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Original Article

Impact of gestational omega-3 supplementation on offspring immunity in goats

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Abstract

Background: Gestational nutrition, particularly in organic dairy goat farming, where natural feeding is mandatory for early gestation, plays a crucial role in determining the health of farm animal offspring. Omega-3 fatty acids are important for extending gestation periods, enhancing neonatal vitality, and increasing birth weights, primarily through their positive impact on colostrum composition. **Aims:** This study focused on the potential benefits of omega-3 fatty acids for developing passive immunity in offspring. **Methods:** Sixty-nine pregnant German Fawn x Hair crossbred does were divided into two groups. One group received fish oil (group F, n=35) and the other rumen protected fat (RPF) (group P, n=34) during the first half of gestation. In the second half of gestation, these groups were further split: group FF (n=16) continued on fish oil, while group FP (n=19) switched to RPF; group PP (n=17) remained on RPF, and group PF (n=17) switched to fish oil. Blood was collected from 60 kids at various times post-birth to measure immune factors. Immunoglobulins were quantified using the ELISA method, while biochemical parameters were assessed spectrophotometrically. **Results:** The PF and PP groups showed significantly higher IgA levels ($P<0.05$). The PF group also had a significant increase in total protein ($P<0.05$). **Conclusion:** The dietary strategy in our study did not positively influence passive immune transfer. Further research is needed to determine the optimal dosage and timing of these supplements to maximize benefits.

Key words: Fish oil, Goat, Omega-3 fatty acids, Pregnancy, Supplementation

Introduction

Gestational nutrition is crucial for the health of farm animal offspring, with omega-3 fatty acids, particularly ALA, EPA, and DHA, being essential for metabolism, structure, and signaling (Annett *et al*., 2008; Öztabak *et al*., 2019; Ponnampalam *et al*., 2021). These fatty acids must be obtained from the diet due to the rumen's biohydrogenation, which limits their availability during late gestation when fetal growth is rapid (Chilliard *et al*., 2001; Alshdaifat *et al*., 2023). Fish oils, containing long-chain PUFAs like EPA (20:5n-3) and DHA (22:6n-3), may naturally resist biohydrogenation, thus supporting immune function and overall health (Ashes *et al*., 1992; Palmquist, 1994). Furthermore, omega-3 fatty acids are instrumental in anti-inflammatory molecule production and immune modulation, contributing to central nervous system development and reducing premature birth risks (Petit and Twagiramungu, 2006; Ponnampalam *et al*., 2021). During fetal development, omega-3 fatty acids accumulate in the uterus and are primarily transferred to offspring via the placenta. Thus, maternal feeding practices are important (Roque-Jiménez *et al*., 2021).

Active lipid sources, like fish oil, can negatively impact feed digestibility in ruminants by disrupting rumen microbial populations and fermentation processes. This can lead to reduced feed intake and potential fetal development issues if used during early pregnancy. To reduce these effects and maintain milk fat yield, the use of protected or by-pass fats is recommended (Erez and Serbester, 2023). Rumen-protected fats (RPF) are commonly used in ruminant nutrition to enhance dietary energy density and overall performance in animals such as cattle and sheep. Also known as by-pass fats or rumen-inert fats, RPF resist ruminal degradation and are available for digestion and absorption in the lower gastrointestinal tract (Serbester *et al*., 2005; Palmquist and Jenkins, 2017; Behan *et al*., 2019; Gümüş *et al*., 2022).

