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Associations between serum gamma-globulin concentration, enzyme activities, growth and survival in preweaning Alpine goat kids

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ABSTRACT

Colostral immunity is crucial for young ruminants, but the individual factors that may affect passive transfer status and its effects on preweaning growth performance have not been widely investigated in goats. The methods to quantify immunoglobulins G can be expensive. Colostrum enzymes, though, pass the intestinal barrier and might be suitable as markers of passive transfer status, as demonstrated in other ruminant species. This study aimed to investigate the effect of sex, litter size, dam parity, and birth body weight on passive transfer status and the relationship between gamma-globulin concentration (GG) and pre-weaning growth performance in Alpine goat kids. The association between serum GG, serum total protein concentration and serum activity of colostrum enzymes including γ-glutamyltransferase (GGT), alkaline phosphatase (ALP), aspartate aminotransferase (AST), and lactate dehydrogenase (LDH) was examined for their use as predictors of passive transfer status in neonatal goat kids. Sixty-six Alpine goat kids (39 males, 27 females), born to 28 does at one dairy goat farm during two delivery seasons, were enrolled. Kids nursed their dams in group housing until weaned at 50 days of age. Blood samples were collected 24 h after birth. Body weights (BW) were taken at birth and weaning. Serum enzyme activities and total protein concentration were measured using a clinical biochemical analyser. Serum GG was determined by gel electrophoresis. Statistical analysis was performed using GraphPad Prism (v. 8.2.1). No significant differences in serum GG between males and females, singlets and twins, multiparous' and primiparous' kids were found. No association was detected between birth BW and GG. Serum GG was strongly and significantly associated with TP (R^2 =0.85; p 0.0001) and moderately associated with GGT (R^2 =0.47; p 0.0001). No correlation was found with ALP, AST, and LDH. Although partial failure of passive transfer (FPT) was diagnosed in 23% of kids, no effects on morbidity (3%), mortality (0%) and pre-weaning growth performance were observed. Our results confirm that serum total proteins can be used to indirectly estimate immunoglobulin concentration. Contrarily, passive transfer status can be predicted with little success by measuring the activity of serum GGT. It is not advisable to use ALP, AST and LDH as indicators of passive transfer status. Finally, FTP is not necessarily associated with the health and preweaning growth performance of Alpine goat kids reared in non-intensive breeding systems that follow good farming practices.

1. Introduction

In goats, and ruminants more in general, the synepitheliochorial placenta prevents the transfer of immunoglobulins (Ig) from the mother to the offspring during foetal life. Therefore, the acquisition of passive immunity through the ingestion of Ig (of which IgG account for the largest fraction) from maternal colostrum is critical for the health and survival of neonatal goat kids (Barrington and Parish, 2009). The intestinal absorptive capacity of Ig halves 6 h after birth and is depleted after 24 h in calves and lambs, but it seems to last longer in goat kids (Smith and Sherman, 2009). Besides colostrum quality, quantity, and ingestion time, individual factors such as sex, litter size, birth body weight (BW), and dam parity, may affect passive transfer status but have not yet been thoroughly explored in goats, especially in the Alpine breed

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(O'Brien and Sherman, 1993; Mellado et al., 1998; Chen et al., 1999; Massimini et al., 2007; Castro et al., 2009).

Failure to timely ingest an adequate amount of good quality colostrum can result in hypogammaglobulinemia and the so-called failure of passive transfer (FPT), which is associated with increased risk of illness and death (Vihan, 1988; O'Brien and Sherman, 1993; Argüello et al., 2004). Hence, the early diagnosis of FPT is essential for the proper management and treatment of newborn goat kids.

In calves, the generally accepted definition of FPT is a serum IgG concentration below 1 g/dL (Uyama et al., 2022), whereas calves with serum IgG concentrations > 1.5 g/dL are considered to have excellent passive transfer of immunity (Shivley et al., 2018). Indeed, recently, a single threshold has been deemed too simplistic, because it does not consider the relationship between increasing IgG concentration and lower morbidity risk and improved production performance (Godden et al., 2019). There is still disagreement regarding where to place the threshold between normal serum IgG concentration and hypogammaglobulinemia in newborn goat kids. O'Brien and Sherman (1993) defined FPT as serum IgG concentrations < 1.2 g/dL, whilst other authors set the threshold at 0.8 g/dL (Constant et al., 1994; Mellado et al., 1998). The same disagreement occurs when characterising FPT in lambs, with some authors using the threshold set for calves (McGuire et al., 1983), while others consider a cut-off value of 1.5 g/dL (Alves et al., 2015; Viola et al., 2022).

