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Role of maternal variables on the development of neonatal hypoglycaemia and influence of neonatal hypoglycaemia on performance of goat kids

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ABSTRACT

The study evaluated the influence of maternal variables (age, body weight and body mass index; BMI) during mating on the development of hypoglycaemia and investigated whether hypoglycaemia at birth impairs thermoregulation, metabolism, body weight gain and immunoglobulin concentration in neonatal goat kids. Post-kidding, the kids born with hypoglycaemia ($n = 19$) and normoglycaemia ($n = 19$) were immediately identified and postnatal blood samples, body weight and cardinal physiological variables were determined. Results revealed no significant ($P < 0.05$) difference in pre-mating maternal variables between dams that kidded hypoglycaemic and normoglycaemic kids. Kids born with hypoglycaemia had lower ($P < 0.05$) blood glucose concentration from birth, until Day 2, when values became comparable between the two groups. Afternoon respiratory and pulse rates were markedly ($P < 0.05$) unstable in kids born with hypoglycaemia and the early postnatal rise ($P < 0.05$) in morning rectal temperature in both groups was accompanied by a decrease ($P < 0.05$) on day 20 in kids born with hypoglycaemia. Blood cholesterol and triglyceride concentrations were lower ($P < 0.05$) in hypoglycaemic kids and the normoglycaemic kids showed marked increase ($P < 0.05$) in circulating immunoglobulin concentration 24 h after birth, while age had no ($P > 0.05$) effect in hypoglycaemic kids. A more pronounced decrease ($P < 0.05$) in weekly weight gain was observed in hypoglycaemic kids. It was concluded that neonatal goat kids born with hypoglycaemia may have compromised thermoregulation, metabolism and body weight gain, and the cause of hypoglycaemia in kids may not be related to pre-mating maternal variables.

1. Introduction

The productivity and perpetuity of a livestock farm are highly dependant on the survival of neonates. The survival of the neonates greatly relies on adequate maternal energy stores, right from the point of mating, and also on the metabolic adjustments of the neonates immediately after parturition (Habibu, Kawu, Aluwong & Makun, 2021; Pesantez-Pacheco et al., 2019b). Accumulation of sufficient pre-gestational energy store is a prerequisite to successful gestation; it supports maternal metabolism and provides nutrients for foetal development and growth (Estrada-Cortes et al., 2009; Mohammadi, Anassori & Jafari, 2016), especially during late gestation when feed intake alone cannot meet increased metabolic demand (Pesantez-Pacheco et al., 2019). Body weight and body mass index (BMI) are often used as indicators of body energy reserve or nutritional status in goats (Estrada-Cortes et al., 2009; Habibu, Kawu, Makun, Aluwong & Yaqub, 2016; Tanaka, Yamaguchi, Kamomae & Kaneda, 2003). Body weight and BMI are important pre-gestational maternal factors that may be associated with the dam's fecundity and age, and collectively, these maternal factors can influence the ability of a pregnant dam to meet its metabolic requirements (Estrada-Cortes et al., 2009; Gardener, Buttery, Daniel & Symonds, 2007).

Neonates have immature anatomical and physiological features that make metabolic adjustment in the immediate extra-uterine life demanding (Saddiqi et al., 2011). During this period, the ruminant is essentially monogastric and glucose provides the energy needed to sustain the physiology of body tissues, especially the brain, erythrocytes and medulla of the kidneys (Hammon, Steinhoff-Wagner, Flor, Schönhusen & Metges, 2012; Zierler, 1999). Higher birth weight implies large body energy reserve in forms of adipose tissue and hepatic

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Table 1
Distribution of experimental goat kids based on litter-size and sex.

Groups	Litter-size		Sex		Total
	Single	Twins	Male	Female	
Normolycaemia	9	10	9	10	19
Hypoglycaemia	11	8	7	12	19

glycogen. Endocrine regulation of glucose and lipids is essential for efficient thermoregulation to maintain normal body temperature in neonatal ruminants (Plush, Hebart, Brien & Hynd, 2016) and triglyceride in the blood serve as source of energy fuel that is hydrolysed to release free fatty acids and glycerol (Pesantez-Pacheco et al., 2019; Pinent et al., 2008). Efficient postnatal metabolism provides the energy needed to activate motor activities and enables the neonate to stand and suckle colostrum (Arguello, Castro, Zamoranoa, Castroalonso & Capote, 2004; Habibu et al., 2021). Early and adequate intake of colostrum could enhance the immunity of neonatal ruminants and subsequently improve their survival and productivity (Arguello et al., 2004; Yalcin, Temizel, Yalcin & Carkungoz, 2010).

Hepatic glycogen store in neonates is not enough to maintain the supply of blood glucose and therefore, a high postnatal glucagon-insulin ratio, induces the synthesis of gluconeogenic enzymes (McGowan, 1999; Nafikov & Beitz, 2007). Gluconeogenesis is important in neonatal ruminants, providing about 75% of their total glucose needs (Donkin & Hammon, 2005; Nafikov & Beitz, 2007). Inadequate stores of glycogen and gluconeogenic precursors (fatty acids, glycerol, amino acids and lactate) and/or the presence of a poorly-responsive endocrine system at birth, may predispose to disrupted glucose homoeostasis and result in neonatal hypoglycaemia (McGowan, 1999). It is generally acknowledged that there is yet a universally-acceptable definition of neonatal hypoglycaemia. However, in human neonates, the most widely used definition is a blood glucose concentration below 47 mg/dL (2.6 mmol/L; Dixon et al., 2017; Edwards & Harding, 2020; Harris, Weston, Battin & Harding, 2014). In goat kids and calves, neonatal hypoglycaemia with blood glucose levels below 20 and 38 mg/dL, respectively is often reported and the condition may resolve a few hours postnatal (Habibu et al., 2021; Kirovski et al., 2011).