Immune transfer from mother to offspring occurs via the placenta and colostrum, the latter being the primary source of immunoglobulins and proteins crucial for neonatal immunity and development (Constant *et al*., 1994; Chucri *et al*., 2010). Fish oil supplementation enhances colostrum's composition, increasing protein, fat, immunoglobulins, lactoferrin, and vitamin A, and improve the fatty acid profile (Grodkowska *et al*., 2023). Immunoglobulin G (IgG), the most abundant immunoglobulin in human serum (Hurley and Theil, 2011), can be transferred from placenta to fetus around the 20th week of pregnancy, continuing progressively until term (Chucri *et al*., 2010). In sheep and goats, the syndesmo-chorial placenta restricts the transfer of maternal immunoglobulins to offspring. Since lymphoid tissue is underdeveloped, newborns must rely on colostrum consumption for passive immunity development (Argüello *et al*., 2004; Karaca and Yörük, 2010; Piccione *et al*., 2011). Therefore, the transition of IgG remains limited in ruminants. Colostrum is also rich in immunoglobulin A (IgA) and immunoglobulin M (IgM), which are essential for mucosal immunity and the initial immune response (Moallem and Zachut, 2012). Neonates primarily acquire immunoglobulins through colostrum consumption. Ruminants primarily consume linolenic acid-rich vegetative sources, but their conversion to EPA and DHA is inefficient. They depend on dietary PUFAs, as they cannot synthesize them. The concentration of PUFAs in milk depends on their absorption after ruminal biohydrogenation. Chilliard *et al*. (2000) found that PUFA-enriched diets increase milk PUFA levels, highlighting dietary importance. DHA enrichment in colostrum and milk is vital for neonatal health, especially in organic dairy goat farming. Omega-3 fatty acids are linked to extended gestation, improved neonatal vigor, and birth weight (Mattos *et al*., 2000; Capper *et al*., 2006). Early omega-3 intake supports brain and visual development, early suckling, and environmental responsiveness (Cattaneo *et al*., 2006; Duvaux-Ponter *et al*., 2008). Higher omega-3 and conjugated linoleic acid levels in colostrum enhance brown adipose tissue, aiding thermoregulation and offspring vitality (Encinias *et al*., 2004).

Materials and Methods

Animal model and management of goats

The research was conducted at the University of Çukurova, Faculty of Agriculture, Dairy Goat Research and Application Unit located in Adana, Turkey. This facility practices semi-intensive farming methods. Eighty-six German Fawn x Hair crossbred does, aged between 2 and 5 years, were used in this study. The does had an average body weight of 47.9 ± 3.97 kg (mean±SD). The study was conducted in a specially designed open barn. The animal material was housed in 12 pens, each measuring 6 × 12 m (width × length), constructed within this barn. Each pen was equipped with a feeder and a waterer. Wheat straw or wood shavings were used as bedding in the pens. All animals used in the study underwent comprehensive health assessments by a veterinarian prior to the commencement of the study. All animal maintenance and handling procedures adhered strictly to ethical standards and received approval from the University of Çukurova Animal Care and Use Committee (approval protocol No.: 2015-2:4).

Synchronization stage

To optimize birth consolidation and alleviate environmental variables (such as climate and diet), the estrus cycles of 86 doe goats were synchronized following Özer and Doğruer's (2011) protocol. A sponge (Chronogest CR, Intervet, France) containing 20 mg of micronized cronolone (flugeston acetate) was inserted vaginally for 12 days. Two days before sponge removal, 400 IU of PMSG (Chronogest/PMSG, 6000 IU, Intervet) and 75 mcg of d-cloprostenol (Synchrodine, Vetaş, Türkiye) were administered intramuscularly. Oestrus was detected by introducing teaser bucks for 60 min twice daily for 5 days, starting 12 h after sponge removal. Does were placed in breeding compartments when they exhibited estrus and mated with breeding goat bucks (10 does per buck). Ultrasound examination 45 days after mating confirmed pregnancy in 69 out of 86 does. Ultimately, a total of 94 offspring were successfully delivered by all pregnant does (Table 1).

Nutritional management of doe goats during gestation phases

The average gestation period in goats spans 149 days (Fatet *et al*., 2011). During the first 20 days of pregnancy, embryo implantation occurs, followed by placentation, tissue differentiation, and organ development, which completes around the 75th day. In the second half of gestation, significant growth of organs, tissues, and the fetus occurs. This study investigated the feeding regimen for doe goats during two distinct phases: fetal development (from mating to the 75th day, termed the 1st term) and from the 76th day to birth (the 2nd term).