The optimal time to measure IgG concentration is around 24 h after birth, when they show a peak (Chen et al., 1999). Direct IgG measurement methods, such as single radial immunodiffusion (SRID) and enzyme-linked immunosorbent assay (ELISA) are expensive, technically demanding, time-consuming, and not routinely available in all diagnostic laboratories. Gel electrophoresis is cheaper in comparison to other laboratory tests, is used more widely in diagnostic laboratories, and allows the quantification of gamma-globulins as a proxy for the concentration of serum IgG (de Souza et al., 2021). However, there still is interest in finding alternative, indirect methods that are fast, inexpensive, and readily available for farmers and veterinarians.

Since neonatal intestinal absorption is nonselective in ruminants, a variety of macromolecular substances, including proteins and enzymes, can pass the intestinal barrier and may therefore be suitable as markers of passive transfer status (Britti et al., 2005). The association between serum γ-glutamyl transferase (GGT) activity and Ig concentration has been investigated in newborn calves (Braun et al., 1982; Perino et al., 1993; Parish et al., 1997; Wilson et al., 1999; Zanker et al., 2001; Hogan et al., 2015) and lambs (Tessman et al., 1997; Maden et al., 2003; Britti et al., 2005; Gokce et al., 2021), but data on goat kids are scant (Braun et al., 1984; Batmaz et al., 2019). Fewer studies have examined the activity of alkaline phosphatase (ALP), aspartate aminotransferase (AST), and lactate dehydrogenase (LDH) (Zanker et al., 2001; Britti et al., 2005).

Besides Ig and enzymes, colostrum also contains nutrients, growth factors, hormones, minerals, and trace elements, essential for the development, growth, and productive performance of young ruminants (McGrath et al., 2016). However, differently from calves (Robison et al., 1988; Dewell et al., 2006; Furman-Fratczak et al., 2011), the potential long-term effects of passive immune status on preweaning growth performance have not been widely investigated in goats (Massimini et al., 2007).

This study aimed to examine (i) the effect of sex, litter size, dam parity and birth body weight (BW) on gamma-globulin concentration (GG); (ii) the association between GG, total protein concentration (TP) and serum activity of colostrum enzymes including γ-glutamyl transferase (GGT), alkaline phosphatase (ALP), aspartate aminotransferase (AST) and lactate dehydrogenase (LDH) for their use as predictors of passive transfer status in neonatal Alpine goat kids; (iii) the effect of passive transfer status on pre-weaning growth performance.

2. Materials and methods

This research is part of a larger project approved by the animal welfare body of the *Alma Mater Studiorum* - University of Bologna (Protocol Number 77988 of 08/04/2022).

This study was carried out on Alpine goat kids born at the teaching farm of the Department of Veterinary Medical Sciences of the University of Bologna (Ozzano dell'Emilia, Italy) during two delivery seasons in the years 2022 and 2023. The does were group housed indoors on straw bedding, and from April to November they had access to around 2500 sq m of fenced grazing area during daytime. Their diet consisted of 2.0 kg/d of alfa-alfa hay and 0.3 kg/d concentrate (containing wheat bran, sunflower, soybean, barley, corn cob, dried beet pulp, mineral and vitamin mix; analytical constituents 17.8% crude proteins, 3.6% fat, 10.2% crude fibre and 6.6% crude ash) during late pregnancy, which was increased up to 0.8–1.2 kg/d during lactation. They had ad libitum access to water and salt licks. They mated naturally from August to September and were supervised from 0800 to 1800 h during the delivery season (from January to March). In total, 28 different does delivered during the study: in 2022, 8 primiparous does aged between 1 and 2 years and 18 multiparous does between 3 and 9 years old delivered 41 kids; in 2023, 14 multiparous does between 3 and 7 years old delivered 25 kids. The 2023 group of does included 10 of the multiparous and 2 of the primiparous does that delivered in 2022 and 2 multiparous does that did not get pregnant in 2022.

