Lactation in the Horse: Milk Composition and Intake by Foals

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ABSTRACT Milk samples averaging 500 ml were collected weekly from 10 to 54 days postpartum from five lactating mares. Samples were obtained by hand milking after oxytocin administration and while the foal nursed. Dry matter, protein and gross energy were higher in samples obtained at 10 and 17 days postpartum than those obtained during the midlactation period of 24–54 days. Midlactation samples averaged 10.5% dry matter, 1.29% fat, 1.93% protein, 6.91% sugar and 50.6 kcal/100 g. Protein comprised 22% of milk energy. Milk intake was estimated in five foals from deuterium oxide (D_2O) turnover to be 16, 15 and 18 kg/day at 11, 25 and 39 days postpartum. Milk intake differed significantly among foals and at the various postpartum ages, whether intake was expressed as a daily amount, as a percent of foal body weight, per kilogram$^{0.75}$ or per gram of foal body weight gain. Milk production was equivalent to 3.1% of the mare's body weight at 11 days postpartum, 2.9% at 25 days and 3.4% at 39 days. On the basis of metabolic body size milk output by the mare was 149 g/kg$^{0.75}$, 139 g/kg$^{0.75}$ and 163 g/kg$^{0.75}$ at 11, 25 and 39 days postpartum, respectively. Nutrient intakes by foals were calculated from milk composition and intake data. At 11, 25 and 39 days postpartum, respectively, dry matter intake equaled 3.1, 2.1 and 2.0% of foal body weight, and daily gross energy intake was 9380, 7590 and 8910 kcal. For each gram of body weight gain, foals ingested 0.37 g protein and 8.3 kcal at 11 days, 0.26 g protein and 6.7 kcal at 25 days, and 0.30 g protein and 7.8 kcal at 39 days of age. J. Nutr. *113*: 2196–2206, 1983.

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Knowledge of the composition and production of mare's milk is essential for a better understanding of the nutrient requirements of both the mare and the foal. Although many reports on milk composition are available (1, 2), recent information on milk production by the light horse breeds is limited and contradictory. The daily milk yield of 14 Quarter Horse mares as measured by the weigh-suckle-weigh method averaged 10–12 kg/day or about 2.1% of body weight for the first 150 days of lactation (3). Milk production by mares estimated by using deuterium oxide (D_2O) as a tracer of foal body water averaged 16.2 kg/day during the first week of lactation (4). In contrast, hand milking Quarter Horse mares while the foal nursed led to milk production estimates of only 1.5–9 liters of milk daily or about 0.3–1.8% of the mare's body weight (5). The National Research Council (NRC) Subcommittee on Horse Nutrition (6) concluded that mares of light breeds may produce milk equivalent to 3% of body weight during the first 12 weeks of lactation and about 2% of body weight during the second 12 weeks of lactation.

The following study was part of a larger project that compared milk composition

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and production to nutrient requirements and developmental strategies of the suckling young of several mammalian species (7, 8). This paper reports on production and composition of mare's milk and relates these values to estimated nutrient requirements of foals. Milk production was measured from the dilution and turnover of D_2O administered to foals. Both tritiated water and D_2O have been shown to yield valid estimates of milk production if corrections for changes in body water pool size are made (4, 8–10).

TABLE 1

Characteristics of lactating mares and foals

	Breed	Age	Wt	Parturition	Sex of foal	Prior foals
		yr	*kg*	*mo*		
		Milk composition study				
C-30	Thoroughbred	18	—	May	M	3
C-32	Thoroughbred	12	—	Mar	M	1
C-37	Thoroughbred	11	—	Feb	M	1
C-38	Thoroughbred	20	—	May	M	9
C-40	Thoroughbred	14	—	May	F	5
		Milk production study				
C-36	Thoroughbred	7	581	Feb	M	0
C-34	Thoroughbred	10	484	Feb	F	0
C-43	Standardbred	11	499	Mar	F	1
C-43	Thoroughbred	6	522	Mar	M	0
318	Standardbred	5	488	Apr	F	3

MATERIALS AND METHODS

Animals and management. Ten lactating mares and their foals were housed and maintained in box stalls. Mares and foals were allowed to exercise in an outdoor dirt paddock for an hour daily. Mares were fed a mixed grain and molasses feed containing about 13% crude protein, 0.5% calcium, 0.3% phosphorus and 3.4 kcal of digestible energy per gram. Mixed grass–legume hay and water were available to the mares ad libitum. Feed and water intake by the foals was restricted to mare's milk during the first 6 weeks. Foals had access to hay, but consumed limited quantities. Therefore, hay was a negligible source of extraneous water. The characteristics of the mares and foals used in this study are given in table 1.

