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Milk Production of Sarda Suckler Cows with Different Calving Period

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Abstract: The study explored the relationship between the performance of calves and calving season in a Mediterranean rangeland-based beef livestock system. Twenty multiparous Sarda cows, grazing on a natural pasture, with two distinct calving periods (group A, 11 animals, calving date 15/10/2016 ± 16 (means ± s.d.), and group W, nine animals, calving date 26/01/2017 ± 11) were used. Meteorological data, herbage quality, daily milk yield (DMY), total milk yield (TMY), body weight (BW) of cows and calf, body-weight daily gain (ADG) of calves, body condition score (BCS) and calving interval (CI) of cows were assessed. A mixed-effects model was used to DMY and ADG data while TMY, BCS, weaning weight (WW) and CI data were analyzed by a linear model. The most determining factors in the DMY and ADG were detected by means of partial least square regression (PLSR) procedure. Group W showed higher DMY (6.5 ± 0.3 kg/d vs. 4.5 ± 0.3 kg/d, $p < 0.001$) and TMY (1,189 ± 70 kg vs. 830 ± 60 kg, $p = 0.002$) than Group A, but this did not result in a greater ADG of calves (Group A: 0.83 ± 0.04 kg/d/animal and Group W: 0.99 ± 0.09 kg/d/animal, *p*-value not significant) or WW when adjusted for their age (Group A: 216 ± 14 kg/animal and Group W: 250 ± 22 kg/animal, *p*-value not significant). In contrast, the WW actually measured were higher in Group A than in Group W (257 ± 7 kg vs. 175 ± 8 kg, $p < 0.001$). The Group W cows experienced a minor CI than Group A cows (288 ± 13 d vs. 320 ± 8 d, $p = 0.04$). The results of PLSR suggest that the factors with utmost importance for both DMY and ADG were the age and the body-weight of cows, highlighting the excellent maternal ability of Sarda breed and its good adaptation to environment.

Key words: Sarda cow, suckler-cow system, weigh-suckle-weigh method, partial least square regression.

Abbreviations

THI	Temperature-humidity index
WCI	Wind chill index
DM	Dry matter
EE	Ether extract
CP	Crude protein
NDFom	Neutral detergent fibre on an ash-free basis
ADFom	Acid detergent fibre on an ash-free basis
ADL	Acid detergent lignin
MY	Milk yield
DIM	Days in milk
BW	Body weight
BW0	BW at the start of experimental period
BWlast	BW at the end of experiment
ADG	Body-weight daily gain
CI	Calving interval
DMY	Daily milk yield
TMY	Total milk yield
BCS	Body condition score
BCS0	BCS at the start of experimental period
BCSlast	BCS at the end of experiment
ΔBCS	Change in BCS value
BCS120	BCS at the 120th day of lactation
PLSR	Partial least square regression
VIP	Variable importance in the projection
WW	Weaning weight

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1. Introduction

The beef livestock system in Sardinia is based on a suckler-cow system: the cattle, traditionally the small framed Sarda cow, followed by their calf, graze all year around pastures of medium-low nutritive value in the high hill and mountain range of the island. The calving period is mainly between autumn and winter and the calves, weaned at about 6-7 months old, are subsequently sold to the fattening centers. The weaning period is normally between June and July. In fact, in dry Mediterranean mountain conditions, the spring-calving cows are facing a period of limited herbage availability and quality (late summer) with detrimental effect on calf growth and on the recovery of reserves of cows, with negative effects on their reproductive performance.

In this system, the calf WW is the major driver for the economic return of farmers. During the pre-weaning phase, the growth rate of calves is largely determined by milk production of the dam and studies agree in quantifying this effect in 50%-60% of the variation in calf weight [1-5]. Nevertheless, apart from the work of Marongiu *et al.* [6], milk production of Sarda cows and its relationship with pre-weaning growth of calves are little investigated although this knowledge might provide additional useful information for improving the performance of this suckler-cow system. As the efficiency of livestock production based on grazing might improve if nutrient requirements (determined largely by the animal physiological state) are coordinated with seasonal changes in forage quality, the choice of a calving season that better matches cow nutrient requirements and forage nutrient availability assumes considerable importance for the producers [7]. With the aim to better understand the relationship between performance of calves and calving season, the current study evaluated the effect of calving season on milk production of Sarda cows and on pre-weaning calves growth performances in a rangeland-based beef livestock system.