Of the 66 Alpine goat kids included in the study, 39 were males and 27 were females; 14 were singlet and 52 were twins. Right after birth, kids were weighed and identified with a pastern band to minimize stress (they were later ear tagged at 7 days of age). They were then reunited with their mothers to naturally suckle until weaning at 50 days of age, when they were weighed again, unless they were sold at a younger age due to Easter festivities. They had ad libitum access to water and hay since birth and to a commercial starter (containing maize, soybean, barley, sunflower, wheat bran, carob, mineral, and vitamin mix; analytical constituents 19.4% crude proteins, 3.0% fat, 7.0% crude fibre and 6.5% crude ash) from 15 days of age. The goat kids' health status was clinically monitored daily during the first month of age and then every two days until weaning to identify lethargy, dehydration, lack of weight gain or weight loss, diarrhoea, and respiratory disease. Blood samples (3 mL) were collected 24 ± 3 h after birth from the jugular vein following trichotomy and disinfection of the area, using a 23 G Safety-Multifly® needle (Sarstedt, Germany) and a clot activator tube (Vacutest Kima, Italy). They were centrifuged at 3000g for 10 min at room temperature within one hour after collection; the retrieved serum was divided into two aliquots and stored at −20 °C until analysed.

Serum activities of γ-glutamyl transferase (GGT, OSR 6120, Beckman Coulter, USA), alkaline phosphatase (ALP, OSR 6104, Beckman Coulter, USA), aspartate aminotransferase (AST, OSR 6109, Beckman Coulter, USA), and lactate dehydrogenase (LDH, OSR 6128, Beckman Coulter, USA) were measured using a clinical chemistry analyser (AU480, Beckman Coulter, USA). Total serum protein concentration (TP) was measured by the biuret method (Total Protein, OSR 6123, Beckman Coulter, USA). Serum gamma-globulin concentration (GG) was determined by agarose gel electrophoresis (Hydragel 15 protein(e) kit, Hydrasys, Sebia, Lisses, France).

Serum proteins were divided into the following fractions: albumin, alpha, beta, and gamma globulins. The relative percentage of each protein fraction was calculated from the area under the curve created by the protein band using commercially available software (Phoresis, Sebia, Lisses, France).

Statistical analysis was performed using GraphPad Prism (v. 8.2.1). Normality was verified using the Shapiro-Wilk test. Mean ± SD values for serum GG, birth BW, day 50 BW, and average daily gain (ADG) from birth to day 50 were calculated. ADG was calculated by subtracting birth BW from BW at weaning and dividing it by the number of days between birth and weaning. Differences in birth BW and GG depending on sex, litter size, and dam parity were investigated using Student's t-test. Univariate linear regression was used to evaluate the association between birth BW and serum GG, between serum GG, TP, and serum activity of colostrum enzymes (GGT, ALP, AST, LDH), and between serum GG and pre-weaning growth performance. Failure of passive transfer (FPT) was defined as serum GG < 0.8 g/dL; goat kids with serum GG > 1.2 g/dL were considered to have an optimal passive transfer status. Differences in health outcome and survival according to passive transfer status were investigated using Fisher's exact test. Differences in ADG depending on passive transfer status were investigated using one-way ANOVA followed by Tukey's test for multiple comparisons. A p-value < 0.05 was considered significant.

3. Results

Mean ± SD serum GG at 24 h after birth in the overall sample was 1.34 ± 0.75 g/dL. Males and singlets were significantly heavier at birth compared to females and twins, respectively. Birth BW of multiparous' and primiparous' kids was not significantly different. No significant differences in serum GG between males and females, singlets and twins, multiparous' and primiparous' kids were found (Table 1).

