COMPONENT ANALYSIS OF BODY WEIGHT TRAITS AND SUBSEQUENT MILK PRODUCTION IN RED STEPPE BREED HEIFERS

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The main goal of this study was to determine the effects of body weight traits during the rearing period on subsequent milk production of primiparous dairy cows using Principal Component Analysis. Data on lactation performance records of 109 Red Steppe dairy cow progeny of six bulls maintained at the State Enterprise "Pedigree Reproducers" Stepove"" (Mykolayiv region, Ukraine), during 2001–2014, were utilised for the present study. Heifer body weight at birth, 3, 6, 9, 12, 15, and 18 months of age was measured. Records of 305-day milk yield (kg), milk fat percentage (%), milk fat yield (kg), monthly milk yield (kg) and milk fat percentage (%) in the 1st-lactation dairy cows were also available. Principal Components Analysis (PCA) was conducted on the live weights for each heifer between birth and 18 months of age. The first three principal components (PC1-PC3) explained 79.7% of the total variance. Principal component 1 (PC1) showed significant relationship to body weight of heifers at 9, 12, and 15 months of age (post-pubertal period). Body weight at 3 and 6 months of age (pre-pubertal period) had higher scores on the second principal component (PC2). Principal component 3 (PC3) showed significant relationship to body weight of calves at birth. Only groups of heifers with high scores on PC1 and PC2 had significant effect on subsequent milk performance (with the exception of milk fat percentage). Thus, the use of a multivariate technique (Principal Component Analysis) allowed to determine two age intervals of heifers during the rearing period (pre- and postpubertal periods), which were significantly related to subsequent milk production.

Keywords: *body weight, Principal Component Analysis, pre- and post-pubertal periods, milk production, heifers, Red Steppe cattle breed.*

INTRODUCTION

To optimise the profitability of a heifer enterprise, dairy producers should calve heifers at the youngest age possible and strive for a body weight of 550 kg after calving. If these objectives are to be met, heifers need to grow at the highest rate possible without detrimental effects to subsequent milk production. However, researchers have known since the 1960s that rapid growth rates in young heifers can reduce mammary development and subsequent milk production (Lammers *et al.,* 1999).

Many studies have indicated that when pre-pubertal growth rates of heifers increase, subsequent milk yield during first lactation decreases. Swanson (1960) using Jerseys, and Little and Kay (1979) using British Friesians, demonstrated a 15 to 48% decrease in 1st-lactation milk yield by heifers fed high energy diets for higher rates of an average daily gain (ADG). Heifers fed for an ADG in excess of 700 g/day during the prepubertal period had reduced milk yield during first lactation (Gardner *et al.,* 1977; Bettenay, 1985; Peri *et al.,* 1993). The accelerated pre-pubertal growth from 700 to

1000 g/day in Holstein heifers decreased subsequent 1st-lactation fat-corrected milk yield 7.1% (Lammers *et al.,* 1999). A previous study (van Amburgh *et al.* 1998) demonstrated that for Holstein heifers the actual 305-day milk and 4% fat-corrected milk yields of heifers on an accelerated growth treatment (ADG = 1000 g/day) were approximately 5% lower than the milk yields of heifers fed for an ADG of 600 g/day, while the fat and protein percentages were not different.

Other study (Gardner *et al.,* 1988) found no effect on the milk yield of Holstein heifers fed at an ADG in excess of 900 g/day during the pre-pubertal period. Waldo *et al.* (1988) found no effect of accelerated pre-pubertal growth rates from 785 to 995 g/day on subsequent milk yield potential. There was little evidence that Danish dairy and dual-purpose cattle breeds differed in the sensitivity of their subsequent milk yield to excessive rates of gain during the rearing period and also, little evidence supporting the existence of differences among breeds in the response of their nutrient intake or lactational output to the effects of different rearing intensities during pre-pubertal growth (Hohenboken *et al.,* 1995).

