Application of Wood's model to lactation curve of Italian Heavy Draft horse mares

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ABSTRACT

The aim of this work was to study, using Wood's model, the lactation curve in Italian Heavy Draft horse (IHDH) mares, both for milk yield and composition. Interest in mare's milk has grown for use in human nutrition, as a substitute for human and cow milk for premature newborns and allergic children. For this study, 7 IHDH mares were used. Milk yield was evaluated from d 15 to 180 postpartum (every 15 d). Wood's lactation model was used to describe milk yield, fat, protein, and lactose lactation curves in the first 180 d in milk (DIM), with a prediction to 210 DIM. Mean values recorded across the considered lactation period for milk yield and constituents were 16.11 kg of milk/d, 11.38 g of fat/kg, 15.54 g of protein/kg, and 69.72 g of lactose/kg. The lactation curve showed a peak at 69 DIM, with a persistence index of 6.26. Fat (g/kg) and protein (g/kg) lactation curves decreased during the lactation period; instead, the lactose (g/kg) curve increased from the first to the last DIM. The coefficient of determination values indicated a good model fit by Wood's model application to IHDH mare lactation. The research showed good aptitude of a heavy horse breed, such as IHDH, for milk production.

Key words: Wood's model, mare milk, lactation curve

INTRODUCTION

The Italian Heavy Draft horse (IHDH) originated in the northeastern part of Italy at the beginning of the 20th century. It was mainly used in the large farms of the area for plowing the fields or in the army for hauling field artillery. Currently, according to the National Association of Italian Heavy Draft Horses, more than 6,000 of these horses are reared in Italy, and their main use is in meat production (Tateo et al., 2008; De Palo et al., 2009), but potential exists for use in milk pro-

duction. In fact, mare's milk, because of its nutritional characteristics, is a product of great interest not only for human consumption (children, adults, or convalescent consumers), but also as a therapeutic agent and for cosmetic purposes. Recently, interest in mare's milk has grown for use in human nutrition. In particular, the use of mare's milk has been proposed as a substitute for cow milk in allergic children, as a substitute for mother's milk for premature newborns, and for other therapeutic purposes (Curadi et al., 2001; Doreau and Martin-Rosset, 2002; Caroprese et al., 2007). In fact, mare's milk has interesting nutritional characteristics, especially with regard to diets for the elderly, convalescents, and infants (Stoianova et al., 1988; Marconi and Panfili, 1998).

The lactation curve is a graphical representation of the daily milk yield and several empirical models have been developed to describe it (Wood, 1967; Yadav et al., 1977; Dhanoa, 1981; Wilmlink, 1987; Gipson and Grossman, 1989; Cappio-Borlino et al., 1995; Sherchand et al., 1995; Vargas et al., 2000; Ruiz et al., 2000). Particularly, the use of nonlinear models such as Wood's model (Wood, 1967) in dairy cows is common (Macciotta et al., 2005; Choumei et al., 2006). It is also used to describe lactation curves of small ruminants (Tufarelli et al., 2009). Wood's model has been applied to the mare lactation curve and to its major constituents (Santos and Silvestre, 2006, 2008), but nothing is known about heavy horse breeds. Little scientific information exists about both milk quality and quantity production of IHDH. A better understanding of these aspects of IHDH is necessary. The aim of this work was to study, using Wood's model, the lactation curve in IHDH mares, both for milk yield and composition, to better understand the milk yield capacity of heavy horse breeds.

MATERIALS AND METHODS

Animal Management

Data for this study were collected from 7 multiparous nursing IHDH mares aged 6 to 10 yr, with an average

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Table 1. Chemical composition of grass, commercial concentrate, and hay supplied to mares during the study period

Item (g/kg of DM)	Pasture	Concentrate	Hay ¹
DM (%)	420	865	882
CP	155	160	53
Ether extract	41	43	21
Crude fiber	210	82	320
Ash	138	73	58

¹Mixed oat-vetch hay.

BW (mean $\pm$ SD) of 822.3 ± 61.8 kg. These mares were allowed access to pasture during the daytime (except for milking, when they stayed indoors 24 h for milk collection). Pasture samples were collected randomly every 3 mo. Pasture, hay, and concentrate samples were analyzed according to the Association of Official Analytical Chemists methods (AOAC International, 2000). Each mare was fed with 6 kg of mixed oat-vetch hay and 4 kg of commercial concentrate feed per day. The composition of administered feed is reported in Table 1.