No association was found between birth body weight and serum GG (R^2 =0.01; p = 0.42) (Fig. 1A). Serum GG concentration was strongly and significantly associated with TP (R^2 =0.85; p < 0.0001) and could be estimated by the following formula: serum GG (g/dL) = 0.693*(TP [g/dL]) – 2.440 (Fig. 1B). The correlation between GG and GGT was moderate (R^2 =0.47; p < 0.0001) and their relationship described by the following formula: serum GG (g/dL) = 0.00394*(serum GGT activity [U/L]) + 0.1913 (Fig. 1C). No association was found between GG and ALP (R^2 =0.03; p = 0.14), AST (R^2 =0.01; p = 0.37) and LDH (R^2 =0.01; p = 0.52), respectively (Fig. 1D-1F).

No associations were found between serum GG and pre-weaning growth performance in terms of BW (R^2 = 0.04; p = 0.14) and ADG (R^2 = 0.04; p = 0.15) (Fig. 2).

Failure of passive transfer (FPT) was diagnosed in 23% of kids (15/66). No kids died during the study. Two kids, born in 2023, had diarrhoea at one month of age, which resolved spontaneously without requiring any medical treatment (Table 3). Differences in terms of health and survival between kids with serum GG < 0.8 g/dL and kids with higher GG values were at the limit of significance (p = 0.05). No differences in pre-weaning growth performance in terms of ADG at weaning according to passive transfer status were observed (Fig. 3).

Table 1
Mean ± SD serum gamma-globulin concentration (GG) at 24 h, birth body weight (BW), BW at weaning (50 days) and average daily gain (ADG) at weaning in the overall sample and according to sex, litter size and dam parity.

Variable	n	Serum GG (g/dL)	Birth BW (kg)	BW at weaning* (kg)	ADG* (kg/d)
Overall sample	66	1.34 ± 0.75	3.83 ± 0.60	14.51 ± 2.18	0.21 ± 0.04
Sex					
Male	39	1.42 ± 0.79	3.99 ± 0.64[a]	15.32 ± 2.06	0.23 ± 0.04
Female	27	1.24 ± 0.68	3.60 ± 0.47[b]	13.19 ± 1.70	0.19 ± 0.03
Litter size					
Singlet	14	1.48 ± 0.92	4.35 ± 0.65[a]	16.35 ± 2.94	0.24 ± 0.05
Twin	52	1.31 ± 0.70	3.69 ± 0.51[b]	14.19 ± 1.88	0.21 ± 0.03
Dam parity					
Primiparous	9	1.27 ± 0.65	3.77 ± 0.91	12.65	0.19
Multiparous	57	1.36 ± 0.76	3.84 ± 0.55	14.55 ± 2.19	0.21 ± 0.04

Within variable groups means followed by different superscripts are significantly different (p < 0.05).
Mean ± SD of serum TP and activity of colostrum enzymes (GGT, ALP, AST, LDH) at 24 h after birth in the overall sample are reported in Table 2.
* BW and ADG at weaning were calculated on a subset of 53 goat kids (of which only one from a primiparous dam) since the others were sold at an earlier age.

4. Discussion

Despite the well-established importance of colostrum intake in newborn ruminants, failure of passive transfer is still a widespread issue, impairing the health, welfare, and survival of animals, leading to increased drug use, and affecting farming productivity and sustainability (Barrington and Parish, 2009; Smith and Sherman, 2009). Knowledge of FPT risk factors and early diagnosis is crucial to allow immediate intervention and guide the decision-making process. Moreover, monitoring newborns' passive transfer status enables the informed selection of future replacement stock, to improve the health status of the herd and possibly reduce drug use.

We hypothesized that heavier kids (i.e., males, singlets) and multiparous dams' kids had higher GG concentrations. However, in our study, sex, litter size, dam parity, and birth body weight (BW) did not significantly affect passive transfer status. This is in line with what has been observed in other studies carried out on goat kids of different breeds (O'Brien and Sherman, 1993; Mellado et al., 1998; Chen et al., 1999; Argüello et al., 2004; Massimini et al., 2007; Castro et al., 2009) and lambs (Bekele et al., 1992; Massimini et al., 2006a; Chniter et al., 2016). Nevertheless, concerning litter size, Castro et al. (2009) reported significantly lower IgG concentrations in triplets, which had lower birth body weights compared to singlets and twins. It was not possible to investigate this possibility because triplets did not occur in our sample. Contrarily, Chen et al. (1999) unexpectedly detected lower IgG values in singlets, despite colostrum being artificially fed to the kids. However, singlets were only 3 out of the 43 sampled kids, therefore this finding should be taken with caution.

