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Relationship of body condition and milk parameters during lactation in Simmental cows in Bavaria, Germany

Theresa Rabus [a,*], Andreas W. Oehm [a], Gabriela Knubben-Schweizer [a], Martina Hoedemaker [b], Kerstin Müller [c], Yury Zablotski [a]

[a] Clinic for Ruminants with Ambulatory and Herd Health Services, Ludwig-Maximilians Universität Munich, Sonnenstrasse 16, 85764 Oberschleissheim, Germany
[b] Clinic for Cattle, University of Veterinary Medicine Hannover Foundation, Bischofsholer Damm 15, 30173 Hannover, Germany
[c] Clinic for Ruminants and Swine, Freie Universität Berlin, Königsweg 65, 14163 Berlin, Germany

A R T I C L E I N F O

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A B S T R A C T

In dairy cows the body condition forms a reflection of the energy reserves of the organism. Health, welfare and productivity of dairy cows are strongly associated with changes in body condition. As lactation puts substantial demands on the metabolism of dairy cows, farm management aims at avoiding either a deficient body condition or a substantial loss of body condition within a short period of time. A body condition higher or lower than recommended (*over*- and *underconditioning* in the following) compromises dairy cow productivity. While the body condition of Holstein Friesian cows has been thoroughly explored, few is known about the consequences of deviations from a target body condition for health and productivity of cows from other breeds. This study explores the percentage of over- and underconditioned cows at different days post partum [dpp] and their association with production parameters i.e., milk yield, milk fat and milk protein content of Simmental cows on Bavarian farms, categorized by parity (primi- or multiparous). Our study displays that in Simmental cows, overconditioning is more prevalent than underconditioning. While the middle of lactation (dpp = 100–199) resulted in higher percentage of overconditioning, the dry period (dpp = < 0 & > 299) indicated a higher percentage of underconditioned cows. The dry period and the middle of lactation are therefore the most challenging lactation stages for Simmental cows. We found milk protein content to have the strongest association with over- and underconditioning in Simmental cows. The probability of overconditioning was higher with higher milk protein content for every lactation stage and the probability of underconditioning was lower with higher milk protein content in every lactation stage. This study provides a theoretical basis for potential improvements in stockbreeding, which, if implemented, could improve not only the milk yield of Simmental dairy cows, but also their health and welfare.

1. Introduction

The body condition score (BCS) of a dairy cow is an assessment of its body reserves, a critical factor in managing its health (Stockdale, 2001; Buckley et al., 2003), milk production and reproduction (Roche et al., 2009; Hoedemaker et al., 2009; Silva et al., 2021). Body condition scoring is a widely accepted, non-invasive and cost-effective method to evaluate the body condition of dairy cows (Waltner et al., 1993). The primary aim is to prevent cows from calving in either excessive or insufficient body condition, thereby avoiding production diseases, while maximizing milk production (Klopčič et al., 2011).

Particularly, emaciated cows were found to be more susceptible to endometritis and may develop reproductive problems like a lower frequency of cycling (Hoedemaker et al., 2009; Domecq et al., 1997; Souissi and Bouraoui, 2019). On the other hand, obese cows face a higher risk of metabolic disorders (Sundrum, 2015; Locher et al., 2015; Jorritsma et al., 2001) such as ketosis, downer cow syndrome, "fat cow syndrome" with complications like fatty liver or mastitis (Morrow, 1976), or milk fever (Heuer et al., 1999; Kellogg, 2010; Bewley and Schutz, 2008). Moreover, overconditioned cows are more prone to reproductive problems, including dystocia, retained placenta, reduced fertility or higher culling rates (Halász and Jónás, 2014; Shaver, 1997; Correa et al., 1990). Differences exist among parity groups with respect to health problems. For instance, Markusfeld et al. (1997) discovered a higher risk of

* Corresponding author.
E-mail address: theresa.rabus@gmx.de (T. Rabus).

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retained placenta and metritis in underconditioned multiparous cows. Additionally, Roche et al. (2009) identified a parity-dependent association between BCS and uterine or mammary infections, leading them to recommend a higher calving BCS for younger cows.

Despite the existing evidence demonstrating the detrimental effects of misconditioning, the precise definitions of over- and undercondition in dairy cows remain ambiguous. These classifications are influenced by diverse factors, including lactation stage, breed and various other variables like parity. Therefore, defining overcondition and undercondition, and subsequently examining the factors influencing these separate conditions, has the potential to enhance our comprehension of the complex relationship between body condition, productivity (e.g., milk parameters) and animal welfare.

The body condition of dairy cows undergoes significant changes throughout lactation (Berry et al., 2002; Banos et al., 2004). Specifically, a dairy cow's body condition profile mirrors her milk production profile, as higher milk yield leads to a lower level of body condition, and vice versa (Roche et al., 2009). The genetic selection for milk production over the past five decades has further intensified this association, particularly for milk-oriented breeds like Holstein Friesian (Dillon et al., 2003). However, the relationship between body condition and milk parameters for Simmental dairy cows has not been thoroughly investigated. Existing publications have provided insights into the condition of Simmental cattle in Bavaria, based on the works of Kritzinger et al. (2009); Kritzinger and Schoder (2009a, 2009b); Martin et al. (2014); Heuwieser and Mansfeld (1992). Nevertheless, a comprehensive exploration of the over- or underconditioning in dual-purpose breeds in general and in Simmental cows in particular, remains lacking.

In this present study, we aim to bridge this gap by utilizing a dataset of thousands of observations (4881) on the Simmental dual-purpose breed. Specifically, this study aims to: 1) investigate the percentage of over- and underconditioned cows at different lactation stages and parity categories, 2) determine their association with production parameters, namely milk yield, milk fat and milk protein content, and 3) improve the examination of Simmental dual-purpose cows on Bavarian farms. To the best of our knowledge, such an analysis has not been conducted before.