Milk Collection and Analyses

Milk yield was recorded on 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, and 180 DIM. In the same days, milk was also sampled and analyzed. The milk sampling procedure was the same during the entire experiment. The mares and foals were separated for 2 h. The mare and foal were able to see, touch, and smell each other, but the foal was not able to suckle. Then, the 2 teats of the mare were hand milked as completely as possible in the presence of the foal. All milking practice was done without administration of oxytocin. The milk collected was then given to the foal. This operation was repeated every 2 h for 24 h for a total of 12 milkings. The daily milk production was calculated by adding together totals from the 12 milkings. A sample of 50 mL was withdrawn from each milking. Two percent 2-bromo-2-nitro-1,2-propanediol was added to each sample as a preservative and refrigerated at 4°C. The 12 samples were mixed proportionally to the quantity produced at each milking and a sample of 100 mL was taken. The total sample was refrigerated at 4°C and immediately transported to the laboratory and analyzed, within 2 h after the last milking, for protein, fat, lactose, casein, urea (IDF, 1993, IDF-20B; IDF, 1996, FIL/IDF 1D), and SCC (IDF, 1995, FIL/IDF 148 method C).

Samples were then prepared for chemical analysis and analyzed by the MilkoScan FT 6000 (Foss Electric A/S, Hillerød, Denmark) by Fourier transformed infrared analysis. Somatic cell count was made by the Fossomatic 5000 (Foss Electric A/S).

Statistical Analysis

Average daily milk yield and composition (protein, fat, and lactose) were used to test Wood's model fit (Wood, 1967):

$$Y_t = at^be^{-ct},$$

where Y_t = milk production (kg) at time t , e = neper number, a = initial milk yield, b = rate of increase until the peak is reached, and c = rate of decline after peak production. Peak yield was defined as $a(b/c)^{b-1}$, and time of peak yield was b/c . Persistency in Wood's model is a dimensionless quantity. However, it can be used for comparison of curves (Santos and Silvestre, 2008):

$$s = -(b + 1)\ln(e).$$

The model parameters were estimated by nonlinear least squares using PROC NLIN of SAS (SAS Institute, 1999).

RESULTS AND DISCUSSION

Milk Composition and Milk Yield

In comparison with bovine milk, equine milk contains less fat, protein, and inorganic salts, but more lactose, with a concentration close to that in human milk (Unmack-Lowe et al., 2010). Moreover, a mare produces 2 to 3.5 kg of milk/100 kg of BW to sustain the growth of the foal (Ofstedal et al., 1983; Doreau, 1994). Results reported in Table 2 (2.25 kg/100 kg of BW) agree with this range.

The average daily milk yield (Table 2) was 16.11 kg, with a minimum yield of 10.53 kg and a maximum yield of 20.84 kg. These results are only in part similar to those obtained by other authors. In fact, despite obtaining similar data regarding kilograms of milk per 100 kg of BW, confirming a range of 2 to 3.5 kg of milk/100 kg of BW (Gibbs et al., 1982; Doreau and Boulot, 1989; Santos and Silvestre, 2008), those authors observed lower average daily production in more light-weight horse breeds such as the Quarter horse (10.9 kg; Gibbs et al., 1982) or Lusitano horses (12.4 kg; Santos and Silvestre, 2008). The higher milk yield due to the greater BW of IHDH compared with other horse breeds is not directly correlated with the protein and dietary requirements (Cunha, 1991), so milk production could be cheaper.

The fat content averaged 11.07 g/kg. These results are comparable to what was reported in the literature by

Table 2. Summary statistics of daily mare milk yield and composition across 180 d of lactation¹

Item	n	Mean $\pm$ SE	CV	Minimum	Maximum
Milk yield (kg)	84	16.11 $\pm$ 2.95	16.79	10.53	20.84
Milk yield (kg/100 kg of BW)	84	2.25 $\pm$ 0.1	16.98	1.40	2.78
Fat (g/kg)	84	11.07 $\pm$ 0.43	35.27	4.00	21.10
Total protein (g/kg)	84	15.54 $\pm$ 0.33	16.64	11.60	25.50
CN (g/kg)	84	10.40 $\pm$ 0.37	10.42	7.60	17.90
Lactose (g/kg)	84	69.14 $\pm$ 0.27	3.03	62.00	72.50
MUN (mg/dL)	84	30.72 $\pm$ 1.36	29.02	15.99	48.47
SCC ($\times 10^3$ /mL)	84	14.55 $\pm$ 0.99	51.63	4.00	34.00

¹All samples were taken at 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, and 180 DIM from 7 mares.