Milk composition studies. Samples were collected from five lactating mares (table 1) at weekly intervals from 10 to 54 days postpartum. Muzzles prevented the foals from suckling for 1–2 hours prior to milking. After administration of 1.0 ml of an oxytocin solution (20 IU/ml) by intramuscular injection, mares were milked by hand in the stall. Only one teat was milked, and an effort was made to completely evacuate the gland. The muzzle was removed from the foal just prior to or during milking, and the foal suckled the opposite teat from the one being sampled. An average of 500 ml (± 177 SD) of milk was obtained in a 15- to 25-minute period.

The weekly samples, representing the time periods 10–11, 17, 24–25, 31–33, 38–40, 45–47 and 52–54 days postpartum, were analyzed in duplicate for major constituents. Total solids content was determined by drying samples in a forced convection oven at 100° for 5 hours. Total nitrogen (TN) and nonprotein nitrogen (NPN) were determined by the Kjeldahl procedure (11). NPN was measured after precipitation of protein in 12% trichloroacetic acid. Protein was calculated as: (TN − NPN) × 6.38. Total lipid was estimated by the Roese-Gottlieb gravimetric method (11). Sugar was determined by the phenol-sulfuric acid method (12, 13), by using lactose monohydrate for preparation of standards. Gross energy (GE) was estimated according to an equation developed from data on five species (14): GE (in kilocalories/100 g) = 9.11(fat %) + 5.86 (protein %) + 7.4(NPN %) + 3.95(sugar %).

Milk intake. Milk intake was estimated from water kinetics of five foals (table 1). D_2O (99.8% purity) was administered by stomach tube to the foals at 6–8 days, 20–22 days and 34–36 days postpartum at the rate of 1.6, 1.3 and 1.2 g/kg of body weight at the respective time periods. The tube was flushed with water and air to ensure complete isotope administration to the foal. The time required for isotope equilibration was found to be 1.5 hours in a 7-day-old foal and 2.0 hours in a 36-day-old foal. Hence 2 hours were allowed for equilibration before 10-ml blood samples were collected. Each foal was bled at 2- to 3-day intervals during each weekly study period. Blood water was isolated by heat distillation and assayed for deuterium concentration by infrared spectrophotometry (15). Deuterium concentration was corrected for body weight changes in computations of fractional turnover rate and body water fraction (7). At the second (20–22 days) and third (34–35 days) administrations of D_2O the residual isotope concentration remaining from the preceding test period was determined by extrapolation. This residual level was considered as a base line to which the subsequent increase in deuterium concentration was measured. With but one foal per mare, it was not possible to correct for isotope recycling; the error is considered minor in that newborn foals urinate and defecate independently with minimal maternal ingestion, unlike altricial or semialtricial species. Estimates of water loss (L), water gain (G), and water intake (I), were calculated as follows:

$$I = L + G$$

$$L = k \cdot F \cdot W_t$$

$$G = F \cdot \Delta W_t$$

where F is the body water fraction (body water pool ÷ body weight), k is an estimate of the fractional turnover rate of body water (regression coefficient for the regression of corrected log D_2O concentration against time), W_t is body weight and ΔW_t is daily change in body weight.

The relationship of water intake (as estimated by D_2O turnover) to milk intake was considered to depend on the free water content of milk and the proportions of milk constituents that are catabolized to yield metabolic water. Milk composition, foal growth rate and the estimated content of fat and protein in the foal's body weight gain were used in iterative calculations of the catabolism of milk constituents and the corresponding water yield. Details of these calculations are given elsewhere (7).

Statistical analyses were performed by using programs of the Statistical Package for the Social Sciences (SPSS) on a Honeywell computer at the Office of Computer Services, Smithsonian Institution.

RESULTS

Milk composition. Means and standard errors for milk constituents at the seven sampling times are presented in table 2. On a whole-milk basis, there were significant differences among sampling times for total solids, protein and gross energy (table 3). At 10–11 days and at 17 days the total solids and gross energy content were greater than at later sampling times. Protein content decreased from 10–11 days to 17 days and from 17 days to 31–33 days. Thus, mare's milk up to 17 days postpartum is not representative of milk composition during midlactation but rather reflects a transitional phase between colostrum and mature milk.