In most of the studies cited above, Holsteins and other globally widespread cattle (Jersey, Friesian etc.) breeds were used, whereas in Ukraine the main dairy breed is Red Steppe cattle. This breed was created in the Ukraine and southern European Russia by crossing of Red East Friesian and Angeln breeds with Ukrainian Grey and later with Swiss Brown and East Friesian breeds. The production per lactation varies from 3000 to 5000 kg (Mason, 1996). The widespread use of Red Steppe cows is due to good feed payment, unpretentiousness, and their adaptability to the steppe zone with its arid climate (Panfilova *et al*., 2021).

Body weight and weight gain at different stages of animal development are generally correlated, making it difficult to study the effect of each variable on reproductive and milk performance in dairy cows independently. Principal component analysis provides a method for explaining the variance-covariance structure among a large number of correlated variables by generating a smaller set of orthogonal linear combinations from the original variables, carrying most of the original variation (Makarechian *et al.,* 1985).

The main goal of this study was to determine the effects of body weight traits during rearing period on subsequent milk production of primiparous dairy cows using Principal Component Analysis.

MATERIAL AND METHODS

The data on lactation performance records of 109 Red Steppe dairy cow progeny of six bulls maintained at the State Enterprise "Pedigree Reproducers 'Stepove'" (Mykolayiv region, Ukraine), during 2001–2014, were utilised for the present study. The heifer body weight at birth (WB), 3 (W3), 6 (W6), 9 (W9), 12 (W12), 15 (W15), and 18 (W18) months of age were measured. Records of 305-day milk yield (kg), milk fat percentage (%), milk fat yield (kg), monthly milk yield (kg), and milk fat percentage (%) in the 1st-lactation dairy cows were also available. Mean values (± *SE*) of 305-day milk yield and milk fat percentage in primiparous cows during study period were 3834.1 ± 62.3 kg and 3.63 ± 0.01%, respectively.

The live weight values for each heifer between birth and 18 months of age were processed by Principal Components Analysis (PCA) using STATISTICA v.7.0 software (StatSoft, Tulsa, OK, USA). This analysis aimed to find a way to summarise the information contained in several original variables (live weight of heifers of different age groups) into a smaller set of new composite variables, called "Principal Components" (PCs), with a minimum loss of information (Buzanskas *et al.,* 2013). Phenotypic correlations between the PCs with the original weight traits (factor loadings) were also calculated. According to the Kaiser (1960) criterion, only the PCs with eigenvalues above the units were used to select ones that explained for most of the variation of the data. The Principal Component scores (indices) for each heifer were considered as potential predictors of the milk performance.

All heifers were assigned to one of three groups according to the PC scores — G1, G2, and G3 (Table 1). One-way ANOVA was used for milk production performance in the 1st-lactation dairy cows using three groups (G1, G2 and G3) based on the PC scores as independent variables using STATISTICA v.7.0 software (StatSoft, Tulsa, OK, USA).

Table 1. Minimum and maximum values of PC1, PC2, and PC3 scores for different heifer groups

PC's	Groups					
	G1		G2		G3	
	n	min…max	n	min…max	n	min…max
PC1	32	≤ –0.200	38	–0.199…+0.750	39	≥ +0,751
PC2	36	≤ –0.300	38	–0.299…+0.360	35	≥ +0,361
PC3	34	≤ –0.390	41	–0.389…+0.470	34	≥ +0,471

Wood's lactation model (Wood, 1967) was used to describe milk yield lactation curves from the 1st through 10th month of lactation based on the average monthly milk yield estimates:

$$Yt = ab^t e^{-ct}, \qquad (1)$$

where Yt – milk production (kg) at time t; a – initial milk yield, b – rate of increase until the peak is reached, and c – rate of decline after peak production.

Peak yield (kg) was defined as:

$$Y_{\max} = a\left(\frac{b}{c}\right)^b e^{-b}, \qquad (2)$$

and time of peak yield (day) was:

$$T_{\max} = \frac{b}{c}. \quad (3)$$

Persistency in Wood's model was estimated as:

$$Persistency = c^{-(b+1)}. \quad (4)$$

The goodness of fit achieved with the model was evaluated using the coefficient of determination (R^2).

The curve of Wood's lactation model generally gave the lowest values for the error mean square (Papajcsik and Bodero, 1988).

