Metabolic adaptation recorded during one lactation does not allow predicting longevity in dairy cows

J. J. Gross[1], L. Grossen-Rösti[1], F. Schmitz-Hsu[2], R. M. Bruckmaier[1]

[1] Veterinary Physiology, Vetsuisse Faculty University of Bern, Switzerland, [2] Swissgenetics, Zollikofen, Switzerland

Summary

Metabolic and health disorders account distinctly for culling in dairy cows. This study investigated if metabolic status obtained once in life during a negative energy balance in early lactation allows to predict age and lifetime performance animals achieved at culling. Metabolically stressed cows entering at least their 3rd lactation (n = 200, parity: 5.0 ± 2.1, mean ± SD) were selected from a field study conducted in Switzerland. Age of cows at culling ranged from 4.7 to 20.2 years with parities from 3 to 17. From cows with known reasons of culling, 28.4% were culled because of fertility, 16.4% due to udder health, 15.5% due to high age and 10.4% because of claw health/lameness. A retrospective classification of the one-time recorded metabolic adaptation in week 4 post partum did not differ between animals of different parities at culling. Furthermore, there was no relationship neither between the metabolic adaptation recorded in a preceding lactation and the number of lactations achieved, nor to the lifetime milk production. Contrary to the wide spread assumptions, an inadequate adaptation due to a high metabolic load in early lactation may not result in an earlier culling of dairy cows, although they are more prone to metabolic disorders.

Keywords: longevity, robustness, metabolism, dairy cow

Metabolische Anpassung während einer Laktation erlaubt keine Vorhersage zur Langlebigkeit bei Milchkühen

Stoffwechselprobleme und andere Erkrankungen tragen wesentlich zu den Abgangsursachen von Milchkühen bei. Diese Studie untersuchte, ob der Stoffwechselstatus, der einmal während einer negativen Energiebilanz in der Frühlaktation erfasst wurde, Rückschlüsse auf das Alter und die Lebensleistung zum Zeitpunkt des Ausscheidens aus dem Betrieb zulässt. Stoffwechselbelastete Kühe ab der 3. Laktation (n = 200, Laktationsnummer: 5.0 ± 2.1, Mittelwert ± Standardabweichung) wurden aus einer in der Schweiz durchgeführten Feldstudie ausgewählt. Das Alter der Kühe zum Zeitpunkt des Abgangs reichte von 4.7 bis 20.2 Jahre und 3 bis 17 Laktationen. Bei den Kühen mit bekannten Abgangsursachen waren in 28.4% der Fälle Fruchtbarkeit, bei 16.4% Eutergesundheit, 15.5% hohes Alter, und bei 10.4% Klauengesundheit/Lahmheit Grund für das Ausscheiden. Eine rückwirkende Klassifizierung nach der in der 4. Laktationswoche erhobenen Stoffwechselbelastung in der Laktation der Beprobung, ergab keine Unterschiede in der Zahl der erreichten Laktationen. Ferner wurde weder ein Zusammenhang zwischen dem Stoffwechselstatus in einer Frühlaktation und der Anzahl der erreichten Laktationen, noch der Lebensleistung festgestellt. Im Gegensatz zur verbreiteten Annahme konnte gezeigt werden, dass eine unzureichende Anpassung infolge einer hohen metabolischen Belastung in der Frühlaktation nicht zu einem früheren Ausscheiden aus dem Betrieb führen muss, obwohl derartige Milchkühe einem höheren Risiko für Stoffwechselerkrankungen ausgesetzt sind.

Schlüsselwörter: Langlebigkeit, Robustheit, Stoffwechsel, Milchkuh

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Introduction

For the last decades, dairy cows were intensively selected for higher milk yield achieving currently approximately more than doubled performance levels than 40 years ago (Oltenacu and Broom, 2010). Numerous studies described the reasons for culling in dairy cows. In particular, metabolic diseases, mastitis, fertility problems and lameness (all predominantly with highest incidence in early lactation) are among the top reasons for culling (Bascom and Young, 1998; Ahlman et al., 2011; Pinedo et al., 2014). In Switzerland, much attention is paid to efficient use of resources, and in this context a long living and metabolically robust dairy cow is crucial for a profitable and sustainable dairy business. Of course, cows are mostly culled during or shortly after diseases when the animal is foreseen for slaughter. The most critical period for surviving of dairy cows is the transition period (Hadley et al., 2006; Pinedo et al., 2014). Not urgent reasons for acute culling but affecting long-term profitability of dairy farms are for instance high age of cows or not getting pregnant, where farmers milk the cow as long as feed costs are covered by returns on milk sales (Nor et al., 2014).