2. Materials and Methods

2.1 Experimental Site and Animals

The experiment was conducted in accordance with the Italian guidelines on animal welfare (DL No. 116, 27/01/1992) and the EU Directive 2010/63/EU for animal experiments. The study was conducted from January 2017 to June 2017 at the Foresta Burgos experimental farm of the Agricultural Research Agency of Sardinia (AGRIS Sardegna) located in the inner mountainous area of Sardinia (latitude 40°25′ N, longitude 8°55′ E, altitude 850 m above sea level (asl)). The site has a Mediterranean climate, characterized by minimum and maximum mean temperatures of 1.7 °C (January) and 28.0 °C (July), respectively; the long-term average annual rainfall is 816 mm, falling mostly in winter.

Twenty multiparous Sarda beef cows (8 ± 4.5 years old), randomly selected from the larger herd of Foresta Burgos, featured by two distinct calving periods (autumn, Group A, 11 animals, average calving date 15/10/2016 ± 16 (means ± s.d.), and winter, Group W, nine animals, average calving date 26/01/2017 ± 11) were used. The initial live weight (LW) and BCS (five-point scale [8]) were 397 ± 67 kg and 2.89 ± 0.56 for Group A, and 403 ± 62 kg and 2.91 ± 0.37 for Group W. The cows grazed all together a natural pasture of about 40 ha with scattered oak tree, mainly *Quercus pubescens* L., not fertilized for a long time. More information on the vegetation of the site can be found in Ref. [9]. The bulls were introduced for each group 45 d after the group's average calving date. No supplement was fed to cows or calves during the experiment.

2.2 Measurements

2.2.1 Meteorological Data

Meteorological data relating to the period between average calving date and 180th day in milk for both groups were obtained from weather stations of the agro-meteorological service of Sardinia located near the experimental site. The meteorological factors analyzed were maximum, minimum and mean air temperature, total rainfall, mean and maximum THI [10] and mean and minimum WCI [11]. THI incorporates the effects of environmental temperature with relative humidity and it is a good indicator of stressful thermal climatic conditions. According to Silanikove [12], THI values of 70 or less are considered comfortable, 75-78 stressful, and values greater than 78 cause extreme distress.

In line with Siple and Passel [11], WCI values of 10 or more are considered comfortable, values between 10 and -1 cause slight discomfort, values below -10 discomfort and values lower than -18 extreme distress.

2.2.2 Pasture Chemical Composition

In six occasions during the experiment, herbage samples were collected by cutting 28 quadrats of 1 m × 0.5 m at ground level. The samples were immediately frozen at -20 °C, until being freeze-dried, then grounded using a hammer mill with a 1 mm sieve, and analyzed to determine the DM content, ash, EE and CP [13], NDFom, ADFom, and ADL [14].

2.2.3 Animal Performance

MY of cows was measured on five occasions for each group by the weigh-suckle-weigh technique [15], in coincidence with average DIM of 32, 85, 116, 140 and 180 d. Briefly, on the day before each evaluation (Day 1), calves were separated from their dams at 11:00 AM and then re-joined with them at 15:45 PM, when they were allowed to suckle for 30 min, until to exhaust the milk from the mammary glands. Then the cows were again separated from their calves until the next morning. Overnight, cows were kept in a small pasture paddock with water availability whereas the calves remained fasting in a pen. The next day (Day 2), at 08:00 AM, calves were weighed (BW1), then put to suckle for 30 min [16] and weighed again (BW2). According to Le Neindre and Dubroeucq [15], the DMY was estimated by the formula:

$$\mathrm{DMY} = a(\mathrm{BW2} - \mathrm{BW1}) + 0.091 \qquad (1)$$

where a = 24/time lapse between suckling on Day 1 and suckling on Day 2.

The animals were weighed using D410 electronic scale (Società Cooperativa BILANCIAI, Modena, Italy) with the maximum capacity of 1.500 kg and precision of the 0.500 kg.

The individual LW of cows and calves was assessed on seven (for Group A) and on five occasions (for Group W). The average ADG of calves was then calculated as the coefficient of the linear regression of LW upon time. The body conditions of cows were scored in four occasions for both groups.

The CI of experimental cows was obtained from the subsequent calving dates.

2.3 Statistical Analysis

2.3.1 Computations

The THI was calculated by the followed formula:

$$\mathrm{THI} = 1.8T_{\mathrm{a}} - \left(1 - \frac{U_{\mathrm{r}}}{100}\right)(T_{\mathrm{a}} - 14.3) + 32 \qquad (2)$$

where T_{a} = air temperature (°C) and U_r = air humidity (%).