RESULTS

The correlation coefficients between live body weight estimates at different age of dairy heifers are presented in Table 2. The correlation coefficients ranged from 0.215 (between WB and W6) to 0.724 (between W12 and W15). The relationships between body weight estimates at each two consecutive times of live weight measurement (i.e. W3 vs W6, W6 vs W9, etc.) were positive and highly significant ($p < 0.001$).

Linear correlations of the live weight traits of dairy heifers between birth and 18 months of age with Principal Component 1 (PC1), 2 (PC2) and 3 (PC3) are presented in Table 3. The first three principal components (PC1–PC3) explained 79.7% of the total variance. Principal Component 1 (PC1) showed significant relationship to body weight heifers at 9, 12, and 15 months of age (post-pubertal period). Body weight at 3 and 6 months of age (prepubertal period) had higher scores on the second Principal Component (PC2). Principal Component 3 (PC3) showed significant relationship to body weight of calves at birth.

All heifers were assigned to three groups (G1, G2, and G3) for each PC depending on the set of factor scores. The groups of heifers identified on the basis of PC1 and PC2 scores had significant effect on milk performance in the 1st-lactation dairy cows (with the exception of milk fat percentage) (Table 4). However, there was no statistically significant relationship between body weight of calves at birth (PC3) and subsequent milk production.

One-way ANOVA of groups with different PC1 and PC2 scores confirmed that monthly milk yields in the 1st-lactation dairy cows were significantly different during 3rd to 8th, and during 3rd to 9th months of lactation, respectively (Table 5). No significant differences existed between the PCs groups and monthly milk fat percentages in different months of lactation. Some significant *F*-values for the monthly milk fat percentages appear to be random (Table 5), due to the low number of cattle per group.

Figure 1 shows the lactation curves of the 1st-lactation dairy cows for the three groups according to PC1 scores. The coefficient of determination of variation (R^2) ranged from 83.7% to 88.4% in heifers from different groups. The shape of the lactation curve for milk yield varied visibly between groups.

Table 2. Correlation coefficients between live body weight estimates at different ages of heifers

Trait	WB	W3	W6	W9	W12	W15	W18
WB	X	ns	0.215	ns	ns	ns	0.228
W3		X	0.499	0.254	ns	ns	ns
W6			X	0.577	0.373	0.358	ns
W9				X	0.639	0.685	0.291
W12					X	0.724	0.462
W15						X	0.574
W18							X

ns, not significant

Table 3. Variable loadings of and percentage of the variation explained by the first three Principal Components for the live weight traits of heifers between birth and 18 months of age

Trait	Principal Component		
	PC1	PC2	PC3
WB	0.298	-0.050	**0.932**
W3	0.208	**0.845**	0.042
W6	0.641	**0.605**	0.101
W9	**0.848**	0.189	–0.224
W12	**0.841**	–0.187	–0.112
W15	**0.866**	–0.267	–0.169
W18	0.588	–0.545	0.136
Total variance (%)	43.8	21.7	14.2

PCA loadings > 0.7 are displayed in bold

Table 4. One-way Analysis of Variance ($F_{2;\,106}$; *p*) for total milk production in the 1st-lactation dairy cows using three groups for Principal Components 1, 2, and 3 as independent variables

Parameter	PC1 scores (for three groups)	PC2 scores (for three groups)	PC3 scores (for three groups)
305-days milk yield	5.96**	4.43*	ns
Milk fat percentage	6.25**	ns	ns
Milk fat yield	6.70**	5.04**	ns

* $p \leq 0.05$; ** $p \leq 0.01$. ns, not significant

Lactation curves of the G2 and G3 groups (heifers with high factor scores on PC1) had highest Wood's model coefficient "*a*" and peak yield values (Table 6). Thus, there was a significant effect of live weight during 9–15 months of age (i.e. PC1 scores) on the total milk production in 1st-lactation dairy cows. This effect was primarily associated with different shapes of the lactation curves.

