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NUTRITION AND GASTROINTESTINAL PARASITISM IN RUMINANT PRODUCTION

NUTRICIÓN Y PARASITISMO GASTROINTESTINAL EN PRODUCCIÓN DE RUMIANTES

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SUMMARY

In order to increase ruminant performance, producers have to deal with two main obstacles: health and nutrition. Resistance to traditional anthelmintic drugs and the increasing "organic production" of food are demanding alternative parasite control methods. When cattle parasites alter food intake and cause a lower use of the absorbed nutrients, they greatly interfere with productivity. "Immunonutrition" is considered a potential and sustainable method of antiparasitical control. Protein, vitamin and mineral availability are important factors to optimize production and the resistance of the host to certain parasites. Secondary substances of some plants can have antiparasitical effects in animals grazing on them. The purpose of this work is to, based on a review of previous research studies, point out some of the existing interactions between nutrition and parasitism in ruminants, and to show how a rational nutritional management can be seen as an efficient antiparasitical control method.

RESUMEN

En pos de aumentar el rendimiento animal, los productores se enfrentan con dos grandes obstáculos: sanidad y nutrición. La resistencia a las drogas antihelmínticas tradicionales y el incremento en la producción orgánica de alimentos están llevando a buscar alternativas para el con-

trol de los parásitos. Los parásitos producen alteraciones que afectan desde el consumo de alimentos hasta la utilización de los nutrientes ingeridos, interfiriendo gravemente en la producción. La "inmunonutrición", se considera una medida potencial y sustentable de control antiparasitario. La disponibilidad de proteínas, vitaminas y minerales es un importante factor para optimizar la productividad y la resistencia del hospedador a ciertas parasitosis. Los metabolitos secundarios de algunas plantas pueden tener efectos antiparasitarios para los animales que las pastorean. El objetivo del presente trabajo es, basado en revisiones de trabajos de investigaciones previas, señalar algunas de las interacciones existentes entre nutrición y parasitismo en rumiantes y mostrar cómo un manejo nutricional racional puede ser considerado un método eficiente de control antiparasitario.

INTRODUCTION

Demographic growth, particularly seen in developing countries, needs a parallel and compensatory growth in food production systems. This expansion in animal production has to be based not upon raising the number of animals or on increasing the amount of forage given to them but on

improving the efficiency of production with the given resources. Increasing cattle production has generally two main obstacles: nutrition and health. Depending on the environment, malnutrition or parasitic diseases and sometimes both together can limit production efficiency (Knox and Steel, 1996).

Parasites, especially gastrointestinal nematodes, can be considered one of the main threats for health and production of cattle in extensive production systems (Coop and Kyriazakis, 2001; Louvandini *et al.*, 2002; Suleiman *et al.*, 2005). They cause considerable losses in the production in the whole world, mainly in young animals and periparturent females (Larsson *et al.*, 2006). Economic losses are related to a decrease in fertility, in food intake and in weight gain but also to the lower milk production, to more expensive treatments and control methods and to the death of severely parasitised animals (Romero and Fonrouge, 1987; Knox *et al.*, 2006).

Due to the economical losses caused by parasites it is necessary to establish effective control methods. Traditionally, pharmacological products have been used to control parasites (Athanasidou *et al.*, 2000; Min and Hart, 2003; Muturi *et al.*, 2005). These methods, however, offer some difficulties because of the growing resistance to the commonly used anthelmintic drugs. Furthermore, the high costs of the pharmacological products and the increasing demand of the population to be provided with food without residues, mainly those that could be toxic for the environment, stimulate to look for alternative non-chemical strategies to control parasites (Coop and Kyriazakis, 1999, 2001; Kyriazakis and Houdijk, 2006). Non-pharmacological tools are based on the use of vaccines, breeding of resistant genotypes, biological control, (Van Hountert and Sykes, 1996), grazing of alternative hosts, manual removal of faeces, frequent and rational pasture

rotation, supplementary feeding to improve the nutritional condition or the utilization of alternative forages with antiparasitical effects (Coop and Kyriazakis, 2001; Hoste *et al.*, 2006).

Apart from the nutritional value of plants, there are substances in some of them that can have beneficial or undesirable effects for animals feeding on them (Hoste *et al.*, 2006). The effects of certain plants' components on parasites and on animal performance are being investigated (Nguena *et al.*, 2005; Suleiman *et al.*, 2005; Tzamaloukas *et al.*, 2005; Knox *et al.*, 2006). Tannins are secondary metabolites associated to the defence mechanisms of plants against insects and mammals and, though they can have negative effects for the animal that consumes them, ruminants can take advantage of the presence of these compounds (Athanasidou *et al.*, 2001).