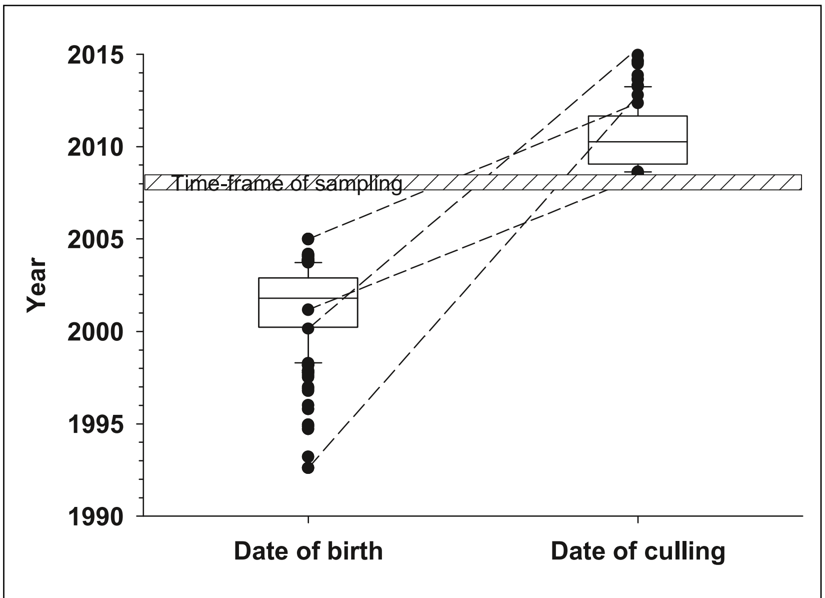

Figure 1: Data of birth and culling of 200 dairy cows. The boxes represent the 25 and 75 percentiles; whiskers show the 5 to 95 percentile; line in the box indicates the median. The shaded cross bar shows the blood sampling period from 2007 to 2008.

Table 1: Descriptive statistics on lifetime performance, metabolic and endocrine parameters of early lactating dairy cows (wk 4 post-partum, n = 200).

Variable	Mean	SD	Minimum	Maximum
Age at culling (years)	9.3	2.5	4.7	20.2
No. of lactations at culling	6.6	2.2	3	17
Total DIM	2028	730	671	5676
Lifetime performance milk yield (kg)	49301	20238	16182	159839
Milk yield per d of life (kg/d)	14.2	2.9	5.1	23.5
Milk yield per DIM (kg/d)	24.1	3.1	13.9	36.3
FFA (mmol/L)	0.33	0.21	0.05	0.97
BHBA (mmol/L)	1.51	1.13	0.21	5.73
Cholesterol (mmol/L)	3.66	0.72	1.59	6.33
Triglycerides (mmol/L)	0.15	0.04	0.05	0.30
Glucose (mmol/L)	3.02	0.53	1.80	5.55
Insulin (μU/mL)	10.2	7.3	1.0	40.3
IGF-1 (ng/mL)	69.1	27.3	14.5	160.8

DIM: d in milk, FFA: free fatty acids, BHBA: β-hydroxybutyrate, IGF-1: insulin-like growth factor-1.

Metabolic disorders in dairy cows are predominantly occurring in the early lactation period after parturition (Drackley, 1999; Kessel et al., 2008). The failure in successful adaptation to the metabolically challenging demands of lactation results inevitably in a vicious circle. Due to the high genetic potential for milk yield of modern dairy cows, energy and nutrient requirements cannot be met by adequate feed intake during the first weeks of lactation. This results in a pronounced negative energy balance (NEB) that forces partly excessive mobilization of body reserves in the adaptation phase in dairy cows (Bauman and Currie, 1980). Metabolic stress increases when the capability to energetically use mobilized fatty acids (FFA) is overloaded, with the consequence of ketone body formation, e.g. β-hydroxybutyrate (BHBA). In a recent study, Ingvartsen and Moyes (2015) supposed that periparturient changes in enodocrine and metabolic factors potentially compromise the immune competence and lead to an increased susceptibility to bacterial infections during the periparturient period, including endometritis and mastitis. With respect to the interaction between single metabolites and health status, BHBA was recently shown to suppress immune function (Zarrin et al., 2014), gluconeogenesis (Zarrin et al., 2013), feed intake (Laeger et al., 2010) and reproductive performance (Castro et al., 2012).