The WCI was calculated by the formula:

$$\mathrm{WCI} = 33 - (33 - T_{\mathrm{a}})(0.474266 + 0.453843\sqrt{V} - 0.0453843V) \qquad (3)$$

where T_{a} = air temperature (°C) and V = wind speed (m/s).

2.3.2 Statistical Procedures

Meteorological data were subjected to analysis of variance using the LM procedure of R software version 3.3.2 [17], with calving period as fixed effect. The test-day regarding MY data was analyzed by the following mixed model:

$$Y = \mu + bw + \mathrm{sex} + T_i + C + e \qquad (4)$$

where: Y is the average DMY, μ is the overall mean, bw is the covariate effect of BW of cows, sex is the fixed effect of sex of calves, T is the fixed effect of treatment (i = 2), C is the random effect of cow nested within treatment and e is the random residual error. The LME procedure of R was exploited to develop the model and the Tukey test was used for multiple treatment comparisons using the emmeans function of R. Significance was declared at $p \leq 0.05$ unless otherwise stated.

The TMY throughout 180 d of lactation was estimated by fitting Legendre polynomials functions to the test-day records, because of its capacity to fit a great range of atypical lactation curves shapes [18, 19].

TMY data were then analyzed by a linear model (lm function of R) with calving season and sex of calves as fixed effects, and cow BW as covariate.

ADG of calves data were analyzed by a linear mixed model, similar to model for DMY analysis, with calving period, and age of calves (which coincides with DIM) and sex of calves as fixed effects, BW of calves at the start of experimental period as covariate and the animal as random effect using the LME procedure of R.

The change in the value of BCS of cows between the beginning and the end of the experiment (ΔBCS) was analyzed by a linear model (lm function of R) with the calving season and the sex of the calves as fixed effects and BCS of cows at the beginning of the experiment (BCS0) as covariate. The same model was used to compare BCS value of Group A and Group W cows at the 120th day of lactation, the end of period with the highest energy demand of suckling cows [4, 20, 21], with calving season and sex of calves as fixed effects and age of cows, BCS0 and DIM as covariates.

The WW of calves were analyzed by a linear model (lm function of R) with calving season and sex of calves as fixed effects and age as covariate.

The CI was analyzed by the same linear model used previously (lm function of R) with calving season and sex of calves as fixed effects.

Least squares means are reported for each variable, unless otherwise stated.

With the aim to identify the most important factors affecting DMY and ADG, relationships were identified between:

(1) DMY as dependent variable (Y), and DIM, cow and calves BW, ADG, age of calves, maximum, minimum and mean air temperature, rainfall, mean and maximum THI, diet chemical composition (DM, CP, NDFom, ADFom, ADL, EE) as independent variables (X), by means of PLSR procedure.

(2) ADG as dependent variable (Y) and the same as before as independent variables, except for the calves LW.

The use of PLSR derives from its ability to handle multivariate regression models with high collinearity among predictors and to make prediction more efficient compared to ordinary multivariate regression or principal component regression [22]. PLSR extracts a set of orthogonal new variables called latent factors, which result from linear combinations of the explanatory variables X, that best model the dependent variable Y [23]. To validate the model, a leave-one-out cross-validation method was used. The prediction ability of PLSR was assessed using the average DMY values of both experimental groups estimated by the weigh-suckle-weigh technique and measured ADG as reference values. The precision and accuracy of the model were assessed implementing the model evaluation system (MES, release 3.1.16 [24]) in which the predicted values were regressed against the observed ones. The evaluation of model precision was based on the coefficient of determination (R^2) whereas that of model accuracy was based on Dent and Blackie test [25], which simultaneously evaluates if the slope of the regression of predicted upon observed values differs from one and if the regression intercept differs from zero.

The VIP scores [26] were used to identify the most relevant predictors X (independent original variables) for explaining Y (dependent variable). VIP allows classifying the X-variables according to their explanatory power of Y, enhancing the model interpretability through the identification of the most important predictors [27, 28].

PLSR was carried out with plsr function (library pls) of R (2016).

3. Results

The quality of herbage on offer is illustrated in Table 1, which denotes the simultaneous decrease of CP content and increase of DM content in June, when most of grass species are at heading or post-heading phase.