Figure 2 shows the lactation curves of the 1st-lactation dairy cows for the three groups divided according to PC2 scores. The coefficient of determination of variation (R^2) ranged from 83.7% to 89.9% in heifers from different groups. The

Table 5. One-way Analysis of Variance ($F_{2;\,106}$; p) for monthly milk yields and monthly milk fat percentages in the 1st-lactation dairy cows using three groups for Principal Components 1, 2, and 3 as independent variables

Month of lactation	Milk yield			Milk fat percentage		
	PC1 scores (for three groups)	PC2 scores (for three groups)	PC3 scores (for three groups)	PC1 scores (for three groups)	PC2 scores (for three groups)	PC3 scores (for three groups)
1	ns	ns	ns	4.03*	7.88***	ns
2	ns	ns	ns	ns	ns	ns
3	5.15**	4.95**	ns	ns	ns	ns
4	5.79**	6.34**	ns	ns	3.45*	ns
5	5.64**	6.79**	ns	ns	ns	ns
6	5.40**	6.94***	ns	ns	ns	ns
7	5.06**	6.82**	ns	ns	ns	ns
8	4.11*	5.73**	ns	ns	ns	5.02**
9	ns	4.45*	ns	ns	ns	2.83#
10	ns	ns	ns	4.04*	ns	5.69**

* $p \le 0.05$; ** $p \le 0.01$; *** $p \le 0.001$. ns, not significant

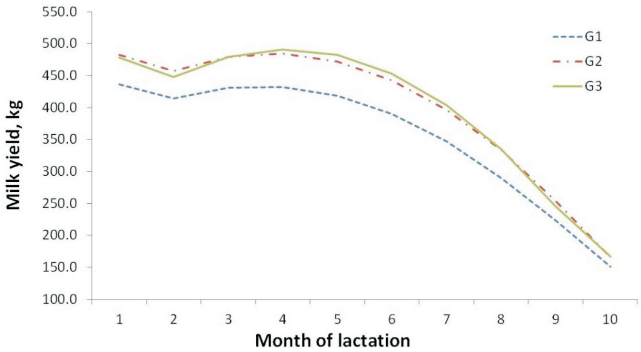

Fig. 1. Lactation curves of the 1st-lactation dairy cows for Principal Component 1 groups.

shape of the lactation curve for milk yield differed markedly in heifers from group G2 compared to the other groups. The monthly milk yields were the greatest for G2 group at 4th to 5th months of lactation (Fig. 2). Lactation curves of the G2 group (heifers with average factor scores on PC2) had the highest Wood's model coefficient "*b*" and peak yield values (Table 7). There was a significant effect of live weight during 3–6 months of age (i.e., PC2 scores) on the 305-days milk yield and milk fat yield in the 1st-lactation dairy cows.

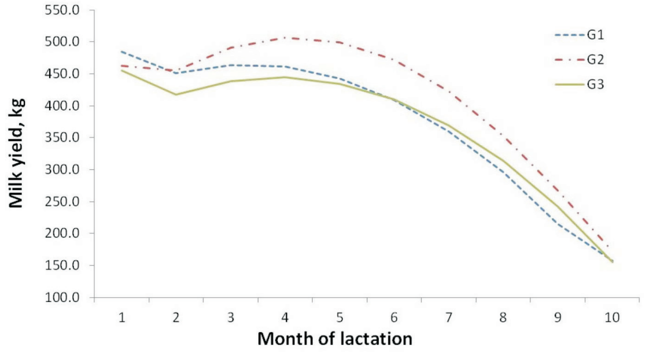

Fig. 2. Lactation curves of the 1st-lactation dairy cows for Principal component 2 groups.

This effect was also associated with a difference in the shape of the lactation curves. Thus, the use of a multivariate technique (Principal Component Analysis) allowed to determine two age intervals of heifers during the rearing period, which were significantly related to subsequent milk production.

DISCUSSION

We found a significant effect of live weight during 9–15 months of age (i.e. postpubertal period) and of live weight during 3–6 months of age (i.e. prepubertal period) on the total milk production in primiparous Red Steppe dairy cows.

Previously, low correlations ($r < 0.2$) were of weight, gain, and feed intake with subsequent milk production. However, several published reports indicate that heifer growth plays an important role in milk production (Lee *et al.,* 1988).