2. Materials and methods

2.1. Farm recruitment and data collection

The data set was collected in an extensive, cross-sectional study, initiated and funded by the German Federal Ministry of Food and Agriculture (BMEL) through the Federal Office for Agriculture and Food (BLE), grant number 2814HS008. Study design, farm selection process, sampling procedure and data collection of this study are elaborated on elsewhere (Oehm et al., 2022a; Oehm et al., 2020; Abele et al., 2022; Oehm et al., 2022b). In brief, the data included information from 765 farms in three structurally different German regions (region North: federal states of Schleswig-Holstein and Lower Saxony (253 farms); region East: federal states of Mecklenburg-Western Pomerania, Brandenburg, Thuringia and Saxony-Anhalt (252 farms); region South: federal state of Bavaria (260 farms)), which were randomly selected by farm size and administrative district. In the present work, only data from study region South (260 farms) were evaluated because only in Bavaria the Simmental breed is the predominant breed. We utilized data within a 21-day window both before and after the BCS visit, as the lactation stage is critical and some stages are short, requiring close proximity between BCS scoring and milk parameter measurement. This further reduced the number of farms to only 134. Due to the Simmental focus, 15 farms were filtered out because they do not have Simmental cows, which resulted in a final number of 119 farms analyzed in this study.

The farm managers provided the data voluntarily with a written consent of interest. Further information such as breed, dpp, parity, milk yield, milk fat content and milk protein content were allocated from the LKV (Dairy Herd Improvement) and from the Milchprüfring Bayern e.V. All farm-specific information was handled according to the principles of the German and European data protection legislation.

The researchers (15 trained veterinarians) visited the farms once between December 2016 and August 2019. Kristensen et al. (2006) confirm that the differences between raters is reduced and the BCS assessment is improved when the assessors are trained by experts. Prior to the start of this study, the observers participated in a three-day workshop training their skills in cow monitoring. This is important to ensure accurate results (Edmonson et al., 1989; Houghton et al., 1990). During the data collection, the assessors were evaluated three times with a two-day workshop including body condition scoring, training and discussion. Their Intraclass Correlation Coefficient (ICC) rose from 0.59 in the first session to 0.79 in the second and maintained this level (ICC = 0.76 in the third session).

During the farm visit, the individual ear tag number was documented for each cow (lactating and dry animals) and the cows were scored for body condition by visual observation. BCS was recorded in the 5-point scale with 0.25-unit increments presented by Edmonson et al. (1989), later modified by Metzner et al. (1993) and adapted to diverse breeds including Simmental cows by Kritzinger et al. (2009); Kritzinger and Schoder (2009a, 2009b); Martin et al. (2014) as well as Heuwieser and Mansfeld (1992). We extend their approach by defining undercondition as the BCS below the recommended optimum range per breed per lactation stage (displayed as categorized dpp) and overcondition as the BCS above the recommended optimum range per breed per lactation stage.

2.2. Data editing

The assessed BCS was transformed from a numeric variable into categorical variables: *overconditioning* and *underconditioning*. Table 1 shows the classification of BCS into different categories for Simmental cattle based on dpp (Kritzinger et al., 2009; Kritzinger and Schoder, 2009a, 2009b; Martin et al., 2014; Heuwieser and Mansfeld, 1992).

Dpp <0 & >299 includes not only dry cows but also cows which are in the dry-off period. There are several reasons why the dry lactation stage in our study still has milk yield. First, high-yielding cows are often dried-off when they still produce some milk (Odensten et al., 2005). Such animals can produce up to 25–30 kg of milk per day (Dingwell et al., 2004). Secondly, the dry-off period differs among farms and probably among cows on a particular farm. Lastly, since controlling for a strict dry period of every animal would be unmanageable, the lactation stage *dry* in this paper was defined to start with dpp >299, no matter whether or not a cow still produced milk or was already in the dry-off period.

The dairy cows were categorized into two distinct groups based on their parity: primiparous and multiparous.

2.3. Statistical analysis

All analyses were conducted using the R Statistical language [version 4.0.5; R CoreTeam (2021)] and the R Studio interface (RS Team, 2021).

We fitted six final multivariable logistic mixed effects models to estimate different conditions (over- and underconditioning as binary response variables of 0 s and 1 s). The conditions were estimated by milk

Table 1
Body condition of Simmental dairy cows in Bavaria, determined by days postpartum and body condition score.

days postpartum	overcondition	undercondition
0–29	>4.25	<3.30
30–99	>4.00	<3.25
100–199	>3.75	<3.25
200–299	>4.25	<3.25
<0 & >299	>4.25	<3.75

yield per day, milk fat percentage and milk protein percentage (further *milk parameters*) for every lactation stage and every level of parity via the interaction between a particular milk parameter and categorical variables *lactation stage and parity* inside of every model. Each of the models included *farm* as random effect on the intercept to account for potential clustering at the farm level and between-farm heterogeneity.,

- overcondition ~ milk x lactation stage x parity + (1|farm _id)
- overcondition ~ fat x lactation stage x parity + (1|farm _id)
- overcondition ~ protein x lactation stage x parity + (1|farm _id)
- undercondition ~ milk x lactation stage x parity + (1|farm _id)
- undercondition ~ fat x lactation stage x parity + (1|farm _id)
- undercondition ~ protein x lactation stage x parity + (1|farm _id)

The model fit was assessed by following indices of model performance: AIC, BIC, R2 (con.), R2 (marg.), ICC and RMSE.

The Odds Ratios (OR) for every condition, parity and for each lactation stage were then extracted from these models (Table 4). Three values (mean-SD, mean, mean+SD) per milk parameter were chosen automatically by the software in order to display change in probabilities of conditions (on the y-axes) with the change in a particular milk parameter per lactation stage (on the x-axes, Fig. 2).

Results with a p-value ≤ 0.05 were considered statistically significant. Due to the exploratory nature of our study, we did not perform p-value corrections for multiple testing in order to reduce the probability of Type II Error.