Table 2 shows the meteorological data (as average and the range of values) referred to period of test-day data (from average calving date to Day 180 in milk) of the two experimental groups. As evinced from Table 2, lactation of Group W took place in a period characterized by higher temperatures. Actually, THI and WCI indexes never attained values causing extreme discomfort and, in particular, the first one never reached the stressful level. However, the Group A experienced a slight discomfort, with minimum WCI averaging value of -1.3.

In Table 3, BW and BCS of cows are reported at the start and at the end of experimental period, BCS120, DMY, TMY as estimated by Legendre polynomials functions, ADG and WW of calves and cow CI. Cows in both groups enhanced their BW and body condition (BCS), without differences between groups. The calving season affected DMY, BCS120 and TMY with greater values in Group W than in Group A whereas the ADG values, though numerically different, did not reach statistical significance. Since calves are normally sold at weaning, it was decided to show the values of their weights as measured at that time (WW, Table 3) because they are the ones that actually determine the breeder's income. The weights shown in Table 3 do not take into account the different age of calves at the weaning time (Group A 247 ± 5 d old and Group W 143 ± 6 d old, $p < 0.001$, data not shown in Table 3). When the WW analysis took into account the age and sex of calves, the result was different; the calving season did not affect the adjusted WW (Group A 216 ± 14 kg/animal and Group W 250 ± 22 kg/animal, *p*-value not significant, data not shown in Table 3). Moreover, the Group W cows experienced a shorter CI than Group A cows (Table 3).

The sex of calves did not affect DMY, TMY, ADG and CI (Table 4). The WW of calves were not affected by sex, although males registered at that time 15 kg more weight, on average (Table 4).

Table 5 shows the range of values of the variables used in the PLSR procedure and represents the conditions within which the PLSR model can estimate DMY and ADG values. Figs. 1 and 2 display the

Table 1 Chemical composition of herbage on offer of the natural pasture grazed by the experimental cows.

	DM (%)	EE (% DM)	CP (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)
19/11/2016	20.8	4.2	21.9	48.4	25.4	2.8
10/01/2017	22.4	4.0	19.7	43.9	22.1	1.5
08/02/2017	13.7	3.3	22.3	46.4	24.1	3.9
28/02/2017	23.58	4.8	23.9	34.3	19.9	2.8
11/04/2017	23.86	4.0	20.3	42.9	24.3	2.7
17/05/2017	24.2	2.9	15.8	53.6	29.6	2.6
20/06/2017	54.9	2.6	4.6	55.1	31.8	3.9

Table 2 Meteorological data in the period from average calving date to 180 DIM of suckling cows with calving season in autumn (Group A) and in winter (Group W).

	Group A	Group W	*p**
Maximum air temperature (°C)	1471 ± 0.4	19.9 ± 0.4	< 0.001
Minimum air temperature (°C)	3.6 ± 0.4	5.5 ± 0.4	< 0.001
Mean air temperature (°C)	8.7 ± 0.4	13.0 ± 0.4	< 0.001
Total precipitation (mm)	1.9 ± 0.4	0.8 ± 0.4	0.03
No. of hours below 3 °C (h)	3.1 ± 0.3	1.5 ± 0.3	< 0.001
No. of hours below 7 °C (h)	8.9 ± 0.5	5.2 ± 0.5	< 0.001
No. of hours above 25 °C (h)	0.06 ± 0.2	1.99 ± 0.2	< 0.001
Mean THI (n)	48.0 ± 0.5	54.4 ± 0.5	< 0.001
Maximum THI (n)	56.4 ± 0.6	62.7 ± 0.6	< 0.001
Mean WCI (n)	6.1 ± 1.3	13.3 ± 0.6	< 0.001
Minimum WCI (n)	-0.03 ± 1.1	5.60 ± 0.5	< 0.001

**p* values for the effect tested; n.s. = not significant.

Table 3 BW and BCS at the start of experimental period (BW0 and BCS0) and at the end of experiment (BWlast and BCSlast), ΔBCS, average DMY, BCS120, TMY, ADG of calves, WW of calves and CI of cows with calving season in autumn (Group A) and in winter (Group W) (LS means ± SE).