In neonatal calves, hypoglycaemia is strongly associated with mortality, as more neonatal calves with hypoglycaemia died within 48 h of hospital admission as compared to those with normoglycaemia (Trefz, Feist & Lorenz, 2016, 2017). Despite the key role of glucose in the metabolic adjustment and survival of neonates (Kaneko, 2008; Panzardi et al., 2013; Trefz et al., 2016), there is paucity of information on the impact of hypoglycaemia at birth on metabolism, thermoregulation, body weight gain and immune status in goat kids. We hypothesised that neonatal hypoglycaemia in goat kids at birth is associated with impaired thermoregulation, metabolism, body weight gain and immunity, and also, the development of neonatal hypoglycaemia at birth is influenced by the age, body weight and BMI of the dam during mating.

2. Materials and methods

2.1. Experimental location and animals

The animals were housed in National Animal Production Research Institution (NAPRI), Ahmadu Bello University, Shika, Nigeria (latitudes 11 and 12° N and longitudes 7 and 8° E). Zaria is located in a guinea Savannah climate and has an annual ambient temperature and relative humidity of 16 °C – 40 °C and 15 – 78%, respectively (Minka & Ayo, 2016). The rainy season in Zaria is mainly between April and October

Table 2
Mean (± SEM) values of maternal blood glucose levels (at birth), body weight, BMI and age (before oestrus synchronization) according to glycaemic status and litter size of the kids.

Does N	HS 5	HTT 4	HNT 5	NS 9	NTT 6
Blood glucose (mg/dL)	128.00 ± 21.79	65.33 ± 17.84	106.80 ± 12.58	110.20 ± 8.50	116.20 ± 15.10
Body weight (kg)	11.80 ± 0.86	13.50 ± 0.76	12.20 ± 1.42	11.33 ± 1.23	14.67 ± 1.45
BMI	0.42 ± 0.02	0.49 ± 0.03	0.43 ± 0.04	0.47 ± 0.05	0.45 ± 0.04
Age (years)	1.38± 0.10	1.50 ± 0.00	1.90 ± 0.37	1.42 ± 0.08	1.33 ± 0.17

No statistical difference was observed between groups ($P > 0.05$). HS = does that born single hypoglycaemic kids; HTT = does that born twin hypoglycaemic kids; NS = does that born single normoglycaemic kids; NTT = does that born twin normoglycaemic; HNT = does that born both hypoglycaemic and normoglycaemic twins; BMI = body mass index.

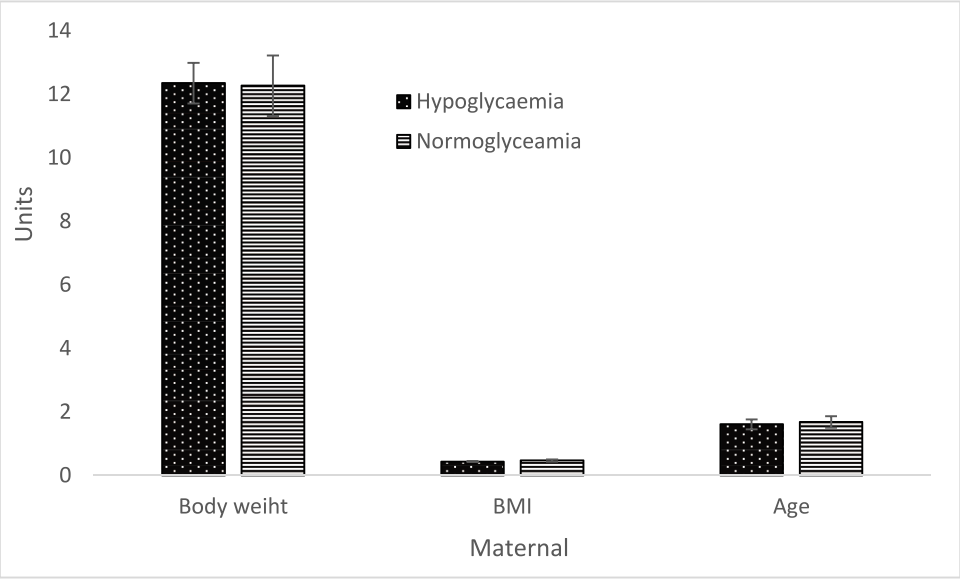

Fig. 1. Mean (± SEM) values of maternal body weight, body mass index (BMI) and age before oestrus synchronization, classified based on glycaemic status of kids (hypoglycaemia and normoglycaemia) at birth. Dam that kidded normoglycaemic kids ($n = 21$) and those that kidded hypoglycaemic kids ($n = 15$).

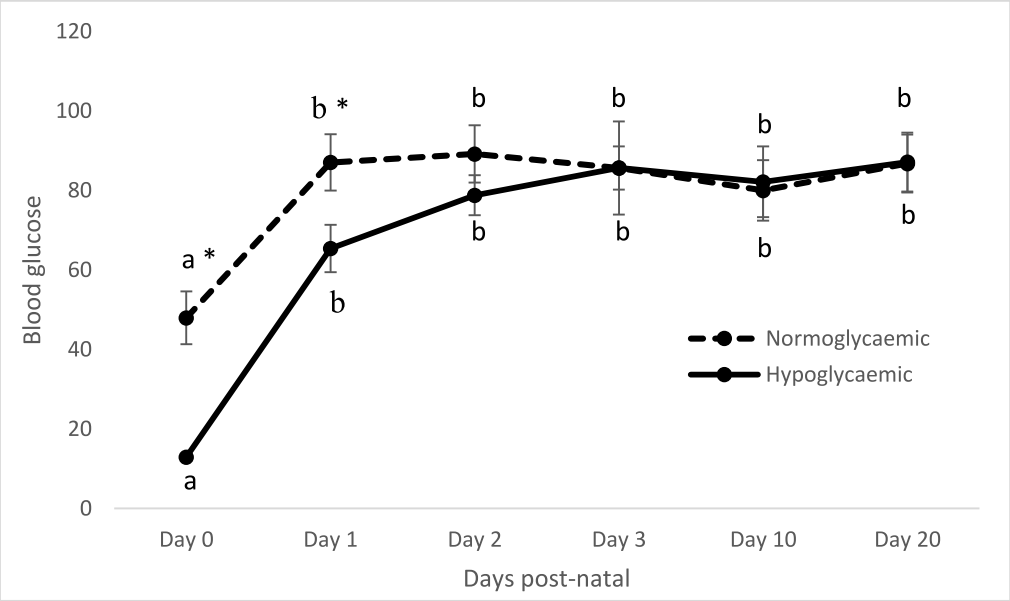

Fig. 2. Mean (± SEM) values of blood glucose concentration in normoglycaemic and hypoglycaemic neonatal goat kids. Values with asterisk (*) and a, b indicate significant difference ($P < 0.05$) between glycaemic groups and ages, respectively. The time x breed interaction was significant ($P < 0.013$).