If data for the two early sampling times are excluded, there are no significant differences in the composition of whole milk among the remaining sampling times (table 2). Representative values for the composition of mare's milk in midlactation are shown in table 4. There are significant differences among the seven sampling times with regard to protein and sugar on a dry matter basis (table 3). An increase with time in the percentage of milk energy derived from sugar is also apparent. If the two early sampling times are excluded, however, no significant differences among sampling times remain, either on a dry matter or gross energy basis ($P > 0.05$).

Given the significant effect of sampling time on milk composition for many constituents, differences among mares over the period of 10–54 days were tested by analysis of covariance (table 3). As expected, the covariate effect (days postpartum) was highly significant for most constituents tested; more surprisingly, a significant animal effect was found for all constituents except protein (whole-milk basis) and sugar (dry matter basis) (table 3). On a whole-milk basis, average total solids content for 10–54 days postpartum varied among mares from 10.4 to 11.1%, fat from 0.99 to 1.70%, sugar from 6.70 to 7.12%, residual dry matter from 0.17 to 0.68% and gross energy from 48.7 to 56.1 kcal/100 g. Protein comprised from as little as 17.8% of dry matter (21.2% of gross energy) to as much as 21.0% (26.3% of gross energy). These significant interanimal differences suggest that the representative values for midlactation milk (table 4) may be influenced by the small number of mares involved in the present study.

Nonprotein nitrogen (NPN), varied from

TABLE 2

Composition of mare's milk at various stages of lactation[1,2]

Constituent	Time of milk sampling, *days postpartum* 10–11	17	24–25	31–33	38–40	45–47	52–54
Whole-milk basis							
Total solids, %	11.6 ± 0.11^{a}	11.3 ± 0.19^{a}	10.6 ± 0.11^{b}	10.6 ± 0.21^{b}	10.6 ± 0.68^{b}	10.4 ± 0.09^{b}	10.5 ± 0.21^{b}
Fat, %	1.74 ± 0.127^{a}	1.78 ± 0.236^{a}	1.35 ± 0.128^{a}	1.38 ± 0.220^{a}	1.19 ± 0.224^{a}	1.27 ± 0.130^{a}	1.25 ± 0.166^{a}
Protein, %	2.64 ± 0.140^{a}	2.34 ± 0.063^{b}	2.08 ± 0.092^{bc}	1.92 ± 0.096^{c}	1.96 ± 0.122^{c}	1.83 ± 0.045^{c}	1.84 ± 0.082^{c}
Sugar, %	6.82 ± 0.142^{a}	6.89 ± 0.050^{a}	6.85 ± 0.092^{a}	6.84 ± 0.207^{a}	6.93 ± 0.093^{a}	6.88 ± 0.109^{a}	7.06 ± 0.131^{a}
Residual, %	0.40 ± 0.113^{a}	0.26 ± 0.096^{a}	0.31 ± 0.107^{a}	0.47 ± 0.199^{a}	0.53 ± 0.089^{a}	0.42 ± 0.156^{a}	0.38 ± 0.110^{a}
Gross energy, *kcal/100 g*	58.6 ± 0.79^{a}	57.4 ± 1.97^{a}	51.9 ± 1.27^{b}	51.1 ± 2.53^{b}	50.0 ± 2.65^{b}	49.7 ± 1.36^{b}	50.4 ± 1.73^{b}
Dry matter basis							
Fat, %	15.0 ± 1.03^{a}	15.7 ± 1.87^{a}	12.8 ± 1.11^{a}	13.0 ± 1.89^{a}	11.0 ± 1.85^{a}	12.1 ± 1.16^{a}	11.8 ± 1.39^{a}
Protein, %	22.8 ± 1.10^{a}	20.8 ± 0.81^{ab}	19.7 ± 0.86^{bc}	18.2 ± 0.82^{bc}	18.4 ± 0.94^{bc}	17.6 ± 0.53^{c}	17.5 ± 0.97^{c}
Sugar, %	58.8 ± 1.73^{a}	61.3 ± 1.14^{ab}	64.7 ± 0.99^{bc}	64.8 ± 1.84^{bc}	65.5 ± 1.54^{bc}	66.2 ± 1.02^{c}	67.1 ± 0.61^{c}
Residual, %	3.4 ± 0.95^{a}	2.3 ± 0.86^{a}	2.9 ± 1.02^{a}	4.5 ± 1.87^{a}	5.1 ± 0.93^{a}	4.0 ± 1.50^{a}	3.6 ± 1.07^{a}
Gross energy, *kcal/100 g*	505 ± 4.9^{a}	509 ± 10.3^{a}	490 ± 8.2^{ab}	484 ± 16.2^{ab}	470 ± 12.9^{b}	478 ± 10.0^{ab}	477 ± 9.1^{ab}
Gross energy basis							
Fat energy, %	27.0 ± 1.65^{a}	27.8 ± 2.96^{a}	23.6 ± 1.71^{a}	24.1 ± 2.85^{a}	21.1 ± 3.04^{a}	23.0 ± 1.86^{a}	22.3 ± 2.35^{a}
Protein energy, %	26.4 ± 1.36^{a}	24.0 ± 1.33^{ab}	23.6 ± 1.30^{ab}	22.2 ± 1.56^{ab}	23.0 ± 1.33^{ab}	21.6 ± 0.88^{b}	21.6 ± 1.38^{b}
Lactose energy, %	46.0 ± 1.42^{a}	47.8 ± 1.70^{ab}	52.2 ± 0.92^{bc}	53.1 ± 1.87^{c}	55.3 ± 2.64^{c}	54.7 ± 1.05^{c}	55.6 ± 1.19^{c}