3. Results

3.1. Descriptive statistics

The present study uses body conditions of a total of 4881 Simmental cows from 119 farms in Bavaria. The majority of the cows were in dpp 100–199 (1371 cows) or dpp 200–299 (1224 cows; Fig. 1a), were multiparous (3554 cows; Fig. 1c) and in normal condition (3506 cows; Fig. 1b), while 899 cows were over- and 476 cows were underconditioned.

The distribution between the two different parity groups for particular dpp also showed that the cows were mostly in dpp 100–199 or dpp 200–299 (Table 2).

Table 3 illustrates the trends in milk production throughout lactation. It is evident that the median milk yield is notably high in the early stages and gradually becomes lower as dpp 100 – 199 begins. Additionally, both milk fat content and milk protein content exhibit a lower level from dpp 0 – 29 to dpp 30 – 99, followed by a gradually higher level, eventually reaching slightly higher levels than those observed at the beginning of lactation.

Simmental cattle had a median milk yield between 17 kg per day in dry lactation stage and 31 kg per day in the beginning of lactation (dpp 30–99). The median milk fat content was between 3.86 % and 4.66 % and the median protein content in milk during the whole lactation varied between 3.22 % and 3.93 %.

Table 2
Distribution inside of days post partum and parity of 4881 Simmental dairy cows from 119 farms in Bavaria.

	Days post partum					
	0–29	30–99	100–199	200–299	Dry	Total
Parity						
primiparous	60 (1.2 %)	275 (5.6 %)	396 (8.1 %)	402 (8.2 %)	194 (4.0 %)	1327 (27.2 %)
multiparous	332 (6.8 %)	635 (13.0 %)	975 (20.0 %)	822 (16.8 %)	790 (16.2 %)	3554 (72.8 %)
Total	392 (8.0 %)	910 (18.6 %)	1371 (28.1 %)	1224 (25.1 %)	984 (20.2 %)	4881 (100.0 %)

On closer examination, it becomes apparent that at dpp 100 – 199 the percentage of being overconditioned rose up beyond 30 % (otherwise between 5.9 % in the beginning of lactation and 20.4 % in the dry period). The percentage of being underconditioned was highest in the dry period with 16.2 % of cows being affected (otherwise between 4.2 % and 12.5 %). The dry period was, therefore, the period with the most misconditioned cows.

3.2. Overconditioning

The probability of overconditioning in multiparous cows significantly decreased (all p < = 0.009) with increasing milk productivity in every lactation stage (Table 4 and Fig. 2), while it became significantly lower (p = 0.01) only in dpp 100 – 199 for primiparous cows (Indicators of model fit: AIC: 4174.624, BIC: 4310.979, R2 (cond.): 0.328, R2 (marg.): 0.176, ICC: 0.184, RMSE: 0.354).

In contrast, higher milk protein content resulted in a significantly higher odds of overconditioning in multiparous cows (all p < = 0.01) in every lactation stage. It also significantly increased the odds of overconditioning only at dpp 100 – 199 (p = 0.001), dpp 200 – 299 (p = 0.001) and dry (p = 0.042) lactation stages for primiparous cows (AIC: 4149.163, BIC: 4285.518, R2 (cond.): 0.312, R2 (marg.): 0.209, ICC: 0.131, RMSE: 0.355).

Higher milk fat percentage did not generally change the odds of overconditioning, except in dpp 100 – 199 for primiparous cows, where higher milk fat content led to significantly higher odds of overconditioning (p = 0.029, Table 4, Fig. 2; AIC: 4219.458, BIC: 4355.814, R2 (cond.): 0.288, R2 (marg.): 0.171, ICC: 0.142, RMSE: 0.358).

Dpp 100–199 thus became the most important lactation stage for overconditioning in Simmental cows, as all three milk parameters (milk, fat, and protein) were significantly associated with overconditioning in

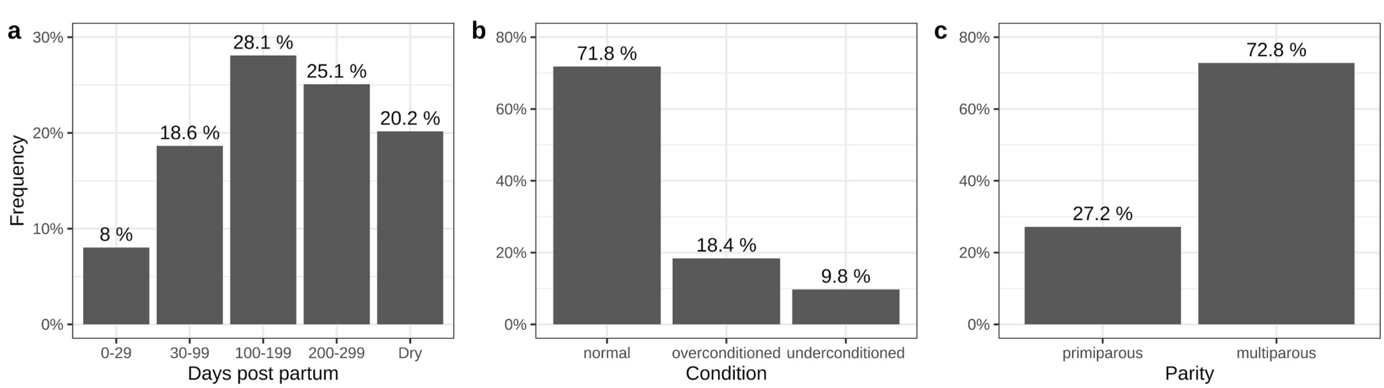

Fig. 1. Percentage distribution of days post partum (left), body condition (middle) and parity (right) of 4881 Simmental dairy cows from 119 farms in Bavaria.

Table 3
Descriptive statistics of variables included into the study, with milk yield, milk fat and protein content being continuous, while overcondition and undercondition being dichotomous (0 and 1; only 1 s are counted and displayed as percent).