Table 1: Summary of kid birth data: birth type, sex, and weight

Maternal nutrition	Litter size			Sex		Birth weight (kg) (Mean±SE)
	Singles	Twins	Triplets	Female	Male	
Group FF	11	5	1	14	10	2.9±0.07
Group PP	11	7		11	14	3.4±0.08
Group FP	12	6		13	11	3.0±0.05
Group PF	11	5		9	12	3.1±0.08

Table 2: Nutrient requirements in early and late pregnancy (twin goat kids; live weights = 2.1-4.8 kg)*

Stage	Dry matter consumption (kg/day)	Energy requirement		Protein requirement		Mineral requirement	
		TDN (kg/day)	ME (Mcal/day)	Crude protein (g/day)	Metabolic protein (g/day)	Ca (g/day)	P (g/day)
Early	1.55	0.815	2.95	139.5	94	6.15	3.55
Late	1.59	1.055	3.81	201	135	6.25	3.6

* Estimating that the goats to be used will be approximately 55 kg live weight. The requirements stated in the table are the average of the requirements for goats weighing 50 kg

Table 3: Composition of fish oil and rumen protected fat (g/100 g oil)

Fatty acid	Fish oil (%)[a]	Rumen protected fat (%)[b]
Myristic acid	5.02	1.18
Palmitic acid	19.85	62.11
Palmitoleic acid	5.73	-
Stearic acid	4.57	29.83
Oleic acid	17.49	6.90
Linoleic acid	1.81	-
Linolenic acid	0.88	-
Arachidonic acid	0.08	-
Eicosapentaenoic acid	9.75	-
Docosahexaenoic acid	26.2	-

[a] Liquid fish oil produced from salmon (Egevizyon, Turkey) and [b] Rumen protected fat (Lactofat R100, Farmann, Germany)

Table 4: Ingredients and composition of total mixed ration

Ingredients (% of DM)	%
Corn	35.2
Barley	9.6
Vinasse (from yeast production)	2.6
Soybean meal	14.8
Wheat bran	6.4
Corn dry distiller grains	12.8
Sodium bicarbonate	0.7
Sodium chloride	0.7
Alfalfa hay	15.0
Limestone	0.9
Protected fat[1]	1.3
Vitamin and mineral premix[2]	0.09
Nutrient composition	%
Dry matter	89.48
Crude protein	17.67
Acid detergent fiber (ADF)	10.72
Neutral detergent fiber (NDF)	23.17
Ether extract	3.51
Crude ash	7.25

[1] Palm rumen protected fat (Lactofat R100, Farmann, Germany), and [2] Provided per kg of vitamin-mineral mixture: 15,000,000 IU vitamin A; 3,000,000 IU vitamin D_3; 30,000 mg vitamin E; 150,000 mg Niacin; 10,000 mg Cu; 800 mg I; 150 mg Co; 150 mg Se; 50,000 mg Mn; 50,000 mg Fe; 50,000 mg Zn; 6800 mg organic Mn; 1400 mg organic Cu; 6800 mg organic Zn; 800 mg organic Fe; 50 mg organic Se

Feeding regime applied at the 1st term: After mating, 86 doe goats were divided into two equal groups: one received fish oil supplementation (group F), and the other received rumen-protected fat (RPF) (group P). These groups were housed on bedding made of either wood shavings or wheat stalks.

Nutritional guidelines were derived from the National Research Council (NRC, 2007), implemented through a total mixed ration (TMR) with a roughage to concentrate ratio of 60:40. The roughage comprised 75% alfalfa hay and 25% wheat straw (Table 2). During the production of the concentrate feed, protected fat and fish oil were incorporated at a rate of 7% on an air-dry basis. The detailed compositions of these fat supplements in the diets of does are presented in Table 3. This strategic formulation aimed to achieve an isocaloric and isonitrogenic diet, balanced in fat content and raw material composition.

Feeding occurred bi-daily, ensuring a 5-10% surplus of TMR remained available. Water was provided *ad libitum*. Pregnancy was confirmed on day 45 post-mating via real-time ultrasonography (Pie, Medical, Falco, The Netherlands), using a device equipped with a 5-7.5 MHz linear rectal probe. Seventeen non-pregnant does were removed, leaving 69 pregnant does for the study—35 in group F and 34 in group P.