Direct IgG measurement by SRID, still considered the gold standard, is hardly applicable in everyday practice due to costs, complexity, and required time (de Souza et al., 2021). It has been shown that the quantification of serum gamma-globulin concentration by gel electrophoresis is the most accurate method to assess passive transfer status in 1-day-old lambs (Massimini et al., 2006b), hence we assumed that it would be an adequate technique for this study. In our sample, a strong association was found between GG and total protein concentration (TP) (R^2 =0.85; p < 0.0001). Since immunoglobulins constitute a large proportion of neonatal ruminants' serum proteins and albumin concentration is relatively constant, TP can be used to indirectly estimate serum immunoglobulin concentration (de Souza et al., 2021). On-field methods, such as refractometry, are available, albeit less accurate. Moreover, the estimate of TP may be distorted in dehydrated animals (Massimini et al., 2006b; Denholm et al., 2021).

GGT is the most studied colostrum enzyme. Several studies performed on calves (Braun et al., 1982; Perino et al., 1993; Wilson et al., 1999; Zanker et al., 2001) and lambs (Tessman et al., 1997; Maden et al., 2003; Britti et al., 2005) proposed serum GGT activity as an additional useful indicator of passive transfer status, with moderate correlation coefficients between IgG and GGT activity. The moderate correlation between GG and GGT observed in our study (R^2 =0.47; p < 0.0001) is in line with the overmentioned studies and with what was reported by Batmaz et al. (2019) (R^2 =0.54; p < 0.001) for 1-day-old goat kids. Differently, strong correlation coefficients have been detected in two studies performed on lambs, where a positive curve linear relationship was detected between serum IgG concentration and the GGT activity (Massimini et al., 2006b; Gokce et al., 2021). However, GGT activity decreases rapidly after peaking at 24 h, therefore its usefulness is further limited to the first week of life (Braun et al., 1982; Perino et al., 1993; Parish et al., 1997; Wilson et al., 1999).

Other enzymes found in first colostrum, such as ALP, AST, and LDH, have been far less researched. It has been observed that the increase of their activity following colostrum ingestion is not as consistent as for GGT, thus suggesting that the activity of these enzymes might result