	Days post partum				
Variable	0–29 N = 392[1]	30–99 N = 910[1]	100–199 N = 1371[1]	200–299 N = 1224[1]	Dry N = 984[1]
milk yield (kg/day)	29 (26, 33)	31 (25, 36)	26 (22, 31)	22 (18, 26)	17 (14, 20)
milk fat content (%)	4.63 (4.23, 4.91)	3.86 (3.49, 4.31)	4.02 (3.62, 4.44)	4.31 (3.92, 4.76)	4.66 (4.36, 4.91)
milk protein content (%)	3.72 (3.37, 3.94)	3.22 (3.04, 3.43)	3.50 (3.32, 3.71)	3.72 (3.53, 3.94)	3.93 (3.76, 4.09)
Overconditioned	23 (5.9 %)	89 (9.8 %)	432 (31.5 %)	154 (12.6 %)	201 (20.4 %)
Underconditioned	49 (12.5 %)	90 (9.9 %)	126 (9.2 %)	52 (4.2 %)	159 (16.2 %)

[1]Median (IQR); n (%)

Table 4
Odds Ratios for overconditioning (left column) and underconditioning (right column) for milk yield (top row), milk fat content (middle row) and milk protein content (bottom row) of primi- and multiparous Simmental dairy cows in Bavaria.

dpp	Overconditioning				Underconditioning			
	OR (95 % CI) Milk (kg) - primiparous	p.value	OR (95 % CI) multiparous	p.value	OR (95 % CI) Milk (kg) - primiparous	p.value	OR (95 % CI) multiparous	p.value
0- 29	0.86 (0.61–1.22)	0.399	0.91 (0.84–0.98)	0.009	0.95 (0.8–1.13)	0.54	1.06 (1–1.13)	0.05
30–99	0.95 (0.88–1.03)	0.214	0.94 (0.9–0.97)	0.001	1.01 (0.92–1.1)	0.869	1.02 (0.98–1.05)	0.362
100–199	0.95 (0.91–0.99)	0.01	0.96 (0.94–0.98)	0.001	1.04 (0.97–1.12)	0.28	0.99 (0.95–1.02)	0.429
200–299	0.98 (0.9–1.07)	0.63	0.94 (0.91–0.97)	<0.001	1 (0.91–1.1)	0.957	1 (0.95–1.06)	0.875
Dry	0.94 (0.84–1.05)	0.276	0.93 (0.9–0.97)	<0.001	1.07 (1.01–1.14)	0.026	1.06 (1.03–1.1)	0.001
	Fat (%) - primiparous		multiparous		Fat (%) - primiparous		multiparous	
0- 29	0.13 (0.01–2.14)	0.152	0.95 (0.49–1.86)	0.885	0.91 (0.23–3.6)	0.894	0.62 (0.38–1.01)	0.055
30–99	0.96 (0.5–1.86)	0.91	1.08 (0.76–1.52)	0.68	1.8 (0.94–3.45)	0.075	0.91 (0.63–1.3)	0.592
100–199	1.45 (1.04–2.03)	0.029	1.12 (0.91–1.39)	0.287	0.7 (0.36–1.35)	0.285	0.65 (0.47–0.92)	0.015
200–299	0.95 (0.49–1.86)	0.884	0.94 (0.71–1.25)	0.665	0.49 (0.22–1.11)	0.086	1.34 (0.82–2.17)	0.239
Dry	1.73 (0.81–3.69)	0.153	1.16 (0.85–1.6)	0.35	0.89 (0.53–1.48)	0.647	1.04 (0.71–1.53)	0.832
	Protein (%) - primiparous		multiparous		Protein (%) -primiparous		multiparous	
0- 29	39.61 (0.01–104691.48)	0.36	5.65 (1.77–18.02)	0.003	4.51 (0.18–110.74)	0.356	0.18 (0.07–0.44)	<0.001
30–99	3.99 (0.76–21.01)	0.102	5.23 (2.27–12.05)	<0.001	0.11 (0.02–0.72)	0.021	0.18 (0.07–0.48)	0.001
100–199	3.55 (1.63–7.76)	0.001	2.74 (1.69–4.45)	<0.001	0.18 (0.05–0.68)	0.011	0.13 (0.06–0.28)	<0.001
200–299	8.28 (2.26–30.29)	0.001	2.22 (1.21–4.1)	0.01	0.13 (0.03–0.58)	0.008	0.34 (0.11–1.02)	0.055
Dry	5.68 (1.07–30.31)	0.042	3.12 (1.68–5.78)	<0.001	0.14 (0.04–0.46)	0.001	0.31 (0.15–0.67)	0.003

primiparous cows, while two parameters (milk and protein) were associated with overconditioning in multiparous cows. Multiparous cows displayed a stronger association with milk parameters during lactation compared to primiparous cows.

3.3. Underconditioning

In contrast to overconditioning, the probability of underconditioning is significantly lower with higher milk protein content in almost every lactation stage (all p-values <= 0.021, Fig. 2 and Table 4), except dpp 0 – 29 in primiparous and dpp 200 – 299 for multiparous cows, where no effect was found (AIC: 2866.397, BIC: 3002.752, R2 (cond.): 0.250, R2 (marg.): 0.138, ICC: 0.130, RMSE: 0.279).

Contrary to milk protein content, milk fat content revealed no association with underconditioning throughout lactation, except for significantly lower odds of underconditioning (p = 0.015) associated with higher fat percentage in dpp 100 – 199 in multiparous cows (AIC: 2938.206, BIC: 3074.562, R2 (cond.): 0.218, R2 (marg.): 0.091, ICC: 0.140, RMSE: 0.282).

High milk yield was found to be associated with higher odds of underconditioning only in the dry lactation stage in primiparous cows (p = 0.026) and in dpp 0 – 29 (p = 0.05) and dry (p = 0.001) lactation stages in multiparous cows (AIC: 2935.200, BIC: 3071.555, R2 (cond.): 0.224, R2 (marg.): 0.079, ICC: 0.158, RMSE: 0.281). In other lactation stages, in both primiparous and multiparous cows, there was no association between elevated milk yield and underconditioning.