These effects further aggravate the metabolic adaptation and risk of metabolic disorders (e.g. ketosis) associated with lameness, mastitis and performance. The link between metabolic adaptation and risk of suffering from associated health disorders seems indisputable. Disorders occurring in the periparturient period were shown to be inter-related, and for instance cows experiencing milk fever are very likely to linking up to other disorders such as ketosis, displaced abomasum, and metritis (Drackley, 1999). However, the impact of metabolic adaptation during a NEB on lifetime performance and longevity in modern dairy cows has not been elucidated so far. Therefore, the objective of the present study was to investigate if metabolic adaptation recorded in one preceding lactation during a NEB allows predicting lifetime performance and age at time of culling.

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Animals, Material and Methods

Animals

The experimental procedures followed the Swiss law on animal protection and were approved by the committees responsible for animal welfare affairs in the cantons of Bern, Lucerne and Vaud, Switzerland. Two hundred multiparous dairy cows investigated earlier in a field study conducted from October 2007 to July 2008 in Switzerland (Graber et al., 2010) with a previous lactation 305-d milk yield of 7.542 ± 99 kg (mean ± SEM), which were metabolically characterized in early lactation in week 4 post-partum (p.p.), were selected for this present study (Brown Swiss: n = 78, Red Holstein: n = 68, Swiss Fleckvieh (= Simmental × Red Holstein): n = 41, and Holstein-Friesian: n = 18). Based on results from milk recordings in the first 2 months of their previous lactation, cows with a milk fat percentage >4.5% and a fat to protein ratio >1.5 were selected to ensure metabolic adaptation in early lactation. Blood sampling was performed in week 4 p.p. in cows with parities 3 to 14 (5.0 ± 2.1, mean ± SD). Calving season ranged from mid November 2007 to mid April 2008. Feeding and housing conditions between farms were comparable as described by Graber et al. (2010).

Blood sampling

For all animals, week 4 p.p. was chosen to represent a time-point in early lactation where animals are in a NEB and metabolic status is characterized by low plasma glucose and elevated FFA and BHBA concentrations. Using evacuated tubes containing tri-potassium-EDTA and sodium fluoride/tri-potassium-EDTA (for the analysis of glucose concentration), blood was sampled from the coccygeal vein between 0900 h and 1400 h and immediately cooled down to +5°C. After centrifugation for 15 min at 3,500 × g, plasma for the determination of metabolites and endocrine factors was stored at –20°C until analysis.

Laboratory analysis

Plasma concentrations of glucose, FFA, and BHBA were measured enzymatically by using commercial available kits from bioMérieux (Geneva, Switzerland; glucose: no. 61269), from Wako Chemicals (Neuss, Germany; FFA: no. 994-75409), and from Randox Laboratories Ltd. (Schwyz, Switzerland; BHBA: no. RB 1007). Concentrations of total cholesterol, and triglycerides were measured with kits from BioMerieux, Marcy l'Etoile, France (nos. 61219, and 61236, respectively). Plasma concentration of insulin, and IGF-1 were measured by RIA as described by Vicari et al. (2008). Until May 2015, all cows were followed for their age at culling, reason for culling and lifetime performance in milk yield.

Statistical analysis

Data presented in text and figures are means ± SEM, or SD where stated. Data were checked for normal distribution by the UNIVARIATE procedure in SAS (Version 9.4, SAS Institute, Cary, NC, USA). In cases of not being normally distributed, data were log-transformed. In order to identify effects of metabolic and endocrine factors on life-time performance, average milk yield per day of life and per day in milk (DIM), the GLM procedure of SAS with parity and breed as fixed effects was used. Parity and breed did not have a significant effect in the statistical model. Pearson's correlation coefficients between metabolic and endocrine parameters, and longevity key data (life-time performance, milk yield per d of life and per d in milk), age at culling, and reason for culling were evaluated with the CORR procedure of SAS. Significant effects were assumed at a level of $P < 0.05$.