and the average annual rainfall is approximately 1100 mm (Taiwo, Buvenandron & Adu, 2005). Animals on the farm were dewormed routinely and the dams were vaccinated against peste des petits ruminants (PPR) and haemorrhagic scepticaemia. The goats were housed in standard pens with each having dimensions of 6.1, 6.1 and 2.2 m for length, width and height, respectively. Each pen had a stocking density of 20 does. The does were allowed to graze in natural pasture and were supplemented with *Digitaria smutsi* hay and concentrate ration at 3% body weight per day. The hay composed of moisture, fibre, carbohydrate, proteins, lipids and ash at 3.50, 2.77, 89.85, 2.93, 1.85 and 1.87%. Water was provided *ad libitum* and all kids suckled their dams directly without human support, right from the point of birth. After parturition, basic clinical examination was carried out on each kid with emphasis on absence of asphyxiation or foetal-fluid aspiration and the presence of good sucking reflex.

2.2. Determination of maternal variables, animal breeding and kidding

Maternal variables, including body weight, BMI and age were recorded before mating. Body weight and morphometric dimensions of the does were obtained using weighing scale (Salter, Model 250, England) and measuring tape, respectively. Body length represents the length from the external occipital protuberance to the base of the tail, while withers height is the length from the surface of a platform to the withers (Hassan & Ciroma, 1992). Body mass index was calculated using the formula described by Tanaka et al. (2003): gBMI = bodyweight (kg)/{withersheight(m)/bodylength(m) × 10}.

About 100 apparently healthy, cycling Red Sokoto does with parity of 1 – 2 were used for the study. Oestrous synchronisation was carried out by a single intramuscular (thigh muscle) injection of cloprostenol (Synchromate®; 0.263 mg/mL) at a dose of 1 mL/doe. ageing of the does was done using dentition formula (Oltenacu, 1999) and verified using farm records. All birth was vaginal without assistance and no apparent congenital defect was observed in the kids. The gender and litter-size of the kids were recorded after parturition.

2.3. Experimental design

The pre-gestational maternal variables were grouped based on the glycaemic status of their kids, into dams that kidded hypoglycaemic kids and those that kidded normoglycaemic kids. Furthermore, the pre-gestational variables were classified based on both glycaemic status and fecundity of the dams, such that the maternal groups in this category included: does that born single hypoglycaemic kids (HS), does that born single normoglycaemic kids (NS), does that born twin hypoglycaemic kids (HTT), does that born twin normoglycaemic (NTT) and does that born both hypoglycaemic and normoglycaemic twins (HNT). Immediately after kidding, 0.5 mL of blood was collected from the dam through jugular venipuncture for determination of blood glucose.

Post-kidding, blood samples for glucose determination were collected 10 min after commencement of suckling to enhance maternal-kid bounding. Subsequently, blood samples were collected from all kids on Days 1, 2, 8, 10 and 20 in the morning hours (07:30 – 08:00 h GMT + 1). Using the values of blood glucose concentration obtained at birth, nineteen ($n = 19$) goat kids with hypoglycaemia were identified and then 19 goat kids with normoglycaemia were randomly selected from the kids that were normoglyceamic at birth. Thus, selection of hypoglycaemic kids and their dams was based on occurrence of hypoglycaemia at birth, while the kids born with normoglycaemia and their respective dams were selected randomly from several kids born with normoglycaemia. The goat kids born with glucose concentration that was less than 20 mg/dL were considered hypoglycaemic, while goat kids with values greater than 20 mg/mL (normal range: 35 – 45 mg/dL) were considered normoglycaemic (Habibu et al., 2021; Van Saun, 2002). The rectal temperature, respiratory and pulse rates were recorded on Days 0, 1, 2, 8, 10 and 20, postnatal in the morning (07:00 h) and afternoon (13:00 h) hours (+ 1 GMT), representing the diurnal nadir and zenith, respectively. Distribution of the kids based on gender and litter-size is shown on Table 1.

2.4. Determination of variables in kids and blood sample collection

Respiratory rate was determined by counting flank movements at the paralumbar fossa for one minute and was presented as number of breaths per minute. Pulse rate was determined by counting the pulsations felt on the femoral artery in one minute and recorded in number of beats per minute. Rectal temperature was measured using digital thermometer (Wilson-Supreme, Japan) by inserting the sensory tip into the rectum of a properly restrained kid and the value of rectal temperature was recorded in °C after an alarm sound, which indicates the completion