Milk protein once again emerged as the most critical milk parameter related to body condition, as there were significantly lower levels of

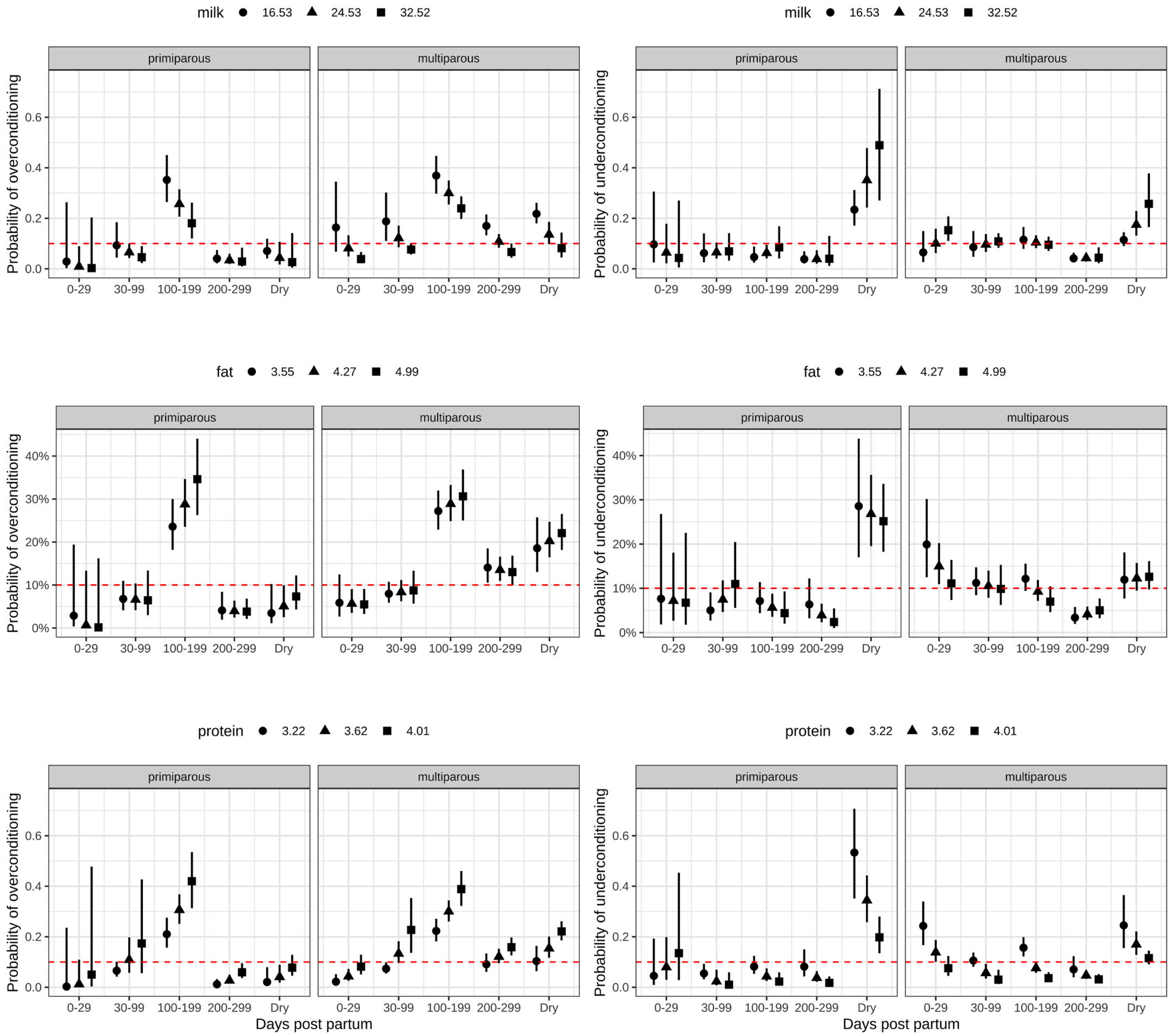

Fig. 2. Probabilities of overconditioning (2 columns on the left) and underconditioning (2 columns on the right) estimated for milk yield (top row), fat content (middle row) and protein content (bottom row) for days post partum of Simmental dairy cows in Bavaria, stratified into primiparous and multiparous. The three values of each parameter (mean-SD, mean and mean+SD) were meant to uncover existing trends between the magnitude of the parameter and the probability of a given condition. The horizontal dashed line at 10 % is the recommended threshold for misconditioning (Kellogg, 2010), which is not supposed to be exceeded.

underconditioning associated with increasing protein content in nearly every lactation stage. The dry stage emerged as the most critical lactation stage for underconditioning. In this stage, both milk protein content and milk yield exhibited associations with underconditioning in both primiparous and multiparous Simmental dairy cows.

3.4. Parity

Due to limited data availability, a more refined categorization of parity (into e.g. 1, 2, 3+) was not feasible. Even within these two broad categories, the confidence intervals appear quite wide, primarily due to the relatively limited amount of data available for each lactation stage, specific condition and parity group when compared to the scenario where no such separation was made.

Our models suggest that there are differences between primiparous and multiparous Simmental dairy cows in Bavaria (Fig. 2). Specifically, the model for milk yield indicates that multiparous cows have a slightly higher probability of overconditioning in comparison to primiparous cows in every lactation stage. In the models for fat and protein content, multiparous cows exhibit a higher probability of overconditioning at the end of lactation, particularly in dpp 200 – 299 and dry lactation stages, while the differences between primiparous and multiparous cows in dpp 0 – 29, dpp 30 – 99 and 100 – 199 are less pronounced.

The most significant difference in the probability of underconditioning is observed in the dry stage, where the probability of underconditioning is higher in primiparous cows compared to multiparous cows for all three parameters (milk, fat and protein). In other lactation stages, there are no noticeable differences between primiparous and multiparous animals in any of the milk parameters.