	Group A	Group W	*p**
BW0 (kg/animal)	395 ± 19	410 ± 21	n.s.
BCS0 (n)	2.84 ± 0.41	2.96 ± 0.50	n.s.
BWlast (kg/animal)	446 ± 20	467 ± 22	n.s.
BCSlast (n)	3.84 ± 0.28	3.49 ± 0.34	n.s.
ΔBCS (n)	0.80 ± 0.08	0.58 ± 0.09	n.s.
DMY (kg/d/animal)	4.5 ± 0.3	6.5 ± 0.3	< 0.001
BCS120	2.90 ± 0.04	3.64 ± 0.06	< 0.001
TMY (kg/animal)	830 ± 60	1,189 ± 70	0.002
ADG (kg/d/animal)	0.83 ± 0.04	0.99 ± 0.09	n.s.
WW (kg/animal)	257 ± 7	175 ± 8	< 0.001
CI (d)	320 ± 8	288 ± 13	0.04

**p* values for the effect tested; n.s. = not significant.

Table 4 Effect of sex of calves on average DMY and TMY of dams, ADG, WW of calves and CI (LS means ± SE).

	Female	Male	*p**
DMY (kg/d/animal)	5.7 ± 0.3	5.3 ± 0.3	n.s.
TMY (kg/animal)	1,049 ± 57	959 ± 80	n.s.
ADG (kg/d/animal)	0.88 ± 0.04	0.94 ± 0.04	n.s.
WW (kg/animal)	225 ± 7	240 ± 8	n.s.
CI (d)	313 ± 8	294 ± 14	n.s.

**p* values for the effect tested; n.s. = not significant.

Table 5 Means and range of value of meteorological data, DMY, ADG, DIM and BW of cows, age and BW of calves, diet chemical composition (DM, CP, NDFom, ADFom, ADL, EE) used in PLSR procedure to estimate DMY and ADG.

	Means ± S.D.	Range of values
Maximum air temperature (°C)	17.4 ± 7.8	5.7-28.5
Minimum air temperature (°C)	3.9 ± 1.9	0.8-6.4
Mean air temperature (°C)	11.5 ± 4.9	3.8-18.6
Total precipitation (mm)	2.9 ± 4.9	0.0-13.2
Mean THI (n)	51.8 ± 7.5	38.8-61.8
Maximum THI (n)	58.9 ± 9.9	41.9-71.6
Mean WCI (n)	13.6 ± 4.3	7.9-18.3
Minimum WCI (n)	5.0 ± 2.1	2.2-7.0
DMY (kg/d/animal)	5.11 ± 1.73	1.40-11.18
DIM (d)	137 ± 64	16-232
BW of cows (kg/animal)	420 ± 67	291-586
Age of calves (d)	137 ± 64	16-262
BW of calves (kg/animal)	154 ± 59	53-308
ADG (kg/d/animal)	0.87 ± 0.28	0.00-1.51
Herbage DM (%)	28.7 ± 13.4	13.7-54.9
Herbage CP (% DM)	17.2 ± 6.8	4.6-23.9
Herbage NDF (% DM)	46.2 ± 7.6	34.3-55.1
Herbage ADF (% DM)	25.7 ± 4.4	19.9-31.8
Herbage ADL (% DM)	2.9 ± 0.8	1.5-4
Herbage EE (% DM)	3.6 ± 0.8	2.6-4.9