[1] Values are means ± SEM. [2] Where superscripts in a row are the same, means do not differ by more than the shortest significant range at the 0.05 significance level (Duncan's multiple-range test).

TABLE 3

Statistical tests on milk composition data for horses[1]

Constituent	Analysis of variance by sample order	Analysis of covariance with days postpartum as covariate	
	Between groups	Covariate effect	Animal effect
	$F(6,28)$	$F(1,29)$	$F(4,29)$
Whole-milk basis			
Total solids, %	0.001	0.001	0.05
Fat, %	NS	0.001	0.001
Protein, %	0.001	0.001	NS
Sugar, %	NS	NS	0.001
Residual, %	NS	NS	0.001
Gross energy	0.01	0.001	0.001
Dry matter basis			
Fat %	NS	0.001	0.001
Protein, %	0.01	0.001	0.05
Sugar, %	0.01	0.001	NS
Residual, %	NS	NT	NT
Gross energy	NS	NT	NT
Gross energy basis			
Fat energy, %	NS	0.01	0.001
Protein energy, %	NS	0.001	0.001
Sugar energy, %	0.001	0.001	0.05

[1] Values in columns represent probability level at which statistical significance was observed. NS, not significant ($P > 0.05$); NT, not tested.

0.033 to 0.064% (mean of 0.0395%) and comprised 8.7–17.3% of total nitrogen. There were no significant differences among sampling times in NPN content of milk.

Milk intake. Milk intake by foals was calculated for the midpoint of each study period, i.e., 11, 25 and 39 days postpartum. Growth rate and estimated body weight at these ages were obtained from linear regressions of foal weight on age during the period of 6–43 days postpartum.

Fractional turnover rate of body water (k) and body water fraction (F) were derived from linear regressions of the logarithm of deuterium concentration in blood water (corrected for body weight changes) on time after isotope administration. Fractional turnover rate per day decreased significantly ($P < 0.05$) from 0.289 in the first study period to 0.236 in the second and to 0.219 in the third (table 5). Body water fraction was estimated as 0.833, 0.756 and 0.793 at 6–8 days, 20–22 days and 34–36 days, respectively. These estimates of F did not differ significantly with time after parturition nor among foals.

Calculated estimates of daily water loss (L), daily gain in body water (G) and daily water intake (I) are presented in table 5. Daily water loss varied significantly with age among foals ($P < 0.05$) but daily water gain did not. Reflecting the large contribution of water loss to water intake calculations, daily water intake was found to differ both among ages ($P < 0.05$) and among foals ($P < 0.05$). Daily water intake was equivalent to 25.5, 18.9 and 18.2% of foal body weight at 11, 25 and 39 days, respectively.