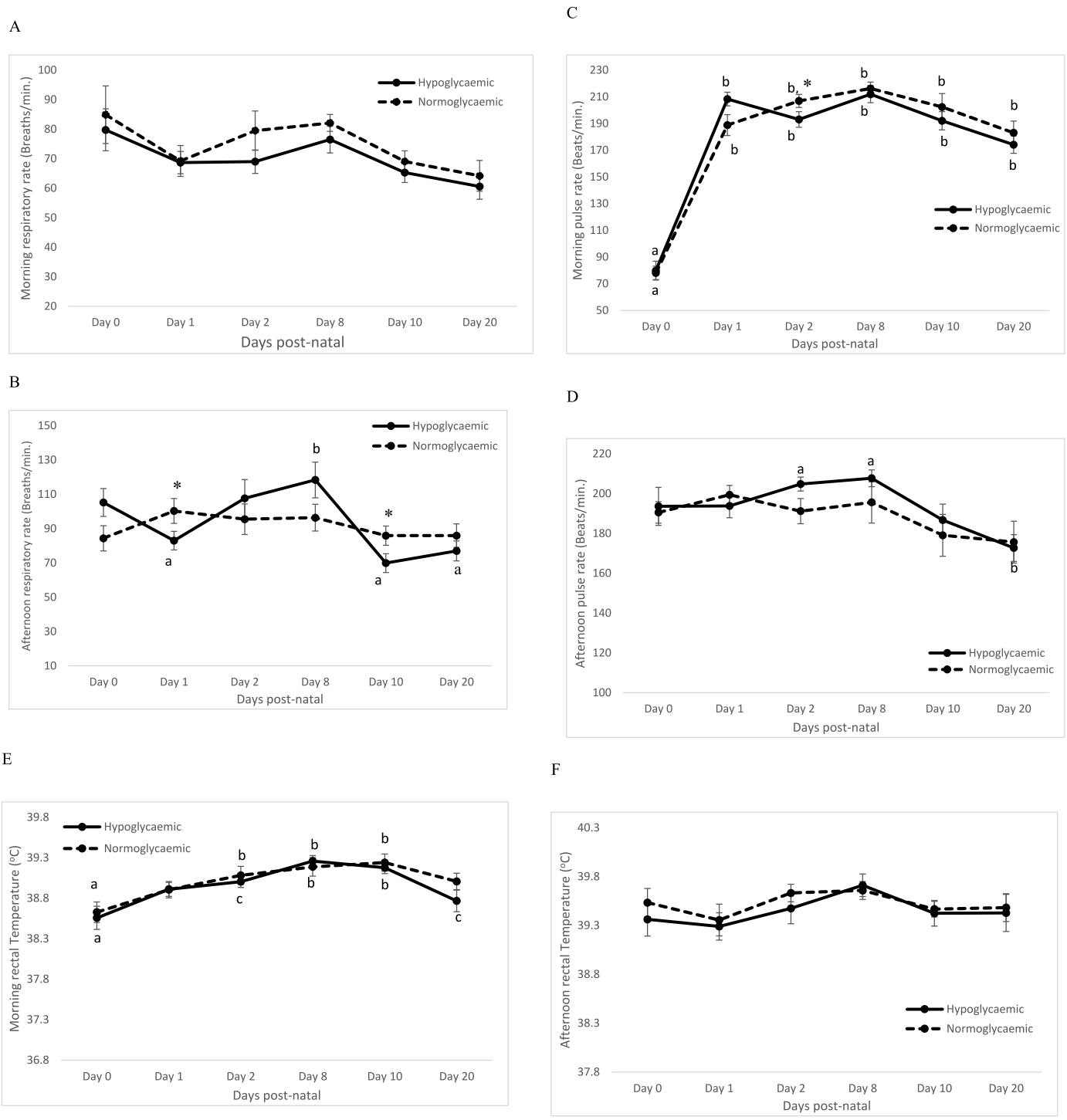

Fig. 3. Mean (± SEM) values of morning and afternoon respiratory rate (A and B), pulse rate (C and D) and rectal temperature (E and F) in normoglycaemic and hypoglycaemic neonatal goat kids. Values with asterisk (*) and alphabets (a, b, c) indicate significant difference ($P < 0.05$) between glycaemic groups and ages, respectively.

of temperature recording (Habibu et al., 2016; Saddiqi et al., 2011). Body weight was determined at birth and weekly for 5 weeks using a weighing scale. Hygrometer (GH Zeal limited, London, England) was used to measure dry-bulb and wet-bulb temperature at the experimental site during the morning (8:00 h) and afternoon (13:00 h) hours. The values of ambient temperature and relative humidity recorded during the study period were 25 – 38 °C and 51 – 70%, respectively.

Post-kidding, blood samples were collected by two experience persons. The neonates were gently restrained using a gloved-hand by experienced animal handler and 5 mL of blood was collected by the second person through jugular venipuncture into blood sample bottle during the morning, between 08:00 h–10:00 h (GMT + 1). About 0.1 mL was dropped on the test area of a test strip, inserted into a hand-held glucometer (Accu-chek®), and the reading was recorded (D'Orazio et al., 2005). This procedure was carried out in an isolated and cleaned site within the farm. The remaining blood sample was gently transferred into anticoagulant-free tubes and allowed to clot. It was centrifuged at 3, 000xg for 15 min to harvest the serum. The serum was stored in serum