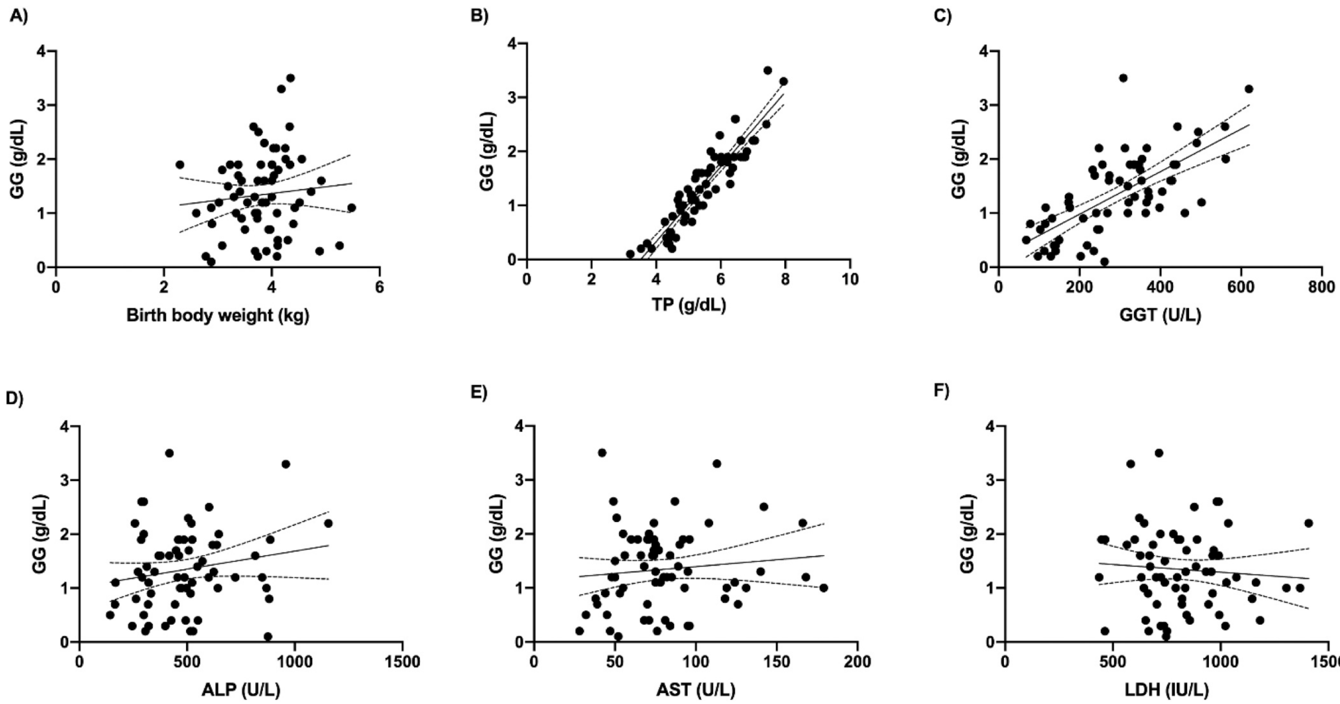

Fig. 1. Scatter plots of the relationship between serum GG and (A) birth body weight; (B) serum TP; (C) serum GGT activity; (D) serum ALP activity; (E) serum AST activity; (E) serum LDH activity. The solid line represents the best fit for the data, determined by means of simple linear regression, the dashed lines represent the 95% confidence interval.

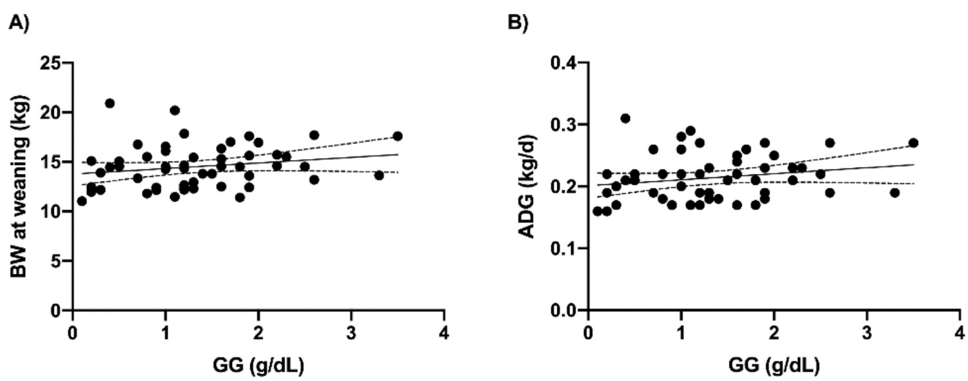

Fig. 2. Scatter plots of the relationship between serum GG and (A) body weight at weaning (50 days); (B) ADG at weaning. The solid line represents the best fit for the data, determined by means of simple linear regression, the dashed lines represent the 95% confidence interval. A subset of 53 goat kids was included in the analysis, since the others were sold at an earlier age.

Table 2
Mean ± SD serum total protein concentration (TP) and activity of colostrum enzymes (GGT, ALP, AST, LDH) at 24 h after birth in the overall sample.

Variable (measure unit)	Mean ± SD
TP (g/dL)	5.50 ± 0.99
GGT (U/L)	293 ± 129
ALP (U/L)	488 ± 205
AST (U/L)	80 ± 33
LDH (IU/L)	820 ± 208

Table 3
Number and percentage of ill and deceases goat kids according to passive transfer status. Kids were classified as having FPT, normal or optimal passive immunity.

Serum GG	n	Morbidity (%)	Mortality (%)
FPT (<0.8 g/dL)	15	2 (13%)	0 (0%)
Normal (0.8 – 1.2 g/dL)	18	0 (0%)	0 (0%)
Optimal (>1.2 g/dL)	33	0 (0%)	0 (0%)

from increased endogenous production and occur independently from colostrum intake in calves and lambs (Kurz and Willett, 1991; Zanker et al., 2001; Britti et al., 2005). Our findings suggest that this might also be the case for goat kids, therefore it is not advisable to use them as indicators of passive transfer status.