Results and Discussion

Performance and metabolic adaptation of cows

Figure 1 shows the range of date at birth and date at culling of dairy cows selected for this study. From the 200 in early lactation metabolically characterized animals born between August 11th, 1992 and December 31st, 2004, eight cows are still alive (as at May 1st, 2015). Age of cows at culling ranged from 4.7 to 20.2 years with parities from 3 to 17 (Tab. 1). It must be emphasized that cows involved in the present study were due to the preselection criteria at least in their 3rd lactation and consequently cows failing to adapt were excluded before. Compared to the reports of worldwide achieved ages at culling (Bascom and Young, 1998; Pinedo et al., 2014),

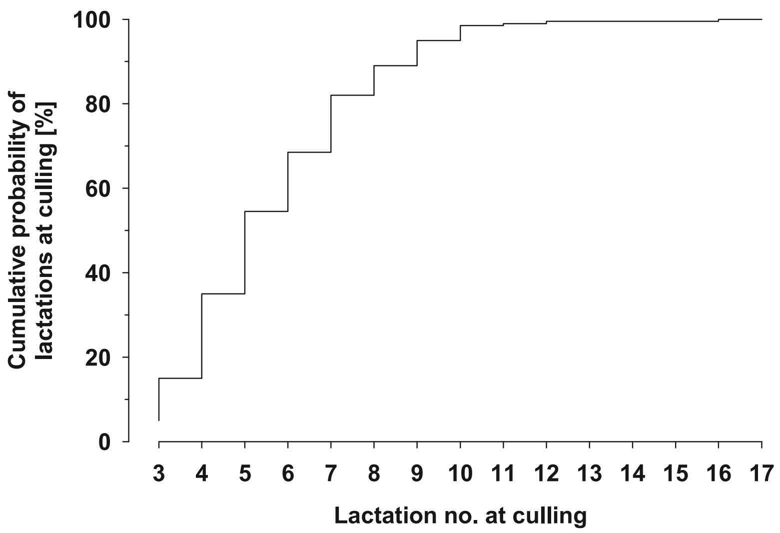

Figure 2: Cumulative probability of lactations at culling (%) of 200 dairy cows.