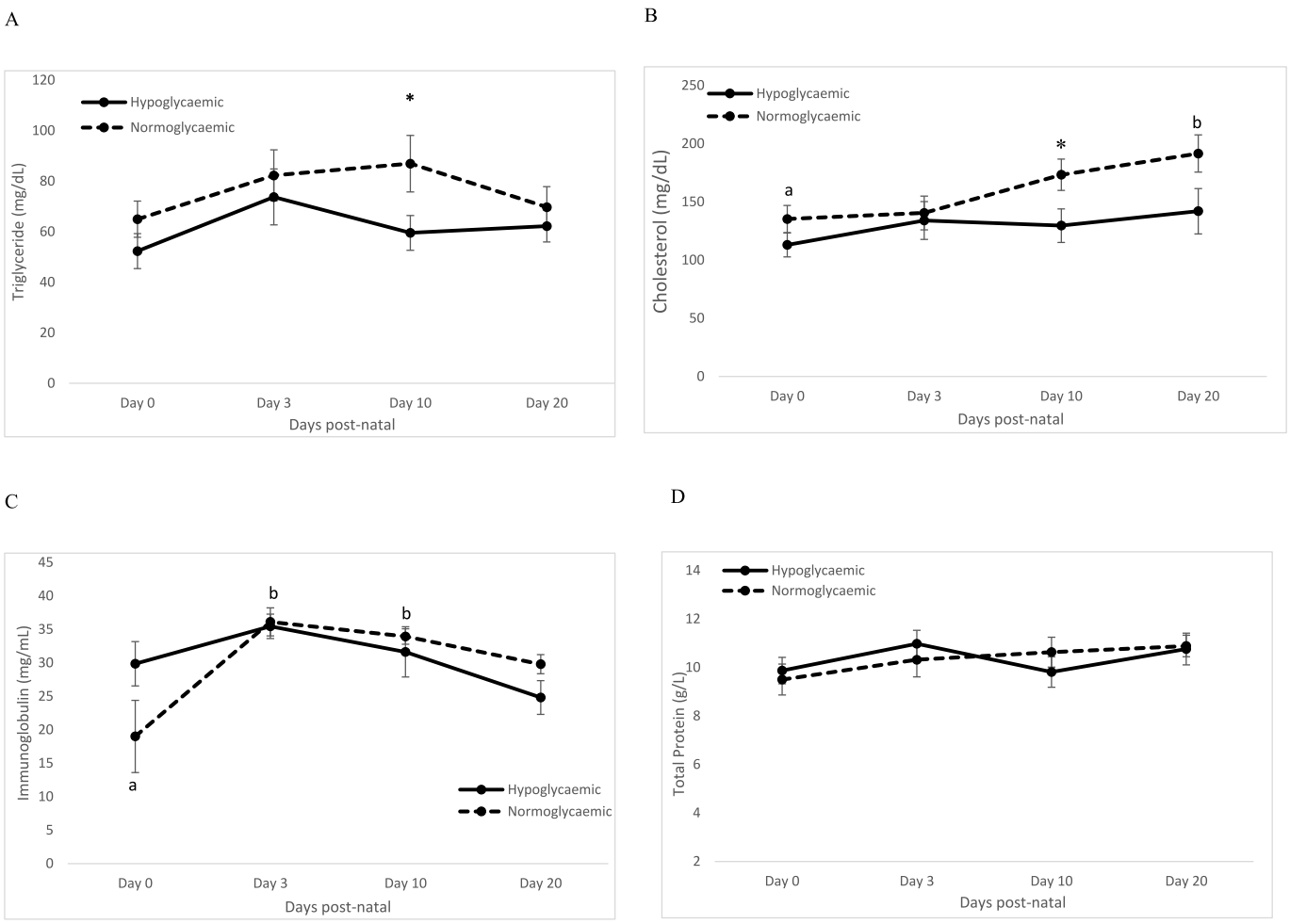

Fig. 4. Mean (± SEM) values of blood metabolites in normoglycaemic and hypoglycaemic neonatal goat kids. Values with asterisk (*) and alphabets (a, b) indicate significant difference ($P < 0.05$) between glycaemic groups and ages, respectively. The time x breed interaction was significant ($P < 0.01$) for immunoglobulin concentration.

sample bottles at −20 °C for analysis of biochemical variables.

Reagent kits (Randox®; London, UK) were used to determine the biochemical variables and globulin concentration was calculated by subtracting the concentration of albumin from that of total protein. Briefly, total protein was determined using the Biuret test, which involves the interaction of cupric ions with protein peptide bonds in alkaline medium, resulting in the formation of a coloured complex. The measurement of serum albumin was based on its quantitative binding to the indicator, bromocresol green. Urea was determined by its conversion to ammonium ions and the formation a green complex (Grant, 1987). Cholesterol was determined after enzymatic hydrolysis and oxidation, forming the indicator quinoneimine (Roeschlau et al., 1974), while triglycerides were determined after enzymatic hydrolysis with lipases (Jacobs & VanDenmark, 1960). The serum concentration of immunoglobulins was determined using the zinc turbidity test as earlier described by McEwan, Fisher, Selman and Penhale (1970) and modified by Hogan et al. (2016).

2.5. Data analysis

The Statistical Package for Social Science (SPSS) version 21 was used for the analysis. Equality of variances in the data was evaluated using the Bartlett's tests. Comparisons in all cases were done at the 5% level of significance. The effects of glycaemia on the kids were determined using repeated measures analysis of variance (ANOVA) for a completely randomised design. Effects of maternal variables (blood glucose concentration, body weight, BMI and age) on the development of hypoglycaemia or normoglycaemia in kids were tested using one-way ANOVA and independent-samples *t* tests. Where appropriate, Kruskal-Wallis test was used. Also, interactions between glycaemic groups and neonatal age were tested to determine the effect of advancing age on the measured variables. Means were separated with the aid of Bonferroni test to compare values.

3. Results

Mean values of age, body weight and BMI during mating as well as the blood glucose concentration immediately after parturition in dams that kidded hypoglycaemic kids and those that kidded normoglycaemic kids is shown in Fig 1 and Table 2. There was no significant ($P > 0.05$) difference in values of all maternal variables (age, body weight, BMI and blood glucose concentration) between dams that kidded hypoglycaemic kids and those that kidded normoglycaemic kids (Fig. 1). Similarly, irrespective of dam fecundity (twins or single), no significant ($P > 0.05$) difference in all maternal variables was observed (Table 2). However, most dams (9/20; 45%) that kidded normoglycaemic kids had singletons, while only few dams (4/14; 29%) that kidded hypoglycaemic kids had twins.

The mean values of blood glucose concentration in neonatal goat kids born with hypoglycaemia and normoglycaemia are shown in Fig. 2.