Malacarne et al. (2002) and Doreau and Martin-Rosset (2002). Caroprese et al. (2007), investigating milk production in Murgese breed mares, showed similar results in hand-milked mares (10.6 g/kg), with an increase in fat content in machine-milked mares (16.3 g/kg), stating that machine milking results in better emptying of milk from alveoli and galactophorous ducts. Protein content averaged 15.54 g/kg, with a minimum of 11.60 and a maximum of 25.50 g/kg. Protein average content is lower than that reported in Lusitano horses by Santos and Silvestre (2008; 18.4 g/kg), in Murgese horses by Caroprese et al. (2007; 18.5 to 19.9 g/kg), and in other mares (Uniacke-Lowe et al., 2010; 21.4 g/kg). The average casein content (10.40) represents the major protein component in this horse breed (casein: whey protein ratio = 2.03:1). This result is different from what Uniacke-Lowe et al. (2010) reported in various horse breeds. In fact, those authors reported that this ratio ranged from 0.84:1 in Orlov Trotters to 1.63:1 in Italian Saddle horses. According to our results, milk produced by IHDH mares is characterized by a lower content in protein compared with milk produced by other horse breeds. Moreover, it is characterized by a higher casein:whey protein ratio. This represents an interesting characteristic, considering what is reported in most of the literature about whey proteins, particularly β -LG. In fact, whey proteins are considered the most responsible (Malacarne et al., 2002), but not the only (Nakajima et al., 1996), proteins for the onset of allergies to milk proteins that affect a significant percentage of infants nourished with maternal milk replacements.

Lactose content ranged from 62.00 to 72.50 g/kg, with an average value of 69.14 g/kg. These values are higher than those for Lusitano mares (Santos and Silvestre, 2008), but similar to that described by Park et al. (2006) and Caroprese et al. (2007).

Little literature has been produced about SCC in mare's milk. This parameter is very low (14.55×10^3 /mL) when compared with SCC in milk of other species, such as cows (Schukken et al., 2003) or small ruminants (Gonzalo et al., 1994), but similar to what was reported for Murgese milk by Caroprese et al. (2007).

Wood Model

The Wood model was applied to data collected in the first 6 mo of lactation, and milk production until the seventh month was calculated (Figure 1). By applying Wood's model, peak lactation was reached at d 69 (Table 3), with an average peak yield of 17.01 kg/d ($R^2 = 0.91$), and an estimated total yield of 2,886 kg at 180 DIM. These results demonstrated greater milk production at a later peak day if compared with other mare breeds studied to estimate their lactation curves. Santos and Silvestre (2006), applying the same hand-milking method, with the administration of oxytocin, in Lusitano mares observed a lower and earlier maximum yield (14.0 kg at d 31), with a total yield estimated of 2,020 kg. Doreau and Boulot (1989), applying mechanical milking, showed milk production at 180 DIM between 2,020 and 2,100 kg. Gibbs et al. (1982), applying the weigh-suckle-weigh method in Quarter horses, observed a maximum yield of 13.4 kg. Moreover, other authors studying the horse lactation curve in different breeds and applying Wood's model observed a lactation peak at 2 mo of lactation (Ofteidal et al., 1983; Doreau et al., 1990; Doreau and Martuzzi, 2006).

The estimated milk yield at 210 DIM is 14.09 kg with an estimated persistency (s value) of 6.26. Grossman et al. (1999) assessed that persistency of lactation yield in cows is an important element of total yield; cows are persistent if they tend to maintain their peak yield within a lactation period. So, great persistency could be positively correlated with milk yield capacity and aptitude.