Feeding regime applied at the 2nd term: After confirmed pregnancies (n=69), groups F (n=35) and P (n=34) were each divided into two subgroups. The first subgroup separated from group F continued to receive fish oil (group FF; n=16), while the second subgroup received TMRs containing RPF (group FP; n=19) until the end of pregnancy. The first subgroup separated from group P continued to receive TMRs containing RPF (group PP; n=17), while the second subgroup was given fish oil (group PF; n=17) until the end of pregnancy. The nutrient requirements for the goats were taken from NRC (2007) (Table 2). To meet the increasing nutrient requirement, the roughage to concentrate feed ratio in the TMR is 60:40. Alfalfa hay and/or corn silage and/or wheat straw were used as roughage. The feeding of the animals was done twice a day, in the morning and evening, and care was taken to ensure that 5-10% of TMR remained in the feeders. Water was provided *ad libitum*. The ingredients and nutrient composition of the concentrate feed and TMR are shown in Table 4.

Management and serological sampling of goat kids

All the kids (female and male) born were housed with their mothers until weaning, thereby preventing them from sucking the mother from another group. Also, special attention was given to ensure that the kids nursed from their mothers immediately after birth. The kids stayed with their mothers for the first 14 days postpartum, during which they had free access to

Table 5: Maternal nutrition and hour affected serum biochemical parameters of the offspring (n=60)

Parameter	Maternal nutrition				SEM+	P^1	Hours					SEM[a]	P^2
	Group FF	Group PP	Group FP	Group PF			24	36	48	72	96		
Albumin (g/dL)	2.9	2.8	2.8	3.2	0.13	0.076	2.8^{x}	3.0^{y}	2.8^{x}	2.9^{xy}	3.1^{z}	0.07	<0.01
Total protein (g/dL)#	5.8^{a}	6.0^{a}	6.5^{ab}	6.8^{b}	0.27	0.018	6.7^{y}	6.4^{xy}	6.2^{xy}	6.0^{x}	6.0^{x}	0.14	<0.01
Globulin (g/dL)#	3.0	3.0	3.7	3.7	0.32	0.064	3.8^{y}	3.5^{y}	3.4^{xy}	3.1^{x}	2.9^{x}	0.15	<0.01
Albumin/Globulin	1.1	1.0	0.9	1.1	0.14	0.814	0.8^{x}	1.0^{x}	1.0^{x}	1.1^{xy}	1.2^{y}	0.08	0.014
GGT (U/L)	214.1	211.3	228.3	199.5	37.15	0.912	299.7^{y}	252.8^{y}	195.5^{x}	159.7^{x}	158.8^{x}	15.00	<0.01
IgA (mg/ml)#	1.0^{a}	1.4^{b}	1.3^{ab}	1.8^{b}	0.17	0.025	1.4	1.2	1.4	1.4	1.4	0.08	0.272
IgG (mg/ml)#	3.4	4.4	4.2	4.5	0.98	0.933	3.9	3.9	4.5	3.7	4.5	0.36	0.329
IgM (mg/ml)#	2.0	2.4	2.7	2.9	0.53	0.746	2.5	2.3	2.4	2.6	2.6	0.19	0.524

+ SEM: Standard error of means, # The effect of birth weight on these parameters is statistically significant (P<0.05), a, b, x, y, z Means within the same line with different letters differ, Fat source x Hour interaction effect was removed from the model since it was statistically insignificant, Group PP: RPF-RPF, Group PF: RPF-Fish oil, Group FP: Fish oil-RPF, Group FF: Fish oil-Fish oil, P^1: Treatment effect (maternal nutrition), and P^2: Hour effect

colostrum and maternal care. Blood samples were aseptically drawn from the jugular vein of goat kids using 4 ml sterile gel vacuum tubes. The sampling occurred at specific time points: 24, 36, 48, 72, and 96 h postpartum. After collection, the samples were centrifuged (Universal 320R, Hettich, Germany) to obtain sera, which were subsequently stored at -20°C for future analysis. Unfortunately, due to hemolysis or insufficient serum quantity, we were compelled to select 60 out of the 94 offspring with complete data (15 from each subgroup) for analysis. Nevertheless, since the available data were suitable for statistical analysis, the number of offspring presented in Table 5 had to be reported differently.