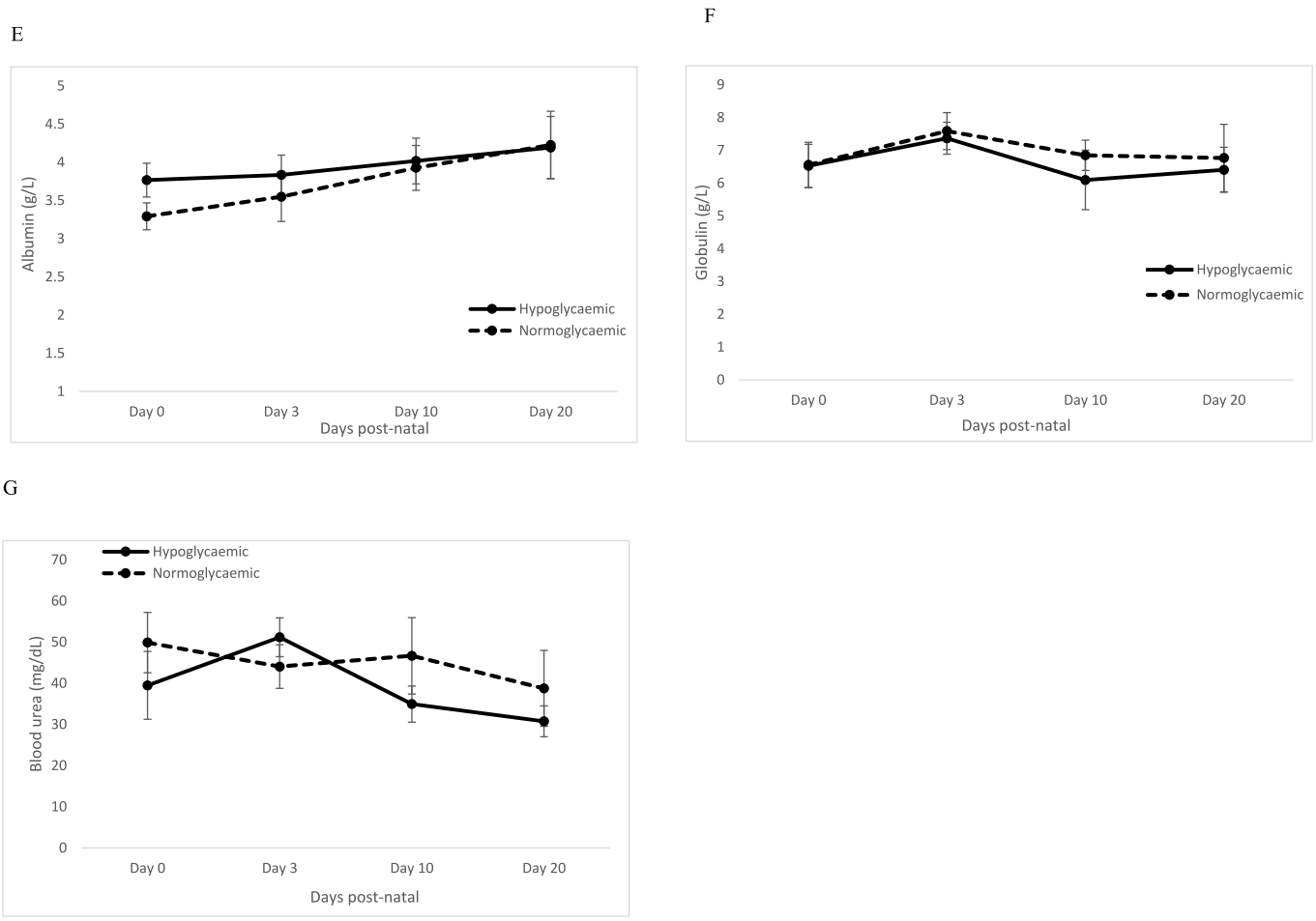

Fig. 4. (*continued*).

Significantly lower blood glucose concentration was observed in goat kids born with hypoglycaemia than those born with normoglycaemia from birth, until Day 2, when values became comparable between the two groups (Glycaemic group: P ⟨ 0.02; Age: $P < 0.03$; Interaction: P ⟩ 0.05). Blood glucose concentration increased ($P < 0.03$) 24 h after kidding in both hypoglycaemic and normoglycaemic goats and the values showed no significant fluctuation subsequently.

The values of postnatal respiratory rate in goat kids born with hypoglycaemia and those born with normoglycaemia were comparable during the morning hours (Fig 3A), while marked fluctuations were observed during the afternoon hours in hypoglycaemic kids. Also, the values of afternoon respiratory rate were lower ($P < 0.05$) in hypoglycaemic than normoglycaemic kids (Fig 3B). Similarly, values of morning pulse rate (Day 2) were lower ($P < 0.05$) in goat kids born with hypoglycaemia than those born with normoglycaemia (Fig. 3C). Afternoon pulse rate was stable in kids born with normoglycaemia, but values in hypoglycaemic kids significantly decreased in late neonatal life (Fig. 3D). Morning rectal temperature (Fig. 3E) was lower at birth, but increased ($P < 0.05$) on Day 2 in both groups of kids. Subsequently, the values in normoglycaemic goat kids showed insignificant ($P > 0.05$) fluctuation, while values in hypoglycaemic kids showed a marked ($P < 0.05$) decreased late neonatal life. However, the values of afternoon rectal temperature showed insignificant ($P > 0.05$) fluctuation from birth and the values were comparable in both groups (Fig. 3F).

Blood triglyceride concentration (Fig. 4A) was consistently higher in goat kids born with normoglycaemia than those born with hypoglycaemia, and values were significant on Day 10 (Glycaemic group: P ⟨ 0.05; Age: $P < 0.31$; Interaction: P ⟩ 0.05). Similarly, blood cholesterol (Fig. 4B) was consistently higher in goat kids born with normoglycaemia than those born with hypoglycaemia and, unlike in hypoglycaemic goat kids, values in normoglycaemic kids significantly increased after birth, steeping in the late neonatal life (Glycaemic group: P ⟨ 0.05; Age: $P < 0.05$; Interaction: P ⟩ 0.05).