The mean serum GG concentration in the overall sample was 1.34 ± 0.75 g/dL. These concentrations are in line with what has been reported in other studies whenever goat kids were left to naturally suckle from their mothers (Argüello et al., 2004; Mellado et al., 2008; Castro et al., 2009) or were fed by the farmer (O'Brien and Sherman, 1993).

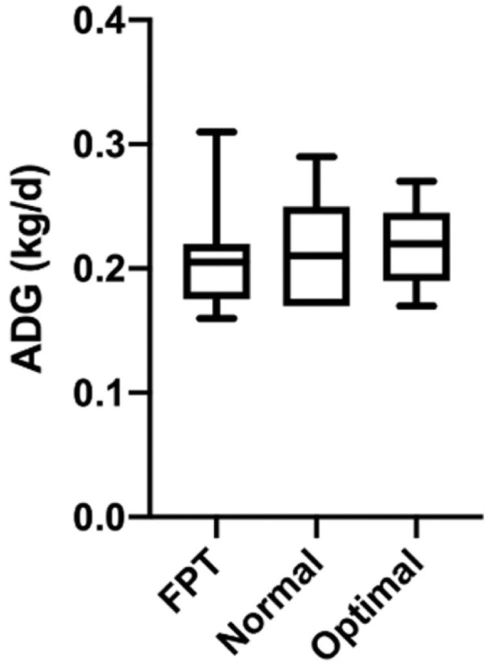

Fig. 3. Box and whiskers plot comparing ADG at weaning (50 days) according to kid's passive transfer status (FPT, normal or optimal passive immunity). The boxes represent the interquartile range from the 25th to the 75th percentile. The horizontal bar in each box represents the median value. The whiskers represent the minimum and maximum values. A subset of 53 goat kids was included in the analysis, since the others were sold at an earlier age. No significant differences were found among groups ($p > 0.05$).

Currently, there is no universally accepted threshold for defining FPT in goat kids (Smith and Sherman, 2009), and different cut-off IgG values have been proposed (O'Brien and Sherman, 1993; Constant et al., 1994; Mellado et al., 1998). Moreover, the establishment of standards with multiple categories according to the IgG levels (e.g., poor, fair, excellent) has been suggested in calves (Shivley et al., 2018; Godden et al., 2019). In our study, FPT was defined as serum GG concentration < 0.8 g/dL, whereas serum GG levels > 1.2 g/dL were considered optimal. In our sample, the prevalence of FPT was 23%, a prevalence markedly lower than that reported by Mellado et al. (1998), regardless of the site of delivery (open range vs pen). This finding is even more significant considering that not only IgG migrate in the gamma-globulin fraction (Stockham and Scott, 2008). We were unable to find other studies regarding FPT prevalence in goat kids. Few dated studies involving lambs, cited by Britti et al. (2005), report FPT prevalence ranging from 3.4% to 20%, with 45–50% mortality rates. Other studies have reported lower survival rates for goat kids with serum IgG concentrations < 0.8 g/dL (O'Brien and Sherman, 1993; Mellado et al., 1998; Argüello et al., 2004). However, in our study population, passive transfer status did not significantly affect kids' health and survival.

Only two 1-month-old kids, born in 2023, got diarrhoea. The context in which this occurred deserves to be mentioned. Indeed, there was an emergency where the person in charge of the barn did not come to work, and cleaning operations were not carried out for three days. Consequently, poor hygienic conditions most likely caused the onset of diarrhoea among the kids most at risk. This confirms an established observation in clinical and zootechnical practice, namely that colostrum intake is not the only factor influencing the health and survival of newborn goat kids, but management practices play a key role in protecting from or exacerbating the health risks animals are exposed to. The affected kids did not require any medical treatment, but monitoring aimed at preventing dehydration, acidosis, and the consequent worsening of clinical conditions was enough. The restoration of good hygienic conditions prevented diarrhoea from spreading to other kids and facilitated its spontaneous resolution in the affected ones.