Serum analysis

Quantitative analysis of immunoglobulin G (IgG), M (IgM), and A (IgA)—markers of passive immunological transfer, and concurrently, total protein and albumin levels, along with gamma-glutamyl transferase activity, were measured in the Biochemistry Research Laboratory of Istanbul University-Cerrahpaşa, Veterinary Faculty. IgG (Catalogue No. 201-07-0065, Shanghai Sunred Biological Technology Co., Ltd. Shanghai, China), IgM (Catalogue No. 201-07-0069, Shanghai Sunred Biological Technology Co., Ltd. Shanghai, China), and IgA (Catalogue No. 201-07-3102, Shanghai Sunred Biological Technology Co., Ltd. Shanghai, China) were quantified using ELISA system (BIO-TEK, Bio-tek Instruments, Inc., USA). Total protein (Catalogue No. 1001291, Spinreact, Spain), albumin (Catalogue No. 1001020, Spinreact, Spain), and GGT (Catalogue No. 1001186, Spinreact, Spain) were assessed using T60U spectrophotometer (PG Instruments Ltd., Germany). The globulin concentrations for each individual were precisely calculated using the formula:

Serum globulin level = serum total protein concentration - serum albumin concentration

Statistical analysis

MS Excel (Office Professional Plus 2016, Microsoft Corp., Redmond, WA) program was used to prepare the data for statistical analysis. The statistical framework incorporated variables such as the dietary oil source administered during caprine gestation (RPF or fish oil) and the precise timings of serum collection postpartum (24, 36, 48, 72, and 96 h). The model initially included both the primary and interaction effects of these factors. However, the interaction effect was subsequently omitted due to its lack of statistical significance. Data were structured as repeated measures and analysed with the SAS/STAT (2004) package, leveraging the PROC MIXED procedure. Compound symmetry was selected as the covariance structure, and restrictive maximum likelihood (REML) was the method of estimation. Kenward-Rogers was applied for determining degrees of freedom, following the guidelines set forth by Littell *et al*. (2006). P-values below 0.05 were interpreted as statistically significant, and findings are reported as least squares means with the standard error of these means. In the statistical analysis, litter size, birth weight, and sex were initially included in the model. However, as these factors were found to be non-significant, they were subsequently removed from the final model to improve clarity and focus on the significant variables.

Results

The concentration of immunoglobulins, total protein, albumin, globulin, albumin/globulin rate (A/G) and GGT activity of the offspring are given in Table 5.

IgA concentration from kids of group PF and group PP were found statistically higher when compared with other groups. Although the values from group PF were marginally higher than those of group PP, yet this difference did not reach statistical significance. In contrast, the groups FP and FF exhibited notably significantly lower IgA concentrations (P<0.05). While the group FF appeared to have the lowest concentrations of IgG and IgM, the differences between groups were not statistically significant. The analysis also revealed no time-dependent differences in immunoglobulin levels when comparing the various blood collection hours. Regarding GGT activity, group FP showed the highest levels, with group PF at the opposite end; however, these differences were not statistically significant. Similarly, no significant differences were found in albumin, globulin, or the A/G ratio across the groups. Notably, PF group had significantly higher serum total protein concentrations compared with other groups (P<0.05).

GGT activity showed significant variation between the 24th and 36th h, but no specific trend was established. Albumin reached its peak concentration at 96 h, while globulin levels and the A/G ratio were highest at 24 h. Furthermore, the total protein levels in samples taken at the 24th h were significantly elevated (P<0.01), indicating a distinct pattern in the early postnatal period.

Discussion

Ruminants rely on dietary polyunsaturated fatty acids (PUFAs), as they cannot synthesize them. The PUFAs' milk concentration hinges on their intestinal absorption post-ruminal bio-hydrogenation. Chilliard *et al.* (2000) observed that PUFA-enriched feeds elevate their milk levels, underscoring the importance of diet in PUFA availability. DHA enrichment in colostrum and milk is crucial for neonatal health, particularly in organic dairy goat farming, where natural feeding is mandatory for the first 45 days. Dietary omega-fatty acids have been linked to extended gestation, enhancing neonatal vigor and birth weight (Mattos *et al.*, 2000; Capper *et al.*, 2006). Early omega-3 intake is vital for brain and visual development, promoting early suckling and environmental responsiveness (Cattaneo *et al.*, 2006; Duvaux-Ponter *et al.*, 2008). Additionally, increased omega-3 and conjugated linoleic acid levels in colostrum boost brown adipose tissue, aiding thermoregulation and offspring vitality (Encinias *et al.*, 2004).