The concentration of circulating immunoglobulins (Fig. 4C) increased 24 h after birth in kids that were normoglycaemic at birth (Glycaemic group: $P > 0.05$; Age: $P < 0.05$), while no significant fluctuation was noticed in kids born with hypoglycaemia (Age: $P > 0.05$). Except for the significant interaction between age and glycaemic groups (Interaction: $P < 0.01$), no significant difference was observed between groups. Concentration of total proteins (Fig. 4D), albumin (Fig. 4E), globulin (Fig. 4F) and urea (Fig. 4G) were comparable between groups and showed no significant effect of age and interaction between glycaemic groups. Birth weight and weekly body weight progressively increased ($P < 0.05$) in both groups (Fig. 5A), while the values of body weight gain (Fig. 5B) decreased ($P < 0.05$) in both groups, but the decrease was more obvious in hypoglycaemic kids (Glycaemic group: $P > 0.05$; Age: P ⟨ 0.05; Interaction: P ⟩ 0.05).

4. Discussion

Maternal age, body weight and BMI during mating as well as immediate postpartum blood glucose concentration seem not to influence the development of hypoglycaemia in goat kids at birth; this is irrespective of the fecundity of the dams. Moreover, contrary to expectations, only a few dams (5/29; 17%) had twin fetuses that were hypoglycaemic at birth. Since the neonatal kids developed hypoglycaemia, despite the similarity in the pre-mating or priming maternal variables (age, body weight and BMI), the maternal factors, if any, that

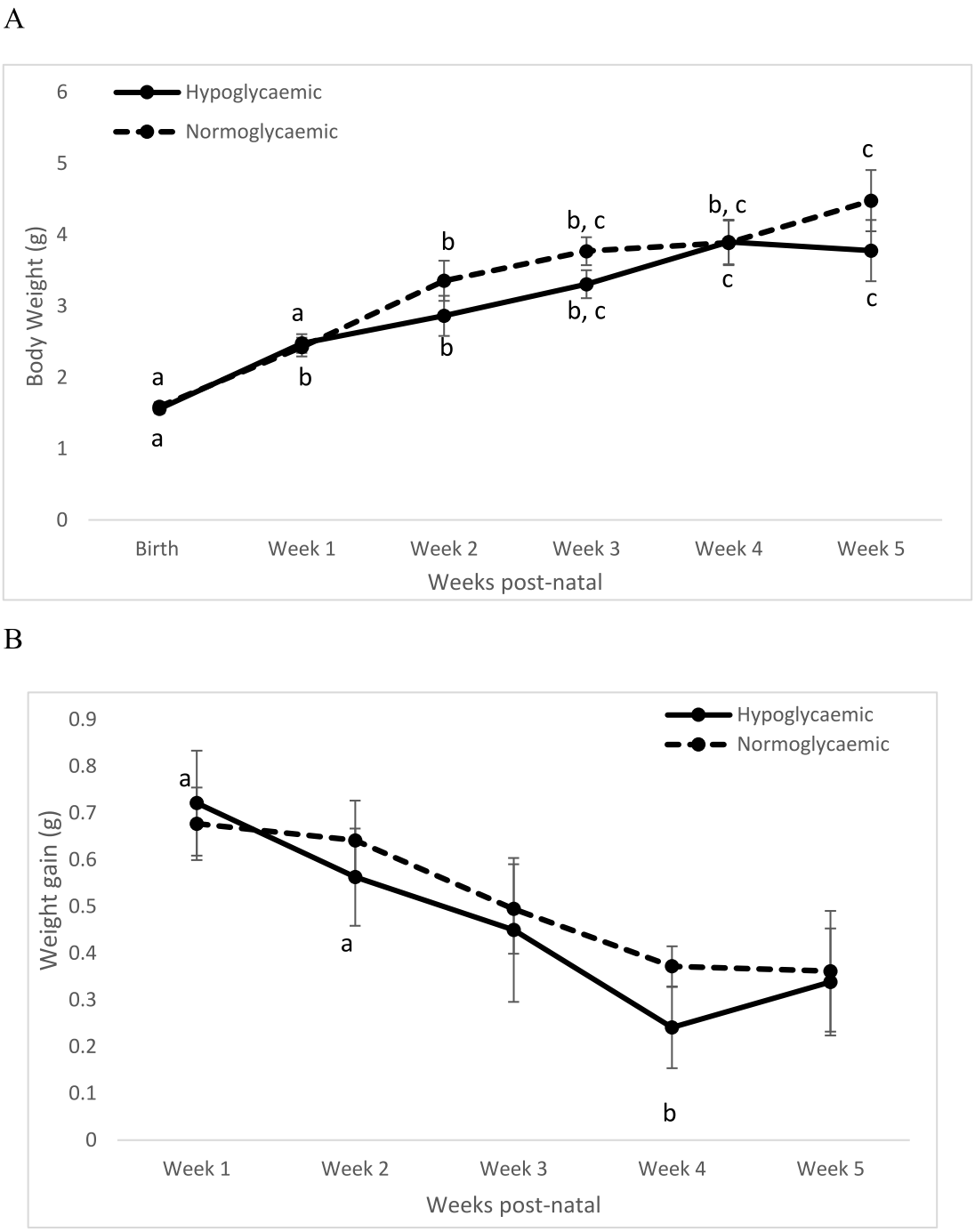

Fig. 5. Mean (± SEM) of weekly body weight (A) and weight gain (B) in normoglycaemic and hypoglycaemic neonatal goat kids. Values with a, b indicate significant difference ($P < 0.05$) between glycaemic groups.

could influence the development of hypoglycaemia at birth may have occurred during gestation, especially in late gestation when energy demand for foetal development and growth is higher (Dwyer et al., 2015; Idamokoro, Muchenje & Masika, 2017). To the best of our knowledge, there is paucity of studies evaluating the effects of maternal factors on the development of neonatal hypoglycaemia in goats. However, maternal under-nutrition during gestation may affect the metabolism of the neonate and the administration of nutritionally-inadequate diet to pregnant goats during late gestation has been reported to markedly lower the concentrations of most metabolic variables in the kids; though the concentration of blood glucose remained unaffected (Celi, Tranab & Claps, 2008).