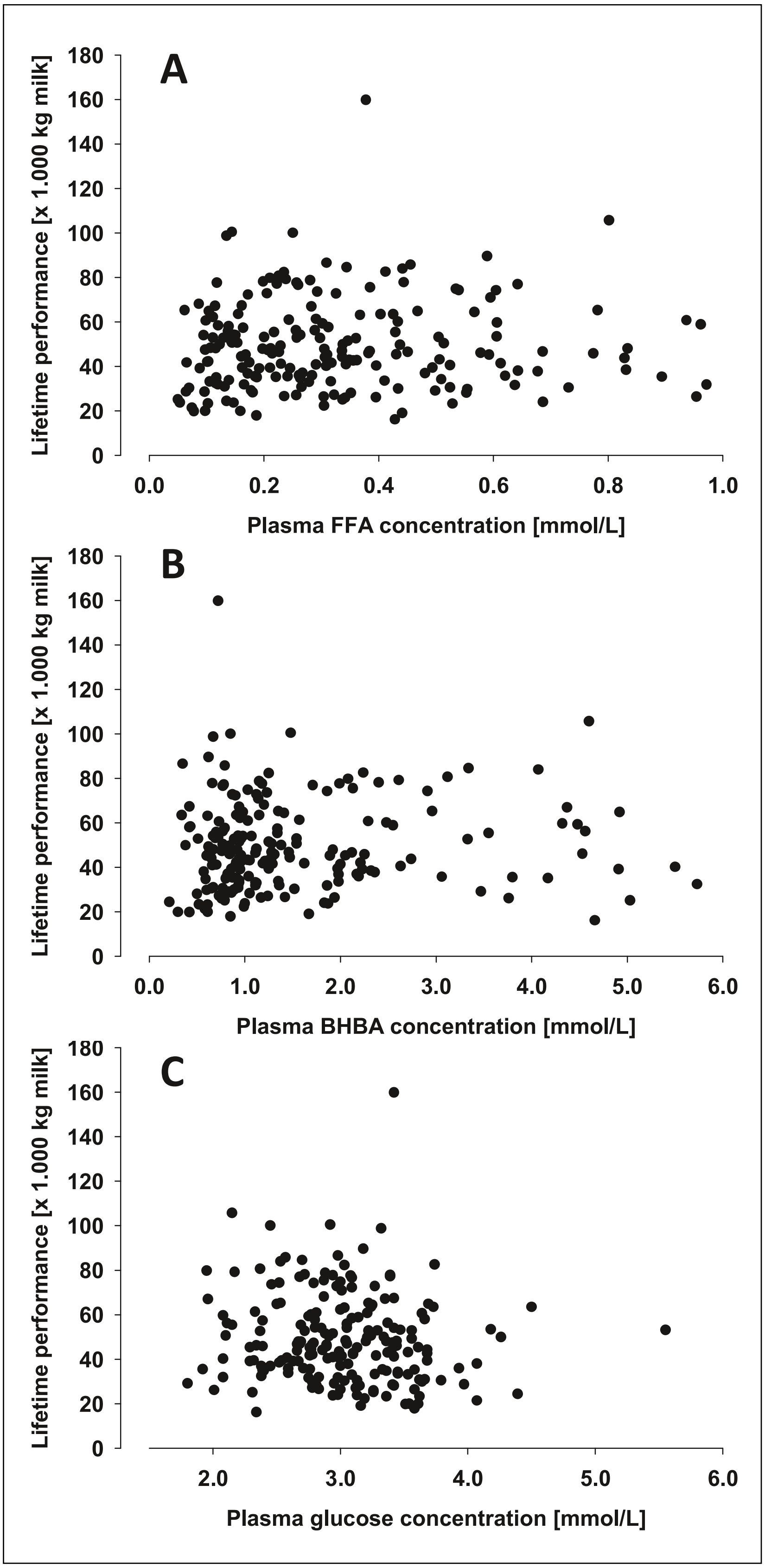

Figure 3: Relationship between plasma metabolite concentrations recorded once in early lactation. A: FFA, free fatty acids; B: BHBA, β-hydroxybutyrate; C: glucose and lifetime performance in milk yield (n = 200).

cows of the present study were already of higher age when entering the experiment. Nonetheless, just these animals surviving the first 2 lactations that might be considered "metabolically robust" showed a wide range of metabolic adaptation in their early lactation. More details on the lifetime performance, metabolic and endocrine parameters are given in Tab. 1. Recently published work by Gross and Bruckmaier (2015) showed that the extent of metabolic adaptation to energy deficient situations is independent from lactational stage and very likely genetically positioned. Assuming this pattern of metabolic adaptation being expressed repeatedly over subsequent lactations, the observations characterizing the metabolic status in early lactation recorded once at an earlier stage of life might be predictive for future periods of similar physiological conditions. Oldest and youngest cows in the present study were not necessarily the first and last animals being culled (Fig. 1). More than 50% of cows were culled up to their 5th lactation and 99% of all animals up to lactation no. 12 (Fig. 2). Despite the higher age of cows at culling in our study compared to previous reports, the steeper gradual increase in cumulative frequency at an earlier age of culling is consistent with findings described for younger cows culled (Pritchard et al., 2013; Pinedo et al., 2014). Unfortunately, for 84 cows the reasons for culling could not be identified. Known reasons of culling for the other cows were as follows (in descending order): Fertility (28.4%), udder health (16.4%), high age (15.5%), others (including bad milkability, teat trauma, accident, acute liver failure, bad udder conformation, abomasal ulceration, extreme edemas after parturition: 14.7%), claw health/lameness (10.4%), still alive (6.9%), insufficient milk yield (4.3%), and health problems around parturition (3.4%). Our observations confirmed fertility and udder health as main culling reasons for dairy cows as described earlier by Bascom and Young (1998), Hadley et al. (2006), and Pinedo et al. (2014).

Relationship between one-time recorded metabolic adaptation and longevity traits

Figure 3 shows the relationship between the one-time recorded key metabolites characterizing the metabolic status in early lactation (FFA: Fig. 3A, BHBA: Fig. 3B, and glucose: Fig. 3C) and the lifetime performance in milk yield. Interestingly, there was no relationship between metabolic adaptation and lifetime performance in milk yield ($P > 0.05$; Fig. 3; Tab. 2). Cows in the present study showed a wide range in plasma concentrations of metabolites as well as longevity traits (e.g. lifetime performance, age at culling, milk yield per d of life; Tab. 1). The elevated risk of cows experiencing health disorders in early lactation to be culled (Pinedo et al., 2014) and the strong association between metabolic adaptation and the occurrence of metabolic diseases after parturition (Drackley, 1999; Kessel et al., 2008) suppose

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Table 2: Pearson correlation coefficients between lifetime performance, and metabolic and endocrine parameters recorded once in early lactating dairy cows (wk 4 post-partum, n = 200). Significant relationships ($P<0.05$) between parameters are indicated by bold type letters.