Conversion of water intake to milk intake required calculation of the predicted ratio of milk intake to water intake by an iterative process. Body weight gain was considered to contain 19.0% protein and 6.5% fat (7). The proportions of ingested fat and protein catabolized were estimated as 73 and 48% at 11 days, 62 and 25% at 25 days, and 67 and 36% at 39 days. In midlactation, 100 g of

TABLE 4

Representative values for the composition of mare's milk at midlactation[1]

Constituent	Whole-milk basis	Dry matter basis	Gross energy basis
	%	%	%
Total solids	10.5 ± 0.08	—	—
Fat	1.29 ± 0.074	12.1 ± 0.64	22.8 ± 1.01
Protein	1.93 ± 0.042	18.3 ± 0.38	22.4 ± 0.56
Sugar	6.91 ± 0.057	65.6 ± 0.55	54.2 ± 0.73
Residual	0.42 ± 0.058	4.0 ± 0.56	—
Gross energy, *kcal/100 g*	50.6 ± 0.83	480 ± 5.0	—

[1] Means ± SEM. Based on 25 samples collected from 24 to 54 days postpartum.

milk will then yield 94.5 g water, of which 5.0 g or 5.3% is of metabolic origin. An average ratio of milk intake to water intake of 1.058 was utilized for all age groups.

Calculated daily milk intake averaged 16.0 kg at 11 days, 15.0 kg at 25 days, and 17.6 kg at 39 days (table 6). Whether expressed as a daily amount, as a percentage of body weight, per unit of metabolic body size (kilograms$^{0.75}$) or per gram body weight gain, milk intake differed significantly ($P < 0.05$) both among foals and among ages. There was a significant increase in the daily amount of milk consumed from 25 to 39 days postpartum ($P < 0.01$), but neither of these amounts was significantly different from daily milk intake at 11 days (table 6). At 39 days the two largest intakes, 20.2 and 18.8 kg, were by foals of multiparous mares. As a percentage of body weight, daily milk intake fell from an average of 27.0% at 11 days to 20.0% at 25 days and 19.3% at 39 days; the two latter values do not differ statistically. In relation to metabolic body size, milk intake was higher at 11 than at 25 and 39 days; milk intake per gram body weight gain increased from 25 to 39 days but not from 11 to 25 days (table 6).

With only one foal per mare, the milk intake estimated per foal is equal to milk output of the mare. Milk production was equivalent to 3.1% ± 0.17 (mean ± SEM) of the body weight of the mares at 11 days, 2.9% ± 0.20 at 25 days and 3.4% ± 0.22 at 39 days. On the basis of metabolic body size, milk output was calculated as 149 g/kg$^{0.75}$ ± 7.1, 139 g/kg$^{0.75}$ ± 9.0 and 163 g/kg$^{0.75}$ ± 10.0 at 11, 25 and 39 days postpartum, respectively.

Nutrient intakes. By combining milk composition and milk intake data, the intake of various milk constituents can be calculated (table 7). At 11, 25 and 39 days postpartum, respectively, dry matter intake equaled 3.13, 2.10 and 2.03% of foal body weight, and daily gross energy intake was 9380, 7590 and 8910 kcal (equivalent to 439, 298 and 302 kcal/kg$^{0.75}$). For every gram of body weight gain, suckling foals ingested 0.372 g protein and 8.26 kcal gross energy at 11 days of age, 0.255 g protein and 6.68 kcal gross energy at 25 days of age, and 0.299 g protein and 7.84 kcal gross energy at 39 days of age.

DISCUSSION

Milk composition. The decrease in total solids and protein of mare's milk observed in this study in the period of 10–11 days to 24–25 days (table 2) agrees with numerous prior studies (1, 16–24). Trends in the fat

TABLE 5

Body water turnover in suckling foals[1]

Time after partu-rition	Body wt W_t	Wt gain ΔW_t	Fractional turnover k	Wt fraction F	Daily loss L	Daily gain G	Daily intake I
day	*kg*	*kg·day*$^{-1}$	*day*$^{-1}$		*kg*	*kg*	*kg*
11	59.2 ± 1.61	1.14 ± 0.041	0.289 ± 0.0160	0.833 ± 0.0290	14.2 ± 0.55	0.95 ± 0.021	15.1 ± 0.54
25	75.2 ± 1.91	1.14 ± 0.041	0.236 ± 0.0158	0.756 ± 0.0239	13.3 ± 0.74	0.86 ± 0.011	14.2 ± 0.76
39	91.1 ± 2.31	1.14 ± 0.041	0.219 ± 0.0161	0.793 ± 0.0266	15.7 ± 0.95	0.91 ± 0.057	16.6 ± 0.94

[1] Means ± SEM.