4. Discussion

This study explores the relationship between body condition and milk parameters in German Simmental cows stratified by stages of lactation and parity. German Simmental cows were chosen in order to reduce the gap in literature about such a relationship for dual-purpose breeds. Similarly to previous studies on Holstein Friesian breed which postulated that higher milk yield and higher milk fat percentage lead to a lower level of the body condition score of cows (Vries and Veerkamp, 2000; Pedron et al., 1993), German Simmental in our study exhibited reduced probability to be overconditioned.

However, in contrast to studies in Holstein Friesian, which did not find milk protein content to be associated with a change in BCS, our results indicate a strong relationship between body condition and milk protein content for dual-purpose cows, where higher milk protein percentage is positively correlated with overconditioning and negatively correlated with underconditioning in both primi- and multiparous cows. Furthermore, we demonstrate that explicitly studying over- and undercondition of dairy cows is a valuable tool that might help to improve the welfare of the animals. In particular, our results uncover an exalted probability of overcondition in the middle of lactation (dpp = 100–199) and an exalted probability of undercondition in the dry stage (dpp = < 0 & > 299), which is highly concerning and needs to be addressed.

4.1. Breed

Although the relationship between body condition and milk parameters is breed-dependent (Roche et al., 2007; Piccand et al., 2013; Zablotski et al., 2022), studies about dual-purpose cattle have been scant and mainly investigate the interplay between body condition and reproduction whereas milk parameters often play a secondary role (Aeberhard et al., 2001; Gillund et al., 2001). Thus, by focusing on dual-purpose Simmental cattle, this study provides new insights into the relationship between body condition and milk parameters.

To the best of our knowledge, this is the first study about body condition and its relationship with milk parameters in Simmental dairy cows in Bavaria. Exploring dual-purpose breeds is important since they do not only provide meat alongside milk, but they are also able to populate mountainous areas, where Holstein Friesians are not used often. Furthermore, Simmental cows are often more robust and resistant to diseases (Schichtl, 2007). Besides, dual-purpose breeds have more muscle than dairy breeds (Bewley and Schutz, 2008) and Holstein Friesian for example deposit more of their fat intra-abdominally than Simmental (Otto, 1990). Therefore, body condition changes in dual-purpose cows are more due to changes in muscle content as compared to dairy cows, where these changes are mostly due to fat content (Campeneere et al., 2000).

However, most of the studies focus on Holstein Friesian dairy cows (Pires et al., 2013; Buckley et al., 2003), so that current knowledge about the relationship between body condition and milk parameters might be highly biased towards the milk-oriented Holstein breed. Some studies draw a comparison with Jersey cows (Roche et al., 2007) or Brown Swiss (Piccand et al., 2013), but we only found a few small studies focusing on the Simmental breed exploring the association of BCS (not the body condition) and milk parameters (Jílek et al., 2008; Erdem et al., 2015). Although the patterns of BCS-change might be similar across dual-purpose breeds and dairy breeds (Aeberhard et al., 2001), it is worth to have a deeper look in the differences.

Our study included 4881 animals from 119 Bavarian farms and found similar (Jílek et al., 2008) as well as different (Erdem et al., 2015) results compared with only a few other studies conducted on Simmental cattle. Some studies used less data (Piccand et al., 2013; Jílek et al., 2008) or had another focus, for example the seasons (Erdem et al., 2015) or muscularity (Frigo et al., 2013).

A limited number of studies, farms, herds and animals might have resulted in incomplete or incongruent results about the relationship between body condition and milk parameters in dual-purpose cows. A significant correlation between protein and body condition uncovered in our study suggests the necessity for more breed-specific research.

4.2. Body condition

There is an agreement in literature that positive milk yield responds to lower BCS (Waltner et al., 1993; Erdem et al., 2015; Jílek et al., 2008). Our results corroborate this statement and demonstrate that the probability of being overconditioned is lower when higher amount of milk produced. Interestingly, despite the dual-purposefulness of the Simmental cattle, the producers' focus of Simmental herds is mostly on milk yield.

In contrast to Holstein Friesian breed, where higher milk yield raises the probability of underconditioning during the whole lactation, there is no similar effect in Simmental breed (Fig. 2). Particularly, in dpp 200–299, the probability of underconditioning is very low (<10 %) and rising milk yield has no effect on the probability of underconditioning in any parity.

According to the literature, less than 10 % of the herd should be over- or underconditioned (Kellogg, 2010). While we agree with this recommendation, our results unfortunately exhibit, that this rarely happens in our data set. Particularly, our results display that preventive measures against overconditioning should be applied in the middle of lactation, while measures against underconditioning should be applied in the end (dry stage) for both parity levels and the beginning of lactation for multiparous cows.

4.3. Body condition and protein

While previous research has often did not find any relationship between protein percentage in milk and the body condition in Holstein Friesian cows (Holter et al., 1990), this study underlines that milk protein is in fact an important predictor of body condition in Simmental cows in every lactation stage for multiparous and most of lactations stages for primiparous cows.

The energy supply along with other factors such as genetics, milk performance or diseases has a major influence on the milk protein content (Richardt, 2004). The reason for higher milk protein percentage in fat cows is the disordered energy balance. Milk protein mirrors the rumen microbiome: the more microbes, the more milk protein because when there are enough precursors (starch, amino acids, urea) available, the protein biosynthesis works well. Low milk protein percentages (<3.00 %) indicate an insufficient energy supply, higher ones (>3.80 %) a (too) high-energy feeding (Swissgenetics, 2021). This coincides with our results: higher milk protein content increases the probability of being overconditioned for both parities.

Some studies reassure the relation between milk protein percentage and welfare of dairy cows. Heckel (2009) found significantly higher milk protein values in peripartally diseased cows. Other studies observed the opposite (Dechow et al., 2002). The role of milk protein content in dual-purpose cattle might not be as harmful though, because they have a higher percentage of body-muscles and lower percentage of body-fat compared to Holstein Friesian cows (Rosenberger et al., 2004).