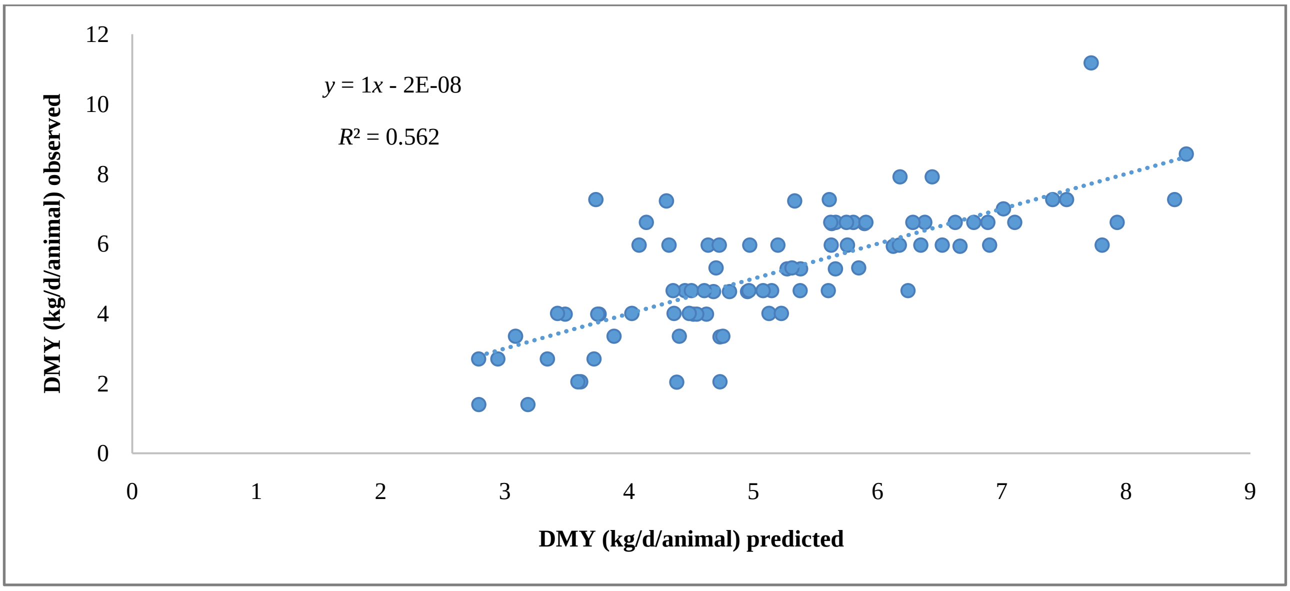

Fig. 1 Plots of observed versus PLSR-predicted values of DMY.

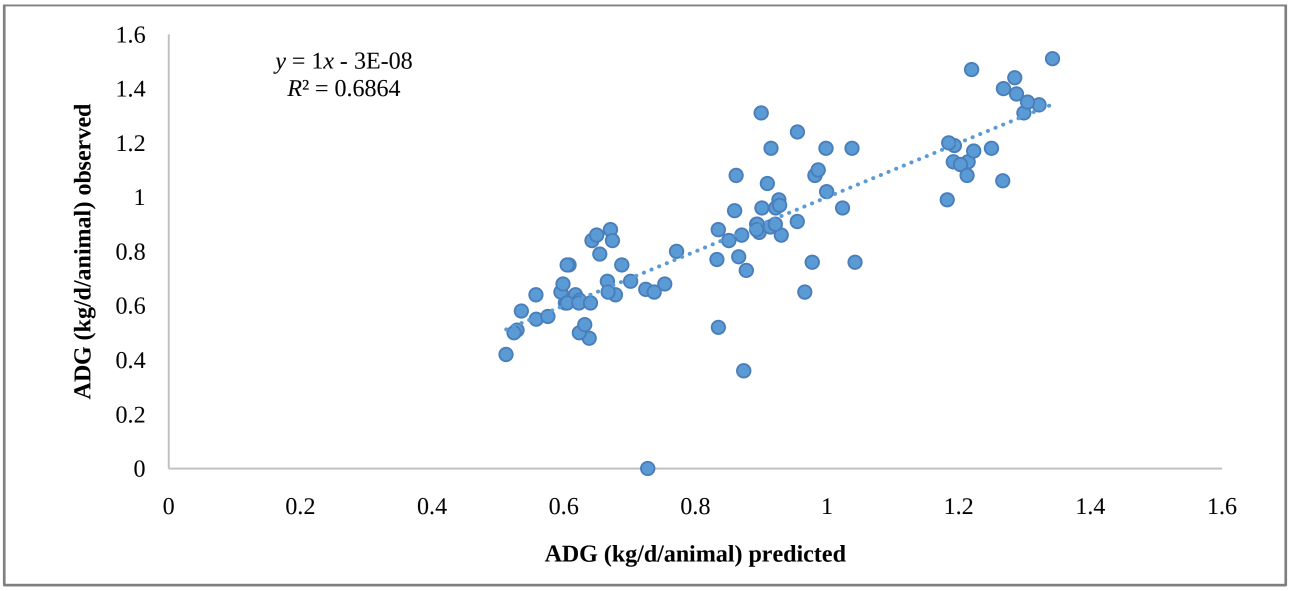

Fig. 2 Plots of observed versus PLSR-predicted values of ADG.

regression equations between predicted and observed values and results of the adequacy of predictions of PLSR procedure, respectively. The PLSR was able to provide accurate estimates of both DMY and ADG (Dent and Blackie test $p > 0.05$). This means that equation parameters, the intercept and slope, were contemporarily not significantly different from zero and one, respectively, thus indicating that all the regression lines pass through the origin and are bisectors of the first quadrant angle. The degree of precision of the models (R^2) was good, although it varied according to the variable considered. The prediction of ADG reported the highest adjusted R^2 (0.68) while the prediction of DMY showed an R^2 value of 0.56. The observed DMY and ADG of calves averaged across all the experimental animals (5.23 ± 1.74 kg/d/animal and 0.87 ± 0.29 kg/d/animal, respectively), were similar to the average DMY and ADG predicted by PLSR model (5.23 ± 1.31 kg/d/animal and 0.87 ± 0.24 kg/d/animal, respectively). For both models, the first latent factor

Table 6 VIP scores of original independent variables related to the first latent factors extracted by PLSR procedure in predicting DMY of cows and ADG of calves.