		Longevity traits					Metabolic and endocrine traits						
		No. of lactations	Total DIM	Lifetime performance milk yield	Milk yield per d of life	Milk yield per DIM	NEFA	BHBA	Glucose	Cholesterol	TG	Insulin	IGF-1
Longevity traits	No. of lactations	–											
	Total DIM	0.94 (P < 0.0001)	–										
	Lifetime performance milk yield	0.88 (P < 0.0001)	0.94 (P < 0.0001)	–									
	Milk yield per d of life	0.52 (P < 0.0001)	0.63 (P < 0.0001)	0.80 (P < 0.0001)	–								
	Milk yield per DIM	0.12 (P = 0.10)	0.17 (P < 0.05)	0.47 (P < 0.0001)	0.76 (P < 0.0001)	–							
Metabolic and endocrine traits	FFA	−0.08 (P = 0.29)	−0.02 (P = 0.77)	0.04 (P = 0.54)	0.17 (P < 0.05)	0.22 (P < 0.01)	–						
	BHBA	−0.00 (P = 0.96)	0.05 (P = 0.46)	0.06 (P = 0.44)	0.09 (P = 0.20)	0.04 (P = 0.56)	0.21 (P < 0.01)	–					
	Glucose	−0.08 (P = 0.24)	−0.11 (P = 0.12)	−0.11 (P = 0.13)	−0.11 (P = 0.14)	−0.03 (P = 0.64)	−0.04 (P = 0.57)	−0.61 (P < 0.0001)	–				
	Cholesterol	0.06 (P = 0.36)	0.03 (P = 0.64)	0.02 (P = 0.78)	0.02 (P = 0.73)	−0.03 (P = 0.69)	0.00 (P = 0.99)	0.02 (P = 0.74)	0.04 (P = 0.56)	–			
	TG	0.03 (P = 0.69)	0.03 (P = 0.67)	0.04 (P = 0.61)	0.07 (P = 0.35)	0.03 (P = 0.62)	0.31 (P < 0.0001)	−0.03 (P = 0.63)	0.33 (P < 0.0001)	0.26 (P < 0.001)	–		
	Insulin	0.14 (P = 0.06)	0.09 (P = 0.21)	0.04 (P = 0.56)	−0.02 (P = 0.81)	−0.13 (P = 0.08)	−0.11 (P = 0.12)	−0.22 (P < 0.01)	0.41 (P < 0.0001)	−0.06 (P = 0.39)	0.23 (P < 0.01)	–	
	IGF-1	−0.11 (P = 0.12)	−0.20 (P < 0.01)	−0.19 (P < 0.01)	−0.10 (P = 0.18)	−0.03 (P= 0.70)	−0.22 (P < 0.01)	−0.29 (P < 0.0001)	0.31 (P < 0.0001)	0.16 (P < 0.05)	0.12 (P = 0.09)	0.17 (P < 0.05)	–

DIM: d in milk, FFA: free fatty acids, BHBA: β-hydroxybutyrate, TG: triglycerides, IGF-1: insulin-like growth factor-1.

the hypothesis that metabolically more stressed animals might achieve a lower lifetime performance. However, we could show that one-time recorded metabolic adaptation in early lactation did not allow predicting longevity performance traits ($P>0.05$; Tab. 2). Even cows kept under the same conditions, similar energy balance and similar milk yield were shown to have a broad variation in metabolic adaptation (Kessel et al., 2008). Though, average milk yield per d of life and per DIM were associated with plasma concentrations of FFA and IGF-1 (Tab. 2). This can be attributed to the impact of higher yielding cows showing a higher degree in uncoupling of the somatotropic axis as well as more mobilization of body fat reserves (Lucy et al., 2009; Grala et al., 2011; Gross and Bruckmaier, 2015). Nevertheless, considering the overall lactation and lifetime performance, no relationship could be identified with metabolic status ($P>0.05$; Tab. 2). Furthermore, we observed a similar range of metabolic adaptation in all parities of cows sampled. This implies that robustness in dairy cows in terms of longevity traits goes beyond the metabolic status in physiological challenging periods, i.e. the early lactation phase. The decision on culling is affected by multiple factors (e.g., feed availability, economic reasons, replacement intensity, etc.). However, as cows in the present study were of parity 3 and older, it is unlikely that selection intensity is very strong for those animals being established in the productive herd. Repeated and more frequent measures of the metabolic situation in subsequent lactations might allow a closer evaluation of relationships towards culling. The reasons for culling of cows here as stated above reflect the importance of fertility, udder and claw health in dairy operations.