TABLE 6

Comparison of milk intakes of suckling foals[1,2]

Postpartum age	Foal body wt	Daily amount	% of foal body weight	Per $kg^{0.75}$	Per gram growth
day	*kg*	*kg*	*%*	*g*	*g*
11	59.2 ± 1.61^{a}	16.0 ± 0.57^{ab}	27.0 ± 0.66^{a}	749 ± 18.6^{a}	14.1 ± 0.51^{ab}
25	75.2 ± 1.91^{b}	15.0 ± 0.81^{a}	20.0 ± 1.15^{b}	588 ± 32.4^{b}	13.2 ± 0.79^{a}
39	91.1 ± 2.31^{c}	17.6 ± 0.99^{b}	19.3 ± 1.14^{b}	596 ± 34.2^{b}	15.5 ± 1.03^{b}
			Two-way analysis of variance		
Animal effect $F(4,8)$	$P < 0.001$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$
Age effect $F(2,8)$	$P < 0.001$	$P < 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.05$

[1] Means ± SEM. [2] Pairs of means in a column that do not share the same superscript letter are statistically different (paired t-test, $P < 0.05$).

content in the first few weeks are less clear. Some studies suggest a decline in fat content in early lactation (17, 21, 24), while others reveal no consistent trend (1, 20, 22). If the effects of sampling time and animal are distinguished by analysis of covariance, however, time after parturition can be shown to exert a highly significant effect on milk fat content (table 3).

Changes in milk composition imply that the first 3 weeks postpartum should be regarded as a transitional period between colostrum and mature, midlactation milk. In the current study, mare's milk was found to be relatively stable in composition between 24 and 54 days after parturition (table 2). The suggestion that total solids and protein continue to decline throughout lactation (3, 21, 24) overlooks the rather constant midlactation period. Most studies indicate that even in late lactation, i.e., 3 or more months postpartum, protein content declines only slightly if at all (1, 3, 21, 24, 25). Total solids and fat, on the other hand, may increase, decrease or remain unchanged in late lactation (1, 3, 17, 19, 21, 24). Milk sugar, measured by difference, has been found to increase in late lactation (1, 21, 24), although Kulisa (25) in a study on 56 mares at 15–150 days postpartum found no significant change in sugar content with time.

Mare's milk at midlactation (24–54 days) contained 10.5% total solids, 1.25% fat, 1.93% protein and 6.91% sugar (table 4). Seven reports published since 1930 include extensive data on the composition of mare's milk at this lactation stage (table 8). Overall mean values for total solids (10.8%) and fat (1.57%) calculated from the combined literature data are somewhat higher than the corresponding values obtained in the present study. Caution is required in interpret-

TABLE 7

Average nutrient intakes of suckling foals from mare's milk

Constituent[1]	Total	Per 100 g body wt	Per $kg^{0.75}$	Per g wt gain
Day 11 postpartum[2]				
DM, *g*	1860	3.13	86.9	1.63
Fat, *g*	278	0.47	13.0	0.25
Protein, *g*	422	0.71	19.8	0.37
Sugar, *g*	1090	1.84	51.1	0.96
GE, *kcal*	9380	15.8	439	8.26
Day 25 postpartum[3]				
DM, *g*	1580	2.10	61.7	1.38
Fat, *g*	194	0.26	7.6	0.17
Protein, *g*	290	0.39	11.3	0.26
Sugar, *g*	1090	1.38	40.6	0.91
GE, *kcal*	7590	10.1	298	6.68
Day 39 postpartum[3]				
DM, *g*	1850	2.03	62.6	1.63
Fat, *g*	227	0.25	7.7	0.20
Protein, *g*	340	0.37	11.5	0.30
Sugar, *g*	1220	1.33	41.2	1.07
GE, *kcal*	8910	9.77	302	7.84

[1] DM, dry matter; GE, gross energy. [2] Based on average milk composition at 10–11 days (table 2) and mean milk intake at 11 days (table 6). [3] Based on representative milk composition values (table 4) and mean milk intake at 25 and 39 days (table 6).

ing these data. Incomplete mammary evacuation could strongly bias results. For example, among Soviet dairy mares, the first or cisternal milk (26) may contain but 0.15% fat while the last or residual milk contains 3.5–7.2%. In none of the studies in table 8 was oxytocin administered to ensure a milk ejection response. In view of the diverse sampling methods used, differences in the estimates of fat and total solids among prior studies as well as between prior studies and the present investigation are to be expected.