The disagreements with the literature are presumably due to the breed differences, mainly driven by the dual-purposefulness of Simmental. A few studies which examined the protein percentage in milk of Simmental cows found similar results (Jílek et al., 2008: 3.35 %; Frigo et al., 2013: 3.43 %; Piccand et al., 2013: 3.31 %) to ours (3.22–3.93 %) while studies analyzing Holstein Friesian cows consistently reported different results (Richardt, 2004: 2.8 %−3.2 %; Yang et al., 2013: 3.02 %; Rodriquez et al., 1985: 3.20 %).

4.4. Body condition and milk yield

The negative relationship between overconditioning and milk yield found in this study has been also reported previously (Veerkamp and Brotherstone, 1997; Roche et al., 2005; Stockdale, 2004). A total of 40–100 days after calving, BCS declines whereas the lactation climaxes (Friggens et al., 2004; Pryce and Harris, 2006; Roche et al., 2006). Afterward, the body condition score shows a shift towards an increase as the milk yield drops (Coffey et al., 2004; Berry et al., 2006; Mccarthy et al., 2007). A negative association between nadir body condition and milk production is often presented in the literature and regularly described as a mirror image (Roche et al., 2009; Frigo et al., 2013). Garnsworthy and Topps (1982a) also saw a negative effect, but with differences between fat and thin cows. On the one hand fat cows take longer to begin regaining lost body condition than thin cows (Pedron et al., 1993). On the other hand, thinner cows produced more milk than the fatter ones due to a greater dry matter intake (DMI). The results of our study do not confirm this statement: the probability of underconditioning rises with higher amount of milk produced only in the dry lactation stage and in multiparous cows only in the very beginning of lactation (dpp 0 – 29).

However, there are studies which did not find any relationship between body condition and milk yield (Garnsworthy and Topps, 1982b; Ruegg and Milton, 1995; Broster and Broster, 1998). It needs to be noted that in these studies, the amount of data was small, mainly Holstein-Friesian breed was studied and the underconditioned cows were often underrepresented.

The reason for the lower level of body condition with higher amount of milk is the negative energy balance (NEB) the cow enters which is driven by the high milk production. This production exceeds the energy intake (Buckley et al., 2003) and the dairy cow needs to take her energy reserves from mobilization of body fat (Agenäs et al., 2003; Coffey et al., 2002). This can make up to 30 % of the whole energy intake in early lactation (Bines and Morant, 1983). As “mobilization of body fat reserves and milk production are closely related” (Pryce et al., 2002), fat reserves are often seen as fostering the amount of milk (Domecq et al., 1997; Markusfeld et al., 1997; Pedron et al., 1993). Horan et al. (2005) prove this hypothesis by turning the arguments around: cows with lower milk yield were reported to have a higher body condition during the whole lactation. Our results maintain these statements: due to the energy conversion from body to product, the probability of underconditioning is higher in the dry stage with higher amount of milk even in dual-purpose breed, like Simmental.

However, severe underconditioning might greatly reduce milk yield. Domecq et al. (1997) state that an increase of one BCS-point in thin cows during the dry stage leads to 545 kg more milk in the first 120 days of lactation. Our results demonstrate, that higher milk yield results into a lower level in over- and no change (except of dry period) in underconditioning.

4.5. Body condition and fat

With higher milk quantity, the percentage of milk fat usually drops (Richardt, 2004; Heckel, 2009). This is due to the lack of energy in the beginning of lactation and due to the composition of the milk which is influenced by external factors such as climate, feeding or animal welfare and by internal factors such as genetics, parity or lactation stages (Glatz-Hoppe et al., 2020; Fox and McSweeney, 1998; Cao et al., 2010).

Lesser overconditioning and higher underconditioning with growing milk fat content found in our study might be due to the conversion from body-fat into milk-fat. This negative correlation between the nadir of the NEB and the peak of the fat percentage in the first days of lactation has also been found in other studies (Vries and Veerkamp, 2000; Domecq et al., 1997; Bourchier et al., 1987). Dechow et al. (2002) confirm: especially breeds which are more prone to lose body condition in early lactation have higher fat percentage in milk.

Our results disagree with the results from studies which report a positive correlation between nadir of the NEB and the peak of the fat-percentage (Stockdale, 2001; Chilliard, 1992; Holter et al., 1990). These studies were conducted with Holstein Friesian cows, which might explain the differences of the results. Frigo et al. (2013) found different milk fat percentages (3.93 %) in Simmental cows as compared to our study (>4.02 %, except dpp 0 – 29), however, they only explored primiparous cows.

The percentage of fat in milk is only significantly related with body condition in dpp 100–199 in our study for overconditioning in primiparous and for underconditioning in multiparous cows. Other authors also found milk fat content not always to be important (Heckel, 2009).

4.6. Parity

In previous research, it has been established that all milk parameters (milk yield, fat and protein content) are influenced by parity ($p < 0.05$), but parities two and higher do not exhibit differential effects due to body condition score or BCS changes, as reported by Roche et al. (2007). Consequently, this study categorizes dairy cows into two groups based on parity: primiparous and multiparous.

Prior investigations have adopted various approaches. Some exclusively focused on multiparous cows (Berry et al., 2003), while others concentrated solely on primiparous cows (Pryce and Harris, 2006; Banos et al., 2004). Additionally, there have been studies that differentiated between parity groups but did not find significant differences between parities (Roche et al., 2006). In our study, we have identified certain distinctions between parities, consistent with observations made by other researchers.

Several authors have reported an association between parity and cows BCS (Dechow et al., 2002; Pryce et al., 2001; Roche et al., 2007). Hoedemaker et al. (2009) demonstrated that the mean BCS in primiparous cows was higher than in multiparous cows by 0.12 BCS points. This observation aligns with the findings of Roche et al. (2007), who noted that "first-parity cows calved at the highest BCS" and observed a tendency for BCS at nadir to be lower in older animals, a trend also supported by others (Mao et al., 2004). Friggens et al. (2007) identified significant differences between parities in terms of body energy change, particularly in the early lactation stages.