Original independent variables	VIP scores for the first factor in DMY prediction model	VIP scores for the first factor in ADG prediction model
Sex	0.00002	0.00113
DIM (d)	0.12858	0.38491
DMY (kg/d/animal)		0.00245
Age of cows (d)	4.35210	4.08957
BW of cows (kg/animal)	0.14017	0.30608
BW of calves (kg/animal)	0.08051	
Maximum air temperature (°C)	0.00236	0.07587
Minimum air temperature (°C)	0.00227	0.00956
Mean air temperature (°C)	0.00154	0.04634
Mean THI (n)	0.00370	0.07345
Maximum THI (n)	0.00468	0.09758
Rainfall (mm)	0.00294	0.04009
Herbage DM (%)	0.00001	0.04439
Herbage EE (% DM)	0.00017	0.00609
Herbage CP (% DM)	0.00015	0.03983
Herbage NDF (% DM)	0.00087	0.06250
Herbage ADF (% DM)	0.00115	0.03965
Herbage ADL (% DM)	0.00052	0.00045
ADG of calves (kg/d/animal)	0.00016	

extracted by PLSR [22] was able to account for more than 99% of original variance explained by the model. The VIP scores of original variables for the first latent factor indicate the variables contribute the most to the Y variance explanation. The original variables that play a major role in the DMY and ADG prediction were the age of cows, the stage of lactation of cow (DIM, which coincides with age of calf) and the BW of cows (Table 6). Less important factors were the variables linked to meteorological conditions and herbage quality.

4. Discussion

The beef production system in Sardinia is based on suckled cows raised in the rangelands, grazing the available resources of pasture. The main products obtained are the calves, sold at weaning to other farms where they are finished. The resource availability in Mediterranean ecosystems is characterized by high seasonality [29]. This implies that free-grazing beef cattle in Mediterranean grasslands may face a reduction in the quantity and nutritional quality of forage during the hot and dry season [30]. This usual decay in herbage quality is experienced by the animals in this work, as demonstrated by the reduction of CP and the rise of DM content and of fibrous component (especially ADF and ADL) of diet in June (Table 1). As nutritional requirements of gestation and lactation of cows are met only if forage quality is adequate, the decrease in herbage quality in late spring must be taken into account by farmers while targeting the calving season. Both periods examined in this paper (average calving date 15/10/2016 ± 16 (mean ± s.d.), and 26/01/2017 ± 11, respectively) foresaw the weaning time in June when the selling prices of the calves in the Sardinian market are more convenient. In this way the farmers avoid growing calves when cow diet is probably unbalanced due to low protein and high fiber levels of grazed herbage. In this work, the calving season affected the DMY of cows, with winter calving cows showing higher DMY than autumn calving cows (Table 3). In line with Rodrigues *et al.* [4], differences in milk production linked to calving period can be related to climate differences, such as temperature, humidity, rainfall. Overall, the weather-related energy demand and welfare conditions of winter calving cows (Group W) were more favorable than those of autumn calving cows (Table 2). In fact, Group A experienced a minimum WCI index value that, although not reaching extreme values, could have caused a “slight discomfort” to animals. Taking into account that the highest energy demand of suckling cows falls between the 60th and the 120th of DIM [4, 20, 21], cold weather and lower ambient temperatures in this period could reduce MY [31]. Moreover, an indirect effect of weather via pasture availability (directly influenced by the weather) on DMY is probable, as suggested by the BCS value recorded at the end of the period with the highest energy needs of the suckler cows (BCS120, Table 4). The higher value of the winter-calving cows indicates a better energy balance, at least in the first part of lactation. After that period, both Group A and Group W cows recovered their body condition and BW (Table 4), demonstrating the fulfillment of their nutritional needs.

As a consequence of their greater DMY, Group W showed higher TMY, without this leading to differences in ADG of calves (Table 3) or in WW (when adjusted for age of calves, Group A 216 ± 14 kg/animal and Group W 250 ± 22 kg/animal (LS means ± SE), *p*-value not significant, data not shown in Table 3). This lack of differences between experimental groups in ADG and adjusted WW value, despite the higher DMY of Group W cows, seems to suggest that the calves of both groups were able to fully express their growth potential and that MY of autumn-calving cows was overall adequate for this potential.