In ruminants, the placenta is impermeable to immunoglobulins, preventing their transfer from mother to fetus. Studies on immunoglobulin levels in goat kids' serum immediately after birth show varying results. Some report minimal or absent immunoglobulins (Constant *et al.*, 1994), while others detect low IgG levels (Guerrault, 1990; Rabbani *et al.*, 1990; Sherman *et al.*, 1990). Although some argue that goat kids are agammaglobulinemic at birth (Constant *et al.*, 1994), other findings suggest the presence of serum immunoglobulins, albeit at low concentrations (Guerrault, 1990; Rabbani *et al.*, 1990; Sherman *et al.*, 1990). Suckling within the first 24 h is generally sufficient for adequate IgG levels (Castro *et al.*, 2009). Chen *et al.* (1999) observed that serum globulin levels peak at 3.33 g/dL 24 h post-colostrum feeding, then slightly decline over the next five days. O'Brien and Sherman (1993) recommend that goat kids attain serum immunoglobulin levels of at least 1.2 g/dL to ensure better health. Britti *et al.* (2005) recommend maintaining serum IgG concentrations above 1 g/dL in 1- to 2-day-old lambs to reduce mortality risk. Yalcin *et al.* (2010) noted an initial increase in in goat kids' IgG levels up to the 4th day of colostrum feeding, followed by a decline after the 7th day. Grodkowska *et al.* (2023) demonstrated that supplementing cows' diets with 150 g of fish oil per day enhances both the quality and quantity of colostrum, thereby promoting healthier calves. Similarly, Alshdaifat *et al.* (2023) found that incorporating fish oil (2.4% and 2.1%) into the diets of pregnant Awassi ewes extended gestation periods, increased lamb birth weights, and improved IgG concentrations in colostrum. According to Annett *et al.* (2008), supplementing with fish oil (40 g/ewe/daily) during late pregnancy enhances lamb vigor at birth and potentially reduces neonatal mortality in sheep. However, they demonstrated that fish oil supplementation also decreases colostrum production by the ewe, which could offset the developmental benefits for lamb survival. In our study, comparing FF and FP groups, statistically insignificant higher IgG data result from fish oil feeding in the 1st period, changing to protected fat in the 2nd period. However, statistical significance remains elusive when comparing PP and PF groups. The comparatively lower values in our study, when contrasted with other research on this topic, may find elucidation in the work of Alshdaifat *et al.* (2023) and Annett *et al.* (2008). The supplementation with fish oil may have adversely affected the quality and quantity of colostrum. Regrettably, our study did not assess the quantity or composition of colostrum.

Neonatal ruminants, such as calves and lambs, exhibit the ability to absorb various proteins, including macromolecules, within the first 24 to 48 h post-birth due to nonselective intestinal absorption. Timely ingestion of colostrum allows its enzymes to cross the intestinal barrier similarly to immunoglobulins, serving as markers for passive transfer status. γ-glutamyltransferase (GGT), a membrane protein crucial for amino acid transport, is found in high levels in seminal fluid, bile, and colostrum. In neonatal calves, serum GGT activity is directly correlated with serum IgG levels, indicating that low GGT activity suggests failure of passive transfer (FPT). In neonatal ruminants, GGT is efficiently absorbed, resulting in high serum activity in calves and lambs consuming colostrum (Maden *et al.*, 2003; Britti *et al.*, 2005; Howard *et al.*, 2005). Numerous studies have highlighted the use of serum GGT enzyme activity as an informative marker for passive immune transfer, with a positive correlation between neonatal serum GGT activity and IgG concentration. The simultaneous elevation in IgG concentrations and heightened GGT activity within 24 h after birth observed in our study aligns with results reported by other investigators.

deSousa-Peirera and Woof (2019) and Li *et al.* (2020) highlight that IgA is the primary antibody on mucosal surfaces and is present in colostrum. Rodríguez *et al.* (2009) found that IgA was undetectable in neonatal plasma at birth but appeared after 24 h of colostrum feeding, with levels increasing between the first and second days before declining. Sánchez-Macías *et al.* (2014) and Koşum *et al.* (2018) observed similar trends. In the present study, no variance in IgA levels was found between FF and FP groups, but a significant reduction was noted in the FF group (P<0.05). The mean IgA values were higher than those reported by Rodríguez *et al.* (2009), Sánchez-Macías *et al.* (2014) and Koşum *et al.* (2018). The study suggests that maternal intake of protected fat during gestation or fish oil supplementation in late gestation may elevate IgA levels in offspring, whereas fish oil use only during pregnancy appears to decrease IgA levels. Unlike other studies, the data remained constant for 4 days.