Selection for milk yield in dairy cattle leads to an increase in body growth capacity of heifers and milk yield of cows. This implies a positive relationship between the growth rate of heifers in the rearing period and their subsequent milk yield potential. The relationship, however, is not straightforward, because a high pre-pubertal growth rate caused by an increased feeding level often leads to reduced milk yield (Sejrsen *et al.,* 2000). Based on an intra-herd multiple regression analysis, body weight was found to be a slightly more important source of the intra-herd variation in actual first-lactation Holstein production than was age. The estimate of the genetic correlation between milk production and

Table 6. Estimated Wood's model coefficients (*a, b, c*) and parameters (persistency, peak day and peak yield) of 1st-lactation dairy cows for PC1 groups

PC1 group	*a*	*b*	*c*	R^2	Persistency	Tmax, days	Ymax, kg
G1	487.89 ± 35.80	0.4744 ± 0.1581	0.1945 ± 0.0423	0.884	11.2	74.4	463.4
G2	535.60 ± 43.00	0.4901 ± 0.1716	0.1914 ± 0.0456	0.861	11.8	78.1	520.1
G3	526.99 ± 47.26	0.5330 ± 0.1903	0.2024 ± 0.0502	0.837	11.6	80.3	518.2

Table 7. Estimated Wood's model coefficients (*a, b, c*) and parameters (persistency, peak day and peak yield) in 1st-lactation dairy cows for PC2 groups

PC2 group	*a*	*b*	*c*	R^2	Persistency	Tmax, days	Ymax, kg
G1	546.19 ± 38.72	0.4441 ± 0.1559	0.1975 ± 0.0425	0.899	10.4	68.6	502.1
G2	512.39 ± 46.64	0.6091 ± 0.1892	0.2125 ± 0.0490	0.837	12.1	87.4	529.2
G3	496.84 ± 41.55	0.4421 ± 0.1787	0.1809 ± 0.0475	0.839	11.8	74.5	474.0

age-adjusted weight was 0.45 (Harville and Henderson, 1966).

According to Hoffman *et al.* (1996), in terms of growth intensity, there is a critical period between the 3rd and approximately the 9–10th month of age. In this period, the mammary gland grows 3.5 times faster than other cells of the body, and excessive energy in the diet leads to the replacement of glandular cells by fat tissue.

Decreased mammary development has been observed as pre-pubertal average daily gain is increased; however, responses in first-lactation milk production to alterations in pre-pubertal ADG have been inconsistent across several experiments (Zanton and Heinrichs, 2005).

In Holstein-Friesian heifers, high feed allowance during the pre-pubertal period did not affect milk production during the first two lactations, but did reduce milk production in lactation #3. It is possible that the expected negative effect of accelerated pre-pubertal growth was masked by greater calving body weight (BW), as BW-corrected milk yield declined with increasing pre-pubertal feed allowance (Macdonald *et al*., 2005). Thus, these results suggest that accelerated pre-pubertal growth may reduce mammary development in grazing dairy cows, but this does not affect milk production in early lactations because of superior size.

There are, however, a number of experiments in which the negative effect of high feeding level in the pre-pubertal period on subsequent milk yield was not observed. It was also shown (Pirlo *et al.* 1997) that Italian Friesian heifers can tolerate an average daily gain of approximately 800 g from 100 to 300 kg of BW without any detrimental effect on future milk production.

In some cases, this lack of effect may be due to very small growth rate differences between treatment groups, a small number of animals, or because treatment periods were outside the critical period (Sejrsen and Purup, 1997). Holstein heifers can achieve higher ADG without marked undesirable effects. Moreover, higher ADG has an accelerating effect on the puberty onset (Le Cozler *et al.,* 2008).

It has been concluded that milk yield responses were associated quadratically with increasing pre-pubertal ADG; 1st-lactation production increased as pre-pubertal gains increased up to 799 g/day, the point of maximal milk production, whereas further increases in pre-pubertal ADG were associated with lower milk production. In that model, milk production was maximal at pre-pubertal ADG of 836 g/day. Milk protein yield was quadratically affected by alterations in pre-pubertal ADG, and milk protein yield was maximised when pre-pubertal growth occurred at 836 g/day (Zanton and Heinrichs, 2005).