The nutritive status of the animals can influence their resistance to parasitosis (Bricarello *et al.*, 2005; Muturi *et al.*, 2005). An improvement in immunocompetence due to an adequate diet (immunonutrition) is considered a sustainable potential control method (Muturi *et al.*, 2005). On the other hand, the degree of each animal's genetic resistance influences the effect that supplementation may have in its response to infections (Bricarello *et al.*, 2005).

Independently of their localization, all parasites may have an indirect impact on the host's nutritional status; the gastrointestinal parasites are, however, those that provoke more notorious consequences because of their direct contact with nutrients.

Ruminants acquire the infecting forms of the gastrointestinal parasites while they feed, which constitutes the beginning of a complex interrelation between two factors: nutrition and parasites (Hutchings *et al.*, 2001).

Two different approaches can be made to the interaction between parasitism and nutrition. On the one hand, the influence of

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parasites on the host's metabolism and on the other, the effect of nutrition on parasite populations and on the ability of the animal to face and get over the infection (Coop and Holmes, 1996; Coop and Kyriazakis, 1999).

In this review, we have analyzed information obtained mostly by experimental means and based on studies performed generally on gastrointestinal parasites of sheep. However, the general concepts can be applied to other animals and other parasite species (Coop and Kyriazakis, 1999; Kastelic, 2006).

The aim of the present study is to establish some of the existing connections between nutrition and parasitism in ruminants, considering both the influence that parasites might have on the host's nutrition and the predisposition to parasitism in different nutritional situations and to show why a rational nutritional management can be used as an efficient antiparasitological control method.

EFFECTS OF PARASITES ON THE HOST

Gastrointestinal parasitoses are widespread and appear in ruminants of all ages (Rossanigo *et al.*, 1992) although it is generally accepted that adults are relatively resistant to internal parasites. Very young animals are generally more affected by coccidia, *Cryptosporidium* and *Giardia* than by gastrointestinal nematodes (Lardy and Stoltenow, 2001). Infections can present a variety of clinical signs, that range from no clinical manifestation at all to diarrhoea, anorexia and weight loss leading to an impairment growth, decrease in productivity and, in severe cases, to death. Subclinical infections represent the majority of cases and cause economical losses due to the suboptimal performance of the animals.

As a consequence of the action of the parasites and of the immune response of the host, several nutritional parameters can be modified, such as food intake and nutrient

digestibility, nitrogen retention and protein, mineral and energy metabolism and utilization (Rossanigo *et al.*, 1992; Muturi *et al.*, 2005) resulting in a lower performance of animal production. In parasited animals the processes leading to preserve the homeostasis, such as the plasmatic protein synthesis, mucus production, reparation of the gastrointestinal tract and immunocompetence, are privileged over other functions such as skeletal growth (Muturi *et al.*, 2005), soft tissue deposition and milk production (Coop and Kyriazakis, 1999).

There seems to be a threshold of exposition beneath which there is no significant reduction of appetite (Kyriazakis *et al.*, 1998; Nari and Fiel, 1994). In a study conducted by Rossanigo *et al.* (1988) a reduction of 15% in food intake was recorded in parasited calves with gastrointestinal nematode burdens lower than 300 eggs per gram (epg) compared to non-parasited animals and of 18% in animals with more than 300 epg compared to controls. A reduction of food intake is believed to take place with burdens above 150 epg. In another study from Rossanigo *et al.* (1992), a reduction of 8.36% in the dry matter intake was proved in parasited animals compared to a control group. After 329 days the non-parasited animals had gained 26 kg more than the parasited ones. The appetite depression can vary between 15-20% according to Coop and Kyriazakis (1999), while other authors state that reductions of up to 30% (Van Hountert and Sykes, 1996) or even 50% (Knox *et al.*, 2006) can exist.

Several hypotheses have been suggested to explain the reduction in food ingestion. On the one hand, the lesions could produce certain pain and digestive discomfort, which would have a negative intake impact (Knox *et al.*, 2006; Rossanigo *et al.*, 1988). On the other hand, the damage produced by the parasites could be located in areas related to the tension regulation and feeling of plenitude which reduces the

ingestion. The alterations in the composition of the food and the protein-energy relation in the absorbed nutrients, in the availability of amino acids, in the intestinal pH, in the reticulo-ruminal motility and in the hormonal metabolism of the digestive tube would also favour a lower intake of food (Rossanigo *et al.*, 1988; Coop and Holmes, 1996; Knox *et al.*, 2006).

Amongst the gastrointestinal hormones, the colecistocinine (CCC) is considered one of the most important factors in the alimentary behaviour (Nari and Fiel, 1994). This hormone is produced by the cells that cover the first part of the small intestine. It is released at the stimulus produced by the presence of food; it produces the contraction of the gall bladder and a plenitude feeling at the central nervous