IgM is the initial antibody class produced upon primary antigen exposure, with broad reactivity but relatively low specificity. Rodríguez *et al*. (2009) reported neonatal goats had IgM levels of 1.49 mg/ml at birth. Logan *et al*. (1978) noted low IgM levels in newborn calves, with the highest plasma IgM concentrations recorded on day 0 across all experimental groups, a trend also observed in calves. Rodríguez *et al*. (2009) suggested variations in findings might stem from differing IgM measurement techniques or interspecies differences. The present study found no statistically significant differences in IgM concentrations between groups, though a noticeable, non-significant elevation in IgM levels was associated with dietary oil modification in both experimental phases. The lowest levels were detected in the FF group, but no statistical significance was found.

Batavani *et al*. (2006) and Mellado *et al*. (2008) emphasize that prenatal blood protein levels indicate the nutritional status of both mother and offspring. Constant *et al*. (1994) highlight colostrum as a crucial source of immunoglobulins and proteins for newborns, essential for their immediate and long-term health. Chen *et al*. (1999) and Piccione *et al*. (2011) note that total protein in colostrum and serum supports neonatal immunity and growth through various nutritional and physiological effects. Diogenes *et al*. (2010) add that total protein regulates physiological functions during pregnancy and lactation. Soares *et al*. (2018) found that total protein and globulin levels during lactation were higher than at the end of pregnancy and birth ($P<0.001$), with albumin levels increasing significantly by the 10th day postpartum. Piccione *et al*. (2011) observed a similar postpartum protein decrease in goats, returning to baseline during lactation. Matras *et al*. (2014) reported no prenatal differences in total protein among diet groups, but a significant postpartum increase in the essential fatty acid-fed group. Annett *et al*. (2008) noted a postpartum decline in globulin in sheep fed fish oil ($P<0.05$). Soares *et al*. (2018) attributed low protein and globulin levels during late pregnancy and birth to globulin migration for colostrum synthesis and albumin decline to offspring development. Mohammadi *et al*. (2016) linked decreased total protein to globulin migration for milk synthesis. In the present study, alternating protected fat and fish oil diets in goats showed no significant differences in serum albumin, globulin, or albumin/globulin ratio in offspring, though PF and FP groups had higher globulin values. Serum total protein was significantly higher in the PF group ($P=0.018$). Unlike previous studies, no decline in serum total protein in offspring was observed, suggesting effective compensation through the feeding regimen.

In this study, a total of 69 pregnant goats were used, and blood samples were collected from 94 kids. While a larger sample size could enhance the generalizability of the findings, the sample size used was sufficient to detect meaningful differences in the measured parameters. Additionally, the goats were selected randomly, reducing the likelihood of selection bias. This ensures that the results obtained are representative of the population studied, within the scope of our experimental design.

Extensive research has shown that dietary fish oil supplementation for doe goats enhances offspring survival rates and reduces neonatal mortality in late pregnancy. However, our study indicates that administering 7% fish oil during pregnancy did not improve passive immune transfer. We suggest that the fish oil dosage may have adversely affected colostrum quality and quantity, thereby hindering effective IgG transfer to the offspring. Subsequent fish oil supplementation after using rumen-protected fat resulted in a minor, statistically insignificant increase. The gestational nutritional status of doe goats is crucial for developing passive immunity in their young. Incorporating omega-3 fatty acids and protected fats into the maternal diet has shown promising results in enhancing antibody transfer and improving immune responses in neonatal kids. Despite this, the dietary strategy in our study did not positively influence passive immune transfer. Further research is needed to determine the optimal dosage and timing of these supplements to maximize benefits. Current evidence underscores the importance of adequate gestational nutrition in promoting robust health and immunity in goat offspring.

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Conflict of interest

The authors have no conflict of interest to declare.

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