These values are greater than what was observed by Santos and Silvestre (2006) in Lusitano mares (persistency = 6.1; milk yield at d 180 = 7.6 kg), although they reported a similar shape of lactation curves obtained for fat, protein, and lactose, both for concentration (g/kg; respectively, $R^2 = 0.90$, 0.97, and 0.98) and total yield (kg; respectively, $R^2 = 0.87$, 0.98, and 0.81). In fact, fat and protein concentration curves showed a continuous decrease, probably because of a dilution effect due to increasing milk production (Santos and Sil-

Table 3. Estimated Wood's model parameters (a, b, and c), peak (day and yield), yield at 180 DIM, persistency, and R² for milk yield and composition of Italian Heavy Draft horse (IHDH) mares

Item	R ²	a ¹	b ²	c ³	Peak		Yield at 210 d	Total yield at 180 d	Persistency
					Day	Yield			
Milk yield (kg)	0.91	8.74	0.2054	-0.2958	69	17.01	14.09	2,886	6.26
Fat (g/kg)	0.90	28.72	-0.1698	-0.2195	—	—	—	—	—
Protein (g/kg)	0.97	35.47	-0.1799	-0.0403	—	—	—	—	—
Lactose (g/kg)	0.98	55.90	0.0542	-0.0198	—	—	—	—	—
Fat (g)	0.87	285.07	-0.0061	-0.4525	—	—	106.67	34,241	5.16
Protein (g)	0.98	423.48	-0.0397	-0.3419	11	282.71	167.01	66,926	4.98
Lactose (g)	0.81	668.79	0.1931	-0.3224	60	1,212.99	954.55	203,987	6.19

¹Scaling factor representing initial average yield.²Rate of increase of peak production.³Rate of decline after peak production ($c \times 10^{-2}$).

vestre, 2008); instead, lactose concentration showed a continuous increase. These last results agree with what has been reported in the literature by other authors for other mare breeds (Mariani et al., 2001; Santos and Silvestre, 2008).

Curves reported in Figure 2 show the protein, fat, and lactose production (g/d). These curves are similar to what was reported by Santos and Silvestre (2008). The fat curve tended to decrease during the lactation period; instead, the protein and lactose curves are similar to the milk yield curve. The differences are in the values registered. Fat production is similar but protein and lactose production is higher than in Lusitano mares. The great protein and lactose production is associated with a higher milk yield and results in a similar percentage of these constituents in milk.

Martin-Rosset et al. (2006) assessed that the lactation peak is influenced by feeding system used and it is

located between the first and the third lactation month. Our lactation peak was at the beginning of the third month, later than that reported by Santos and Silvestre (2008) in Lusitano mares, but in the range expressed by Martin-Rosset et al. (2006). A greater BW gain in foals results in greater energy needs (Doreau, 1994) and probably in greater milk production by mares. Italian Heavy Draft horse foals are characterized by great BW gain. This could explain the great milk yield capacity of IHDH mares.

CONCLUSIONS

Fat, protein, lactose, casein, and nitrogen concentrations in IHDH are similar to those observed in other horse breeds. The difference is in the greater milk yield for IHDH than in other breeds described in the literature. In fact, both the great milk yield and the later

Figure 1. Lactation curves for milk yield (kg), fat, protein, and lactose (g/kg).

Figure 2. Lactation curves for fat, protein, and lactose (g/d).

peak in the lactation curve could justify the use of this breed for milk production. Furthermore, the coefficient of determination values reported in this study showed the goodness of model fit for this horse breed; therefore, this model developed for cattle lactation could be used for IHDH as well. Lactation curve estimation represents a way to calculate the diet requirements of mares and foals. Particularly, it made possible a better formulation of milk replacers for orphan foals in different lactation stages. Moreover, it represents a way to estimate the milk production capacity of IHDH.