The pattern of blood glucose observed in the current study is similar to the findings in our previous report in three tropical breeds (Habibu et al., 2021). The most important metabolic challenge of the hypoglycaemic kids is to establish and maintain normoglycaemia, and the normal blood glucose (35 – 103 mg/dL; Bezdekova, Mikulkova, Pleško, Kadek & Illek, 2020; Celi et al., 2008) in both groups of neonatal goat kids was established 24 h, post-natal in the current study. However, the physiological changes needed by the hypoglycaemic kids to attain comparable glycemic status with the normoglycaemic kids was accomplished 48 h, postnatal. This suggests that the metabolic challenge of neonatal kids born with hypoglycaemia may last beyond the development of normoglycaemia. It was reported that incidence of neonatal

hypoglycaemia may be associated with low glycogen reserve or poor glucose mobilisation during the immediate postnatal life (Habibu et al., 2021; Hegarty et al., 2016; Staarvik, Framstad, Heggelund, Fremgaarden & Kielland, 2019). In lambs, small placental size reduces foetal growth rate and causes chronic prenatal hypoglycaemia and increases the incidence of postnatal hypoglycaemia (Mellor, 1987; Rowan, 1992).

The metabolic adjustment in neonatal goats born with hypoglycaemia seem to have a marked impact on the metabolism of blood lipids. Neonatal kids that were hypoglycaemic at birth maintained lower blood lipids and could not markedly demonstrate the expected postnatal rise in blood cholesterol, unlike in the normoglycaemic goat kids. Postnatally, colostrum and milk intake alone cannot guarantee normal glucose metabolism without adequate and efficient endogenous support through glycogenolysis and gluconeogenesis (McGowan, 1999; Nafikov & Beitz, 2007). Continuous and excessive dependence on lipid mobilisation to supply energy may be responsible for depletion of blood lipids and accounted for the lower blood lipids in goat kids born with hypoglycaemia. Triglycerides in the blood serve as a source of metabolic fuel and undergo hydrolysis to release free fatty acids and glycerol (Patel & Kalhan, 1992; Pesantez-Pacheco et al., 2019; Pinent et al., 2008). Triglycerides are the main oxidizable substrate for thermogenesis and represent a major uptake process by brown adipose tissue (Bartelt et al., 2011; García-Torres, Hudson, Castelán, Martínez-Gómez & Bautista, 2015). The major metabolic fate of glycerol is conversion to glucose, and the surplus glucose is stored as glycogen (Borchgrevink & Havel, 1963; Lin, 1977). In the current study, depletion of the limited body energy reserves, in the form of body lipids, may explain the pronounced decrease in weekly weight gain in neonatal kids born with hypoglycaemia. The decrease in weekly weight gain was insignificant in the neonatal kids born with normoglycaemia.

Although there was no significant difference in values of rectal temperature between groups in the current study, hypoglycaemia at birth complicated the neonatal thermoregulatory adjustments in goat kids. The respiratory and pulse rates were unstable upon exposure to the high ambient temperature of the afternoon hours in goat kids born with hypoglycaemia, suggesting poor ability of the neonates to efficiently dissipate heat, especially during early neonatal life. Similarly, the decrease in morning rectal temperature in late neonatal life may imply a potential thermoregulatory challenge, associated with low thermogenic capabilities in the goat kids that were hypoglycaemic at birth. These blunted thermoregulatory responses may be related to the limited metabolic fuel available to the goat kids that were hypoglycaemic at birth (Mellor & Murray, 1985; Rowan, 1992). In neonatal ruminants, thermoregulation can be negatively affected by hypoglycaemia or hypoxaemia (Rowan, 1992). In the current study, the ability of the thermoregulatory system to mobilise body metabolite, especially lipids, to meet energy demand may account for the comparable values of rectal temperature between groups.

The demonstration of the marked rise in blood immunoglobulin levels in normoglycaemic kids that resulted in significant interaction between age and glycaemic groups, suggests better passive absorption and/or endogenous production of immunoglobulins in kids born with normoglycaemia at birth. A neonatal increase in blood immunoglobulin levels up to post-natal day 4 has been reported and endogenous production of immunoglobulin has been reported to commence after two weeks in goat kids (Arguello et al., 2004; Yalcin et al., 2010). The newborn ruminants are born markedly hypogammaglobulinaemic and depend entirely on passive transfer of colostral immunoglobulins and this passive transfer must be completed within a very narrow time window, as gut closure to immunoglobulin absorption occurs between 24 and 36 h after birth. Thus, adequate uptake of immunoglobulins within the first two days after birth is important to reduce susceptibility of the neonatal ruminant to gut, respiratory, systemic and other infections (Arguello et al., 2004; McEwan et al., 1970; Yalcin et al., 2010).

Comparable changes in blood protein and urea profiles between the two groups, suggest that the catabolic adjustment in the hypoglycaemic kids seems to spare tissue proteins. A rise in circulating urea levels suggests an excess of protein ingestion, increased use of body amino acids stores to provide metabolisable energy or a carbohydrate deficiency, as proteins are catabolised in order to spare glucose oxidation (Celi et al., 2008; Mellado, Pittroff, Garcia & Mellado, 2008).

5. Conclusion

In conclusion, neonatal goat kids born with hypoglycaemia could establish normal blood glucose levels and survive post-natal challenges, but may show compromised thermoregulation, metabolism and body weight gain. The cause of hypoglycaemia in kids is neither associated with maternal age, body weight and BMI during mating nor with maternal blood glucose immediately after birth. Generally, adequate *ad libitum* feeding of colostrum and milk after birth could be enough to resolve hypoglycaemia in neonatal goats, but the negative effects on thermoregulation, metabolism and production performance may linger longer than the development of normoglycaemia.

Ethical approval

The adopted study protocol and experimental design followed the international guidelines for animal welfare and got the approval of the Animal Use and Welfare Committee of Ahmadu Bello University: ABU-CAUC/2019/13.

Declaration of Competing Interest

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

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