In conclusion, longevity could be shown to have a positive impact on lifetime performance of cows. Contrary to wide spread assumptions, a metabolic adaptation with more pronounced changes of key metabolic parameters during NEB in a preceding lactation does not result in an earlier culling of dairy cows, although they might be more prone to metabolic disorders. This will likely cause a reduced economic benefit for the farmer throughout their lifetime as compared to metabolically robust animals. Interestingly, classification of animals by different parities at culling identified an independent and wide range of the earlier obtained metabolic adaptation.

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J. J. Gross et al.

L'adaptation métabolique durant une lactation ne permet pas de pronostic quant à la longévité des vaches laitières

Les problèmes métaboliques ainsi que d'autres pathologies jouent un rôle important dans les causes de réforme des vaches laitières. Dans la présente étude, on a cherché à savoir si le statut métabolique, qui a été noté une fois durant un bilan énergétique négatif au début de la lactation, permettait de tirer des conclusions quant à l'âge et à la performance de vie au moment de la sortie de l'exploitation. On a choisi, dans le cadre d'une étude de terrain effectuée en Suisse, des vache surchargées métaboliquement à partir de la troisième lactation (n = 200, numéro de lactation: 5.0 ± 2.1, moyenne ± déviation standard). L'âge des vaches lors de la réforme variait entre 4.7 et 20.2 ans et ces vaches comptaient entre 3 et 17 lactations. Chez les vaches dont on connaissait la cause de réforme, celle-ci était pour 28.4% des troubles de fertilité, pour 16.4% des problèmes de mamelle, pour 15.5% un âge avancé et pour 10.4% des affections des onglons ou des boiteries. Une classification rétrospective basée sur la charge métabolique dans la quatrième semaine de lactation n'a pas montré de différence quant au nombre de lactations atteint ni quant à la performance de vie. Contrairement à l'idée répandue, on a pu montrer qu'une adaptation insuffisante due à une charge métabolique élevée en début de lactation ne conduisait pas forcément à une réforme précoce, bien que de telles vaches soient soumises à un risque plus élevé d'affections métaboliques.

L'adattamento metabolico durante una lattazione non consente di predire la longevità delle mucche da latte

Problemi metabolici e altre malattie contribuiscono in modo significativo all'abbattimento delle mucche da latte. Questo studio ha esaminato se lo stato metabolico, che è stato riportato una volta durante un bilancio energetico negativo all'inizio della lattazione, permetta conclusioni circa l'età e le prestazioni in vita al momento dell'abbattimento. Delle mucche con fabbisogno metabolico sono state selezionate da uno studio condotto sul campo in Svizzera dalla 3° lattazione (n = 200, numero di lattazione: 5.0 ± 2.1, media ± deviazione standard). L'età delle mucche al momento dell'abbattimento variava dai 4.7 ai 20.2 anni e da 3 a 17 lattazioni. Nelle mucche, i motivi conosciuti per l'abbattimento erano nel 28.4% la fertilità, nel 16.4% la salute della mammella, nel 15.5% la vecchiaia e nel 10.4% la salute dello zoccolo/zoppie. Una classificazione retroattiva, per la quale nella 4° settimana di lattazione vi è un incremento del fabbisogno metabolico dei campioni, non ha mostrato alcuna differenza nel numero di lattazioni raggiunte. Inoltre, non è stata determinata la relazione tra lo stato metabolico all'inizio della lattazione, il numero di lattazioni raggiunte e le prestazioni in vita. Contrariamente all'accettazione generale, è stato dimostrato che un adattamento insufficiente dovuto ad un alto carico metabolico all'inizio della lattazione non deve portare ad una esclusione dall'azienda, anche se tali mucche da latte siano esposte a un alto rischio di malattie metaboliche.

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Corresponding author

Rupert M. Bruckmaier
Bremgartenstrasse 109a
CH-3012 Bern
Switzerland
Phone: +41 31 631 2324
Fax: +41 31 631 2640
E-Mail: rupert.bruckmaier@vetsuisse.unibe.ch