In New Zealand dairy heifers, there was a positive curvilinear relationship between BW and milk production. The response to an increase in BW was greater for lighter heifers compared with heavier heifers, indicating there could be benefits of preferentially feeding lighter heifers to attain heavier BWs. These results show the potential to increase first-lactation milk production of New Zealand dairy heifers by increasing heifer BWs (Handcock *et al.,* 2019).

Pre-pubertal gains somewhere between 600 and 700 g/day result in subsequent maximum milk production for large-breed dairy cattle, and subsequent milk production was curvilinear and associated with the quadratic function of pre-pubertal ADG (Sejrsen *et al.* 2000). It was also reported (Shamay *et al.* 2005) that ADG of about 700 g/day is optimal for achieving maximum performance. On the other hand, ADG of 900 g/day in young heifers significantly reduced milk fat in the first lactation (Abeni *et al.,* 2000).

Lin *et al.* (1985) observed that weight gain from 350 to 462 d of age was highly correlated, genetically and phenotypically, with 1st-lactation milk, protein, and fat yields. Analysis of the genetic and phenotypic correlations among BW at 9, 15, and 21 months and lactation yields from 2365 mixed breed dairy cows showed a 6.7-kg increase in milk production for each 1 kg of BW at 15 months (Van der Waaij *et al.* 1997). Growth rate during the post-pubertal period in Holstein-Friesian heifers was positively correlated with first lactation milk production, and post-pubertal growth rate management was important in first lactation milk production, but did not affect milk production in subsequent lactations (Macdonald *et al.,* 2005).

On the other hand, nutrition after puberty in Italian Holstein-Friesian heifers had no effect on milk production and milk protein concentration, but milk fat concentration was higher in controls animals than in heifers with post-pubertal accelerated gain diet. Milk fat concentration tended to be higher when heifers were bred at lighter weight; however, milk protein concentration was not. Thus, daily gain after puberty did not affect future milk production (Abeni *et al.,* 2000).

Thus, accelerated post-pubertal growth and early calving in heifers reduced performance during first lactation, but the exact mechanisms could not be determined (Hoffman *et al.,* 1996). Overall, the findings of experiments by Carson *et al.* (2000) indicated that accelerated growth in the pre- or post-pubertal period may not be required.

Different growth intensities of heifers before breeding, even under the same housing system and nutritional conditions, seem to influence their milk production during the first lactation (Uhrinčat' *et al.* 2007). These effects tend to be inversely related in the pre-pubertal phase and exhibit a quadratic relationship post-pubertally.

CONCLUSIONS

The first three Principal Components (PC1–PC3) explained 79.7% of the total variance. Principal Component 1 (PC1) showed significant relationship to body weight heifers at 9, 12, and 15 months of age (post-pubertal period). Higher scores on the second Principal Component (PC2) indicated heifers with higher body weight at 3 and 6 months of age (pre-pubertal period). Principal Component 3 (PC3) showed a significant relationship to body weight calves at birth. Only groups of heifers allocated on the basis of their scores on PC1 and PC2 had significant impact on milk performance in 1st-lactation dairy cows (with the exception of milk fat percentage). One-way ANOVA of groups with different PC1 and PC2 scores confirmed that monthly milk yields in the 1st-lactation dairy cows were significantly different during 3rd to 8th and during 3rd to 9th months of lactation, respectively. The shape of the lactation curve for milk yield varied visibly between groups. There was a significant effect of live weight during 9–15 months of age (i.e. post-pubertal period) on the total milk production in the 1st-lactation dairy cows. There was also a significant effect of live weight during 3–6 months of age (i.e. prepubertal period) on the 305-days milk yield and milk fat yield in 1st-lactation dairy cows. Thus, the use of a multivariate technique (Principal Component Analysis) allowed to determine two age intervals of heifers during the rearing period (pre- and post-pubertal periods), which were significantly related to subsequent milk production.

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ĶERMEŅA MASAS PAZĪMJU UN TURPMĀKĀS PIENA PRODUKTIVITĀTES GALVENO KOMPONENŠU ANALĪZE SARKANO STEPJU ŠĶIRNES TELĒM

Rakstā ar galveno komponenšu metodi tiek analizēta teļu ķermeņu masas pazīmju ietekme uz turpmāko piena produktivitāti pirmās laktācijas govīm.