The combined literature data indicate a mean value for crude protein of 2.15% (table 8). In the present study true protein was found to average 1.93%, but if the data are recalculated on a total nitrogen basis, the consequent crude protein estimate (2.18 ± 0.045% SEM) is equivalent to the literature mean. The NPN content of mare's milk has been reported as between 0.033 and 0.045% (1), which is consistent with the current results (0.0395%). Crude protein data overestimate true protein by about $0.0395 \times 6.38 = 0.25$ percentage points.

Most previous sugar estimates are somewhat lower than the 6.9% reported here (table 8). As these values were obtained by difference [total solids − (fat + protein + ash)] they incorporate the cumulative errors of the other analyses and may be somewhat inaccurate.

In 100 g of milk, 0.42 g of solids were not accounted for by the summation of protein, fat and sugar. Part of this residual can be attributed to mineral matter (ash) and part to NPN constituents. Published data on the ash content of mare's milk in the period of 21–60 days postpartum (16, 17, 20, 21, 24) yield an average value of 0.41% (n = 242). By comparison to cow's milk the combined weight of NPN constituents may be approximated by NPN × 5.34, i.e., 0.21% (7). The sum of ash and NPN constituents, 0.62%, exceeds the residual value by 0.20 percentage points suggesting some small analytical error.

The finding of significant differences among individual mares in major milk constituents (table 3) was surprising. All mares used in the study of milk constituents were registered Thoroughbreds so that breed differences were not involved. In a study of six Quarter Horse mares in the first 2 weeks after birth, significant differences in milk protein were observed, but not in the other major constituents (22). Breed differences have been shown for the protein level of colostrum (1) and the fat content of mature milk (22). Further systemic study involving

TABLE 8

Published data on the composition of mare's milk from 21 to 60 days postpartum[1]

Source	Mares milked	Days after birth	n	Total solids	Fat	Crude protein[2]	Sugar[3]
					%		
Linton 1931 (16)	37	21–60	37	10.8	1.56	2.55	6.34
Linton 1937 (17)	6	21–60	32–36	10.4	0.97	2.13	6.95
Neseni et al. 1958 (1)	15	21–60	39	10.6	1.72	2.17	6.36[4]
Ullrey et al. 1966 (21)	10	21–60	30	10.9	2.0	2.5	6.0
Kulisa 1977 (25)	56	30–60	168	—	1.52	1.99	6.02[4]
Bouwman and van der Schee 1978 (24)	5	21–56	100[5]	11.2	1.76	2.15	6.84
Gibbs et al. 1982 (3)	14	30–60	42	10.6	1.4	2.2[6]	—
Mean values, all data combined:				10.8 (n = 284)	1.57 (n = 451)	2.15 (n = 449)	6.36 (n = 406)

[1] Mean values calculated from data provided in source publications.
[2] Total nitrogen times 6.38. Data corrected if other conversion factors were originally used.
[3] Sugar values as reported in original source. Most, if not all, were obtained by difference, i.e., total solids − (fat + protein + ash) = sugar.
[4] Analytical procedure unclear.
[5] Approximate number. More than 100 samples were reported.
[6] Determined by dye-binding.

standardized sampling procedures is needed to evaluate the extent of interindividual and interbreed variation. All but two of the publications (3, 24) referred to in table 8 encompass two or more breeds, ranging in size from ponies to draft horses.

Milk intake. Milk intake estimates are only as accurate as the estimates of body water fraction (*F*) and turnover rate (*k*) on which the calculations are based. Direct body composition studies indicate that foals contain about 73% water at birth and 69% at 4 months of age (27, 28). The current estimates of body water fraction in foals obtained by D_2O dilution are somewhat greater. Doreau et al. (4) report a range of 71–79% body water in foals 1–3 days of age, measured by D_2O. Discrepancies between isotope dilution and direct dessication estimates of body water have been reported for dogs, rats and pigs (29–31), but the magnitude of discrepancy is disputed (32). Error may arise in direct body composition studies by incomplete carcass dessication or water loss prior to analysis (27). Alternatively, incomplete isotope administration, urinary excretion of isotope prior to equilibrium, or exchange with nonwater hydrogen would cause body water to be overestimated.