REFERENCES

- AOAC International. 2000. Official Methods of Analysis. 17th ed. AOAC International, Arlington, VA.
- Cappio-Borlino, A., G. Pulina, and G. Rossi. 1995. A non-linear modification of Wood's equation fitted to lactation curves of Sardinian dairy ewes. *Small Rumin. Res.* 18:75–79.
- Caroprese, M., M. Albenzio, R. Marino, A. Muscio, T. Zezza, and A. Sevi. 2007. Behavior, milk yield, and milk composition of machine and hand-milked Murgesse mares. *J. Dairy Sci.* 90:2773–2777.
- Choumei, Y., A. K. Kahi, and H. Hirooka. 2006. Fit of Wood's function to weekly records of milk yield, total digestible nutrient intake and body weight changes in early lactation of multiparous Holstein cows in Japan. *Livest. Sci.* 104:156–164.
- Cunha, T. J. 1991. *Horse Feeding and Nutrition*. 2nd ed. Academic Press Inc., San Diego, CA.
- Curadi, M. C., P. G. Giampietro, P. Lucenti, and M. Orlandi. 2001. Use of mare milk in pediatric allergology. Pages 647–649 in *Proc. XIV Italian Congress of Associazione Scientifica Produzioni Animali*, Firenze, Italy. University of Florence, Florence, Italy.
- De Palo, P., A. Maggiolino, A. Lestingi, and A. Tateo. 2009. Comparison between carcasses of artificially suckled I.H.D.H. (Italian Heavy Draught Horse) foals slaughtered at 6 months and traditional carcasses obtained by foals slaughtered at 11 and 18 months. *Italian J. of Anim. Sci.* 8(Suppl. 2):700–702.
- Dhanoa, M. S. 1981. A note on an alternative form of the lactation model of Wood. *Anim. Prod.* 32:349–351.
- Doreau, M. 1994. Le lait de jument et sa production: Particularités et facteurs de variation. *Lait* 74:401–418.
- Doreau, M., and S. Boulot. 1989. Recent knowledge on mare milk production: A review. *Livest. Prod. Sci.* 22:213–235.
- Doreau, M., S. Boulot, J.-P. Barlet, and P. Patureau-Mirand. 1990. Yield and composition of milk from lactating mares: Effect of lactation stage and individual differences. *J. Dairy Res.* 57:449–454.
- Doreau, M., and W. Martin-Rosset. 2002. Horse. Pages 630–637 in *Encyclopedia of Dairy Sciences*. Vol. 2. H. Roginski, J. W. Fuquay, and P. F. Fox, ed. MPG Books Ltd., Bodmin, UK.
- Doreau, M., and F. Martuzzi. 2006. Milk yield of nursing and dairy mares. Page 57 in *Nutrition and Feeding of the Broodmare*. Proc. 3rd Eur. Workshop Equine Nutr. EAAP Publication No. 120. N. Miraglia and W. Martin-Rosset, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.
- Gibbs, P. G., G. D. Potter, R. W. Blake, and W. C. McMullan. 1982. Milk production of Quarter horse mares during 150 days of lactation. *J. Anim. Sci.* 54:496–499.
- Gipson, T. A., and M. Grossman. 1989. Diphasic analysis of lactation curves in dairy goats. *J. Dairy Sci.* 72:1035–1044.
- Gonzalo, C., J. A. Carriedo, J. D. Gomez, L. D. Gomez, and F. San Primitivo. 1994. Diurnal variation in the somatic cell count of ewe milk. *J. Dairy Sci.* 77:1856–1859.
- Grossman, M., S. M. Hartz, and W. J. Koops. 1999. Persistency of lactation yield: A novel approach. *J. Dairy Sci.* 82:2192–2197.
- IDF. 1993. Milk: Determination of nitrogen content, Part 3: Block digestion method (semi-micro rapid routine method). Annex—Modified procedure for milk products. Standard FIL-IDF 20B. International Dairy Federation, Brussels, Belgium.
- IDF. 1995. Enumeration of somatic cells. Standard FIL-IDF 148C. International Dairy Federation, Brussels, Belgium.
- IDF. 1996. Proceedings of the International Seminar, Crete, Greece. Bulletin no. 9603. International Dairy Federation, Brussels, Belgium.
- Macciotta, N. P. P., D. Vicario, and A. Cappio-Borlino. 2005. Detection of different shapes of lactation curve for milk yield in dairy cattle by empirical mathematical models. *J. Dairy Sci.* 88:1178–1191.