Besides health and survival, the relationship between passive transfer status and growth performance has been investigated, especially in calves. It has been demonstrated that serum Ig concentration positively affects average daily gain in the first months of life (Robison et al., 1988; Dewell et al., 2006) and heifers with serum GG > 1.0 g/dL reached body weights allowing first insemination earlier (Furman-Fratczak et al., 2011). We found no association between serum GG concentration and pre-weaning growth performance in terms of BW and ADG at weaning, in accordance with O'Brien and Sherman (1993). Other two studies, each carried out on 20 healthy lambs or goat kids, found different results; the former reported a weak but significant correlation between serum IgG concentration and ADG and weight at 28 days (Massimini et al., 2006a), in the latter, a moderate correlation resulted (Massimini et al., 2007). Even after transforming serum GG from a continuous to a categorical variable according to the thresholds proposed in the literature, no significant differences emerged among goat kids with FPT, normal, or optimal passive immunity transfer status. Hence, it is likely that many other variability factors play a role in pre-weaning growth performance, including management, feeding, environment, health status, species, breed, and inherent differences among individuals. Indeed, the improved ADG associated with higher serum IgG concentrations has been linked to decreased morbidity rates (Wittum et al., 1994). Natural rearing might also have had a positive impact on health and growth performance in our study population. Our goat kids continued receiving their dams' transition milk, differently from what happens to artificially reared ones. Feeding colostrum or transition milk even after the intestinal absorption period has been shown to have beneficial effects in terms of development of the gastrointestinal tract, nutrient absorption, incidence of respiratory diseases, umbilical infections, and diarrhoea in dairy calves (Godden et al., 2019). Since we did not have the possibility of artificially rearing a group of kids, this factor could not be assessed.

As previously discussed, in this study the high morbidity rates that are normally reported in newborns affected by FPT were probably mitigated by good farming practices. Therefore, reduced weight gain attributable to low serum IgG concentration and subsequent illness onset was and can be prevented.

The main limitation of this study is the absence of analyses performed on goat colostrum to assess its quality and content in terms of GG and enzymes, which did not allow us to include these elements among the variability factors that might have affected passive immunity transfer. Moreover, the groups comparing litter size and dam parity were numerically unbalanced, and increasing the number of animals could likely enhance the strength of the results, although most of the published studies have been carried out on a similar or even smaller number of subjects (O'Brien and Sherman, 1993; Mellado et al., 1998; Chen et al., 1999; Argüello et al., 2004; Britti et al., 2005; Massimini et al., 2006a, 2007; Mellado et al., 2008; Chniter et al., 2016; Batmaz et al., 2019).

5. Conclusion

Our results show that sex, litter size, dam parity, and birth body weight did not significantly affect passive transfer status in newborn Alpine goat kids reared in a non-intensive system that follows good farming practices. This is in line with previously published studies carried out in different goat breeds and farming systems. Rapid and cost-effective diagnosis of FPT is essential for farmers and veterinarians to quickly identify and correct problems in the herd. Serum total proteins can be used to indirectly estimate immunoglobulin concentration, albeit cautiously. Contrarily, passive transfer status can be predicted with little success by measuring the activity of serum enzymes; only GGT showed some degree of correlation with serum GG concentration, but its use shows several disadvantages. Finally, FPT is not necessarily associated with health and preweaning growth performance. It is likely that other variability factors, including health status, feeding, management, and environment, play a role and may deserve further investigation.

Institutional review board statement

This study reports non-experimental clinic veterinary practice and therefore it does not fall within Directive 63/2010 of the European Parliament and of the Council on the protection of animals used for scientific purposes. The study was evaluated and approved by the animal welfare body of the Alma Mater Studiorum University of Bologna (Protocol Number 77988 of 08/04/2022).

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CRediT authorship contribution statement

Mariana Roccaro: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft **Marilena Bolcato:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – review & editing **Maria Giulia Ferrari:** Investigation, Writing – original draft **Francesco Dondi:** Investigation, Resources, Validation, Writing – review & editing **Arcangelo Gentile**: Funding acquisition, Resources, Supervision **Angelo Peli:** Conceptualization, Funding acquisition, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

No conflicts of interest.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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