The high fractional turnover rates of body water seen in foals (table 5) are not surprising. Mare's milk is low in energy but high in water content; in order to meet energy needs, foals must ingest large quantities of milk. The mean value of k at 11 days postpartum, 0.289, corresponds to a biological half-life for body water of 2.4 days. Foals less than 1 week old also have a half-life for water of about 2.5 days (4). A mature stallion, by contrast, takes 8.4 days ($k = 0.085$) to turn over half of body water (33). The fractional turnover rate falls as foals increase in age (table 5). Daily water intake of foals averaged more than 25% of body weight at 11 days; even at 39 days water intake was above 18% of body weight. Production of milk places a large water demand on lactating mares, making access to drinking water of particular importance.

At 11 days foals were calculated to ingest 16.0 kg milk, a value essentially identical to the estimate of 16.2 kg for foals under 1 week old obtained by Doreau et al. (4) using D_2O. By 39 days foals consumed nearly 18 kg milk. Milk intake values similar to those reported here have also been obtained by measurement of weight gains of foals during suckling bouts. Foals suckling mares with an average weight of 590 kg were found to consume 14.7 kg at 1 month, 16.9 kg at 2 months and 16.0 kg at 3 months of age; the highest individual intake was 21.3 kg (1, 20). The milk intakes of foals of Dutch saddle horses (average weight 616 kg) have been determined as 14.5 kg at 1 week, 16.5 kg at 3 weeks and 17–18 kg at 5–9 weeks postpartum (24). Milk intakes declined steadily thereafter, reaching about 11 kg at 23 weeks of age. The somewhat lower milk intakes measured in Quarter Horse foals (11.8 kg at peak lactation) suggest that the rather long intersuckling interval employed (3 hours) may have depressed milk consumption during the period of study (3). Heavier breeds can be expected to produce more milk: draft horses of 710 kg mean weight produced about 1.6 kg more milk per day in the first 3 months of lactation than did lighter breeds of 590 kg mean weight but yield per unit of body weight was the same (1). A record-breaking 724 kg Soviet draft mare milked for the production of koumiss achieved a maximum daily yield of about 29 kg (34). The low milk yield reported by Ashcraft and Tyznik (5) was probably due to incomplete hand milking.

Peak lactation in horses appears to occur at about 2 months postpartum or a few weeks thereafter (1, 20, 24). Milk intakes at 39 days, as estimated herein, may approximate peak yields. The difference between daily milk intake of 5-week-old foals and 9-week-old Dutch foals (24) was only about 0.5 kg or 3%, a difference which may not be significant. Other studies (1, 20) found a somewhat greater increase of milk intake between foals in their second and third months of life (the former consuming 8–13% less milk than the latter), but the absolute amounts consumed at peak lactation in breeds of comparable size were still less than the 39-day milk intakes estimated in the present study.

Protein and energy intakes in relation to NRC estimates of requirements. Suckling foals ingested 422 g protein and 9830 kcal gross energy at 11 days, 290 g protein and 7590 kcal gross energy at 25 days, and 340 g protein and 8910 kcal gross energy at 39 days postpartum (table 7). These protein and energy intakes may be compared to requirements estimated by NRC (6).

The crude protein requirements of a 3-month-old foal are estimated to be 18.0% when fed a diet containing 3.25 kcal digestible energy per gram (6). On a dry weight basis mare's milk supplies 18.3% protein (20.1% crude protein) and 4.7 kcal digestible energy per gram, assuming apparent digestibility to be 97–99% (7). Thus per 100 kcal digestible energy, mare's milk contains 3.9 g protein (4.3 g crude protein) as compared to 5.5 g crude protein in the recommended NRC diet. Even with allowance for the superior amino acid balance and digestibility of milk protein, the NRC protein level appears excessive and may need revision.

The present finding that foals about 1 month of age ingest 300 kcal gross energy per kilogram$^{0.75}$ can be compared to estimated energy intakes of 3-month-old foals as tabulated by the NRC (6). The NRC data indicate digestible energy intakes (310–340 kcal/kg$^{0.75}$) somewhat in excess of the current results.

Hay intake by foals was not measured but the older foals probably consumed some. Perhaps the intake of hay by the older foals contributed to the apparent increased efficiency of milk utilization as the foal matured. However, water intake from hay consumption would have little impact on estimates of milk intake. Hay contains about 10% water. It was estimated that foals at 39 days of age obtained about 18 kg of water daily from milk. Consumption of 1 kg of hay would contribute only 100 ml of preformed water.

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