- Malacarne, M., F. Martuzzi, A. Summer, and P. Mariani. 2002. Protein and fat composition of mare's milk: Some nutritional remarks with reference to human and cow's milk. *Int. Dairy J.* 12:869–877.
- Marconi, E., and G. Panfili. 1998. Chemical composition and nutritional properties of commercial products of mare milk powder. *J. Food Compost. Anal.* 11:178–187.
- Mariani, P., A. Summer, F. Martuzzi, P. Formaggioni, A. Sabbioni, and A. Lucio Catalano. 2001. Physicochemical properties, gross composition, energy value and nitrogen fractions of Haflinger nursing mare milk throughout 6 lactation months. *Anim. Res.* 50:415–425.
- Martin-Rosset, W., W. D. Austbo, and M. Coenen. 2006. Energy and protein requirements and recommended allowances in lactating mares. Page 89 in *Nutrition and Feeding of the Broodmare*. Proc. 3rd Eur. Workshop Equine Nutr. EAAP Publication No. 120. N. Miraglia and W. Martin-Rosset, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.
- Nakajima, H., S. Hachimura, S. Nishiwaki, T. Katsuki, N. Shimojo, A. Ametani, Y. Kohno, and S. Kaminogawa. 1996. Establishment and characterization of α_{s1} -casein-specific T-cell lines from patients allergic to cow's milk: Unexpected higher frequency of CD8⁺ T-cell lines. *J. Allergy Clin. Immunol.* 97:1342–1349.
- Oftedal, O. T., H. F. Hintz, and H. F. Schryver. 1983. Lactation in the horse: Milk composition and intake by foals. *J. Nutr.* 113:2096–2106.
- Park, Y. W., H. Zhang, B. Zhang, and L. Zhang. 2006. Mare milk. Pages 275–296 in *Handbook of Milk of Non-Bovine Mammals*. Blackwell Professional Publishing, Ames, IA.
- Ruiz, R., L. M. Oregui, and M. Herrero. 2000. Comparison of models for describing the lactation curve of Latxa sheep and an analysis of factors affecting milk yield. *J. Dairy Sci.* 83:2709–2719.
- Santos, A. S., and A. M. Silvestre. 2008. A study of Lusitano mare lactation curve with Wood's model. *J. Dairy Sci.* 91:760–766.
- Santos, A. S., and A. M. D. Silvestre. 2006. The lactation curve in Lusitano mares—A preliminary study. Page 149 in *Nutrition and Feeding of the Broodmare*. Proc. 3rd Eur. Workshop Equine Nutr. EAAP Publication No. 120. N. Miraglia and W. Martin-Rosset, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.
- SAS Institute. 1999. *SAS/STAT User's Guide: Statistics*. SAS Institute Inc., Cary, NC.
- Schukken, Y. H., D. J. Wilson, F. Welcome, L. Garrison-Tikofsky, and R. N. Gonzalez. 2003. Monitoring udder health and milk quality using somatic cell counts. *Vet. Res.* 34:579–596.
- Sherchand, L., R. W. McNew, D. W. Kellogg, and Z. B. Johnson. 1995. Selection of a mathematical model to generate lactation curves using daily milk yields of Holstein cows. *J. Dairy Sci.* 78:2507–2513.
- Stoianova, L. G., L. A. Abramova, and K. S. Ladodo. 1988. Sublimation-dried mare's milk and the possibility of its use in creating infant and dietary food products. *Vopr. Pitan.* 2:64–67.
- Tateo, A., P. De Palo, E. Ceci, and P. Centoducati. 2008. Physicochemical properties of meat of Italian Heavy Draft horses slaughtered at the age of eleven months. *J. Anim. Sci.* 86:1205–1214.
- Tufarelli, V., M. Dario, and V. Laudadio. 2009. Forage to concentrate ratio in Jonica breed goats: Influence on lactation curve and milk composition. *J. Dairy Res.* 76:124–128.
- Uniacke-Lowe, T., T. Huppertz, and P. F. Fox. 2010. Equine milk proteins: Chemistry, structure and nutritional significance. *Int. Dairy J.* 20:609–629.
- Vargas, B., W. J. Koops, M. Herrero, and J. A. M. Van Arendonk. 2000. Modeling extended lactations of dairy cows. *J. Dairy Sci.* 83:1371–1380.
- Wilmink, J. B. M. 1987. Adjustment of test-day milk, fat and protein yield for age, season and stage of lactation. *Livest. Prod. Sci.* 16:335–348.
- Wood, P. D. P. 1967. Algebraic models of the lactation curve in cattle. *Nature* 216:164–165.
- Yadav, M. C., B. G. Katpatal, and S. N. Kaushik. 1977. Study of lactation curve in Haryana and its Friesian crosses. *Indian J. Anim. Sci.* 47:607–609.