The higher probability of underconditioning during the dry period in primiparous cows, as found in our study, may be attributed to the fact that they are still growing (Roche et al., 2009). This growth phase might lead to a slower and less extensive recovery in primiparous dairy cows (Gallo et al., 1996). Additionally, the higher probability of overconditioning observed at the end of lactation in multiparous cows in our study could be attributed to reduced energy demands, as cows produce less milk during this period. If multiparous cows continue to be fed the same amount of feed, they may consume more energy than required, resulting in overconditioning. These findings underscore the necessity for management adjustments. Primiparous Simmental dairy cows should receive preferential treatment during the late lactation stages to ensure they do not enter their second parity with insufficient body condition, while multiparous cows should get a different diet.

4.7. Lactation stages

The present study separates the whole lactation into five lactation stages because the ideal body condition is highly dependent on the lactation stages (Ferguson, 1996). This is important because it gives more insights and a deeper understanding of the relationships between body condition and milk parameters. Significant differences can be observed even between the initial stages of lactation (dpp 0–29 and dpp 30–99), particularly in terms of milk protein content in relation to underconditioning in multiparous cows.

Most of the studies only differentiate between nadir/calving and post calving (if applicable early and late) BCS, some classify three stages of lactation (Erdem et al., 2015: 1 =70 ± 14d, 2 =140 ± 14d, 3 =210 ± 14d). Yet even in this small differentiation a significant difference exists among the lactation stages (Erdem et al., 2015): the lowest BCS mean (3.30) was detected in the first lactation stage (56–84 days), the highest (3.40) in the third (196–224 days). Erdem et al. (2015) explain this by an intensive body reserve mobilization related with milk production at the beginning of lactation and then regaining body reserves with dropping milk yield in later lactation stages. This view is supported by other studies which analyzed different lactation stages (Wattiaux, 1996; Horn et al., 1992).

The reason for overconditioning in dpp 100 – 199 might be due to the change from lactation climax to milk drop 100 days after calving and the associated change to positive energy balance (Friggens et al., 2004; Coffey et al., 2004; Mccarthy et al., 2007). The energy intake is slowly again adequate to fulfill the energy needs of the dairy cow and even exceed them - the cow is getting overconditioned.

The reason for underconditioning in the dry period might be the rising energy demand due to the gravidity (Moe and Tyrrell, 1972). In contrast, the DMI declines around 30 % in the same time (Bertics et al., 1992; Grummer, 1993). At this point, the energy requirement in late gravidity rises up to 75 % compared to equally heavy, non-pregnant cows (Moe and Tyrrell, 1972). Therefore, the effectiveness of body condition buildup in the dry stage is less than in other lactation stages (Gearhart et al., 1990; Wildman et al., 1982). One possible explanation for the high number of underconditioned animals during the dry lactation stage is the reduced amount of food provided to the animals. Additionally, dairy cows are often fed with hay only, aiming to reduce the probability of overconditioning at the start of the next lactation (PraeRi, 2020).

The ideal implementation approach would be a two-phase feeding during the dry stage. Subclassifying dry cows into two groups allows for the implementation of distinct feeding strategies. In the beginning of the dry stage, one group can be fed low-energy feed, while the other group can be prepared for lactation at the end of the dry stage with high-energy forage. PraeRi (2020) reveals that only about 60 % of Bavarian farms actually choose the two-phase feeding. One possible explanation for this situation could be the relatively small average herd size in Bavaria. Consequently, it may not be practical or feasible to separate every stage individually. As a result, cows in the dry stage were often grouped together with heifers or dairy cows in the late lactation stage (PraeRi, 2020). There is definitely a need for action to get Simmental dairy cows out of over- or undercondition for their best productivity during all lactation stages.

4.8. Limitations of the study

The cross-sectional nature of data collection entails certain limitations due to the study design. It is important to be aware that exposures as well as outcomes are assessed at the same time, thus, this might be a potential source of bias (Oehm et al., 2022a, 2022b).

Furthermore, the data of the present study were collected with voluntary participation of the farmers. This might have led to a selection of only motivated and proactive farmers with good stockbreeding conditions on their farms or those which have specific problems in their management and want to solve them. This could hide the true prevalence of misconditioned cows in the Bavarian dairy cow population, so that such true prevalence might be higher or lower.

Another limitation of the study is that we did not conduct multiple testing in the statistical analysis. This was not feasible due to the limited dataset resulting from the complexity of the interaction models. Additionally, the quality of the data may be constrained by the one-time collection during the BCS assessment. Furthermore, the milk parameters were not monitored on a daily basis. These factors contribute to a higher risk of Type II Error (missing a discovery), leading to the decision not to adjust p-values for multiple testing in this study.

Our study adopts a novel approach by distinguishing between overcondition and undercondition, in contrast to most studies (Roche et al., 2007) that utilize BCS. While this approach presents challenges when comparing our study to others, it facilitates more accurate comparisons among breeds since a specific body condition (either over- or undercondition) may correspond to different BCS values in various breeds.

5. Conclusions

This paper aims to bridge the knowledge gap regarding Simmental dairy cows and their relationship between body condition and milk parameters, with a particular emphasis on the significance of milk protein content. Our study highlights the mid-lactation and dry stages as critical periods where the likelihood of over- or underconditioning is notably elevated. Implementing targeted improvements in livestock management tailored to the various lactation stages may contribute to enhanced milk yield, as well as the overall health and welfare of Simmental dairy cows in Bavaria.

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CRediT authorship contribution statement

MH developed the concept of the PraeRi study, applied for funding and provided the overall management of the study. YZ initiated and conceptualized this study. TR and YZ conducted statistical analyses, interpreted the results and wrote the manuscript. MH, GK, AO and KEM were involved in the collection and cleaning the data. All authors revised the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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