In fact, calf growth rates were in line with or higher than those reported by Marongiu *et al.* [6] in similar conditions. It therefore seems reasonable to state that these ADG (0.88 ± 0.10 kg/d/animal (means ± s.d.), as average of all experimental animals) are those obtainable by Sarda calves suckled by Sarda cows in the high Mediterranean hills. It is likely that the moderate stocking rate (represented by the cow-calf pair: 287 ± 55 kg BW/ha (means ± s.d.), as average of all experimental period) and the non-extreme weather conditions allowed to meet the nutritional needs of cows (as demonstrated by the last values of BCS and BW), enabling calves of both groups to fully express their growth potential. Contrary to Rutledge *et al.* [20], Cundiff *et al.* [32] and Gaertner *et al.* [33], the sex of calves did not affect any of the variables under study (Table 4). In line with Casu *et al.* [34], it seems likely that calves in suckling phase still do not fully explain the effect of sex. Nevertheless, at weaning, the males weighed, on average, 15 kg more than the heifers, although this difference was not statistically significant.

The CI recorded by the experimental groups remained within the values that allow one birth per year, beyond which this type of farming becomes often economically unsustainable [35]. This highlights the ability of Sarda cow to sustain calf meat production under extensive conditions without supplementation. As shown by Marongiu *et al.* [6] this could not be the case in the same environment for F1 cows sourced from Charolaise bull × Sarda cow crossing, particularly in years featured by unfavorable weather conditions around calving.

The higher BCS value of Group W cows than Group A ones at the end of the first part of lactation (BCS120, Table 3) could explain their lower CI value, likely due to a better energy balance of Group W cows during the mating period. The BCS in the first months of lactation is a good indicator for estimating postpartum resumption of cyclicity and reproductive performance of beef cattle [6, 36, 37], and it is well known that the re-initiation of oestrus cycle during the postpartum period is affected by energy balance [38].

Within the conditions of this study, the PLSR procedure was able to make an adequate prediction of DMY and ADG. Interestingly, the factors playing a major role in the prediction are the same for both model and primarily linked to the intrinsic conditions of the cow (age, BW and DIM). Whereas the role of stage of lactation in MY appears obvious, the relevance of the age of cows (in line with Rodrigues *et al.* [4], Rutledge *et al.* [20] and Robinson *et al.* [39]) and of its BW, in line with Arthur *et al.* [2], together with the contemporary minor importance of factors linked to meteorological conditions and to herbage quality, indicates that the milk production and the growth rate of calves are more linked to intrinsic conditions of cow than to environmental conditions (sensu latu).

This suggests that Sarda breed is optimally adapted to its environment, being able to guarantee its production regardless of the environmental conditions, at least if these are not too severe. On the other hand, it cannot be excluded that, in the very unfavorable years, there may be the need to supplement the animals (cow and calf) in the suckling period. This points out the importance of further research on this topic.

The fact that PLSR identifies the same drivers for both calf ADG and cow milk production, could suggest that DMY and ADG are strongly related. However, in this study, in contrast with some literature [1, 3, 5], the relationship between DMY and ADG of calves was very weak (R^2 = 0.001, *p*-value not significant, not shown in tables). On the other hand, the decrease in the MY usually is by higher fat and protein contents, which are equally important for calf growth [5, 40]. Unfortunately, the use of weigh-suckle-weigh method does not allow the sampling of milk for constituent determination [20], in order to examine the relation between milk quality and calf growth. The factors involved in the calf growth are numerous and interrelated and the milk production of dams is affected, in turn, by several variables. Therefore, it seems realistic that the same factors that influence milk production are involved in shaping the calf performance as well, at least indirectly.

5. Conclusions

In deciding which calving season is more suitable on a particular farm, the specifics of the rearing environment are important factors to consider. In the harsh mountain range of Sardinia, where the small-frame Sarda cow grazes upland pastures and forests, the winter-calving cows showed higher MY and shorter CI compared to autumn-calving cows. Nevertheless, the CI of all experimental animals were within the time range allowing the production of a live calf per cow every 365 d, a threshold beyond which the profitability of this system is markedly reduced. However, the higher level of milk production in the winter-calving cows did not lead to greater growth rate of calves, likely because the growth potential of these animals was already supported by the MY of autumn-calving cows.

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