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Research paper

Impact of the post-weaning nutritional history on the response to an experimental *Haemonchus contortus* infection in Creole goats and Black Belly sheep

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ABSTRACT

In small ruminants, the response against gastrointestinal nematode (GIN) infections is influenced not only by the host genotype and the physiological stage but also by environmental factors, particularly the nutritional status at the time of infection. In this study we evaluated the long-term effect and the interaction between the host species and the nutritional history on the response to GIN infection in two animal models differing in their phenotypic growth and their level of GIN resistance: Black Belly sheep and Creole goats. Lambs and kids were subjected to three distinct nutritional conditions at weaning: low dietary conditions (100% of the theoretical energy requirement for maintenance, corresponding to 548 v. 484 KJ/Kg $BW^{0.75}$ for lambs and kids respectively and 6% of crude protein, CP), medium dietary conditions (150% of the theoretical energy requirement for maintenance and 13% CP) and high dietary conditions (200% of the theoretical energy requirement for maintenance and 20% CP). This 3-months period was followed by a 1-month period on the medium dietary conditions for all the animals before an experimental *Haemonchus contortus* infection. We monitored the impact of the nutritional history (nutritional condition after weaning), on the intensity of the GIN infection by measuring individual faecal egg counts (FEC), growth rate (ADG), blood eosinophil counts and other pathophysiological parameters. The FEC, growth rate and blood eosinophil counts were significantly affected by the nutritional history in lambs but not in kids. The lowest FEC was found for lambs placed in high dietary conditions, however during the same period body weight loss was observed in this group. In low dietary conditions, kids were more resistant than lambs and the ADG was higher in lambs. However, the anaemia and the level of serum pepsinogen, marker of the abomasal mucosa integrity, were higher in kids. Our data suggest that the impact of the post-weaning nutritional history on the response to an experimental *H. contortus* infection is significantly affected by the host species.

1. Introduction

The constant increase of the prevalence of anthelmintic-resistant gastrointestinal nematode (GIN) strains together with an increasing demand of chemical-free animal products and the potential environmental consequences of anthelmintics increase the importance of alternative control strategies (Beynon, 2012). The objective is no more the search for a unique solution to eradicate the GIN populations, but rather an integration of different control methods to reach a favorable equilibrium for animal production. Among these alternative strategies, the optimisation of the host nutrition to improve resistance and/or resilience to GIN infections is a short-term solution easy to implement (Torres-Acosta et al., 2012).

There is accumulating evidence showing that the nutritional status is closely associated with the capacity of the host to mount an efficient immune response against invading pathogens (Calder et al., 2002; Gershwin et al., 2004). Indeed, mounting an immune response is expensive both in terms of protein and energy because of the metabolic requirement of immune cells, the synthesis of proteinaceous immune mediators and the repairing of damaged tissues (Lord et al., 2001; Sykes, 2010). Thus, numerous studies

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have showed that the response to an immunological challenge must be traded off against other physiological functions such as reproduction, growth and thermoregulation (Sheldon and Verhulst, 1996; Shudo and Iwasa, 2001; van der Most et al., 2011; Zuk and Stoehr, 2002). Moreover, a singular feature of pathogens infection across mammalian and avian hosts is the reduction in voluntary food intake, at a time of increased nutritional demand (Kyriazakis et al., 1998). Recently, Kyriazakis put forward the hypothesis that, in herbivore anorexia can be viewed as both an unavoidable consequence of infection but also as a behavior strategy that enables them to cope with the consequences of infection (Kyriazakis, 2014). Nevertheless, benefits linked to pathogen-induced anorexia would probably require fine homeostatic control, as chronic undernutrition has deleterious consequences for host defense.

The trade-off between the major physiological functions, including the immune response against invading pathogens, is influenced not only by the host genotype and the physiological stage but also by environmental factors, particularly the availability and the quality of the feed in the ecosystem (Lochmiller and Deerenberg, 2000). By the use of a mathematical model, Vagenas et al. 2007a, b showed a higher significant effect of the nutritional status on GIN resistance traits in sheep than the effect of the host genotype, suggesting that discrepancies between published genetic parameters for GIN resistance may be function of environmental factors rather than differences in host genotype). In sheep it has been shown that the nutritional status in early life influenced significantly the resistance to GIN in the later life (Datta et al., 1999). However, data on the relationships between the nutritional status in early life and the resistance to GIN are still scarce in sheep and even more in goats. Hence, in this study we evaluated whether the nutritional history in early life would affect the resistance to an experimental GIN infection in two host species (*i.e.*, sheep and goats).

2. Materials and methods

The experiment was conducted at the Institut National de la Recherche Agronomique (INRA) Animal Production Unit, Guadeloupe (French West Indies) (16° 16′ latitude North, 61° 30 longitude West). All animal care, handling techniques, procedures as well as license for experimental infection and blood sampling were approved by INRA, according to the certificate number A-971-18-02 of authorization to experiment on living animals issued by the French Ministry of Agriculture, before the initiation of the experiment.

2.1. Animals, management and experimental design

The study was carried out with two successive groups of 48 animals ($n = 24$ Black belly lambs; 25.3 ± 2.87 kg BW; 3 months old and $n = 24$ Creole kids; 12.6 ± 2.17 kg BW; 3 months old) during two trials. From birth to weaning the animals were raised in a rotational grazing system in which the pasture was rested for 4 weeks between two grazing period of 5 days. At 3 months of age all the animals were weaned and drenched with ivermectin (Oramec, Merial, Lyon, France, 0.3 mg/kg BW) and toltrazuril (Baycox Ovis, Bayer HealthCare, Loos, France, 20 mg/kg BW). Each trial started at weaning. The first period lasted 105 days during which animals were randomly allocated to one of 3 distinct diets: Low, Medium and High dietary conditions. On the basis of the meta-analysis of Salah et al., 2014 the 3 dietary conditions were balanced in energy and protein as follow: (i) 100% of the theoretical energy requirement for maintenance (548 v. 484 KJ/Kg $BW^{0.75}$ for lambs and kids respectively) and 6% of crude protein (CP) (Low dietary condition), (ii) 150% energy requirement for maintenance (822 v. 726 KJ/Kg $BW^{0.75}$ for lambs and kids respectively) and 13% CP (Medium dietary condition) and, (iii) 200% energy requirement for maintenance (1096 v. 968 KJ/Kg $BW^{0.75}$ for lambs and kids respectively) and 20% CP (High dietary condition). The banana flour, the soya and the additives of the ration were distributed to the animals in the form of pellets (Table 1). During this period, all the animals were reared in individual pens (2 × 2 m) with free-choice access to fresh water and were weighed every 21 days to adjust the offered quantities according to body weight change (Table 1). At the end of this period, the animals were placed in 6 collective pens (for lambs and kids allocated to the 3 distinct diets respectively), and received the pellets corresponding to the medium dietary condition and hay *ad libitum*. After a 30 days period of adjustment to the collective pens and the diet conditions, all the animals were experimentally infected with a single oral dose of 10,000 *H. contortus* third-stage infective larvae (L3).

Table 1
Composition and nutritional values of diets.

	Nutritional conditions		
	Low	Medium	High
Ingredients (g/Kg DM[a])			
Hay	500	582	250
Banana flour	482	250	368
Soya	0	150	364
Premix	7.5	7.5	7.5
Bicalcium	3.5	3.5	3.5
Calcium	7.0	7.0	7.0
Chemical composition (g/Kg DM)			
OM[b]	93.2	92.9	149.2
CP[c]	6.1	13.3	20.0
NDF[d]	45.9	50.8	29.3
ADF[e]	22.2	25.8	14.2
ADL[f]	2.6	3.0	1.5
ME[g] (MJ/Kg DM)	8.7	8.5	11.8
DMI[h]/Kg BW[i]	26.0	40.0	40.0

[a] DM: dry matter.
[b] OM: organic matter.
[c] CP: crude protein.
[d] NDF: neutral detergent fiber.
[e] ADF: acid detergent fiber.
[f] ADL: acid detergent lignin.
[g] ME: metabolisable energy.
[h] DMI: dry matter intake.
[i] BW: body weight.

The L3 were obtained 42 days before challenge from cultures of faeces taken from anthelmintic-susceptible strain harvested from faeces of monospecifically infected donor Creole goats with isolates previously obtained from Creole goats reared on pasture in different farms in Guadeloupe (Bambou et al., 2008). During the experimental infection the animals remained on the same diet corresponding to the medium dietary condition, and the measurement of BW changes, FEC and blood parameters were performed weekly during 5 consecutive weeks.

2.2. Feed intake and growth measurements

During the first period when animals were in individual pens, the average voluntary dry matter intake (DMI) was calculated individually as the difference between the daily amounts of feed offered and feed refusal. The BCS were measured weekly during the last 5 weeks of the first period by palpation of the lumbar and the sternal vertebrae and associated soft tissue. A scale of one (thin) to five (fat) was used and the BCS was the mean score of the lumbar and the sternal region. When animals were placed in collective pens the pellets were distributed first and individually with the help of yoke traps during the consumption lapses' time. Thereafter, the hay was distributed *ad libitum*. Feeding stalls were long enough to avoid competition for hay between the kids. The offered hay was adjusted to the groups BW. During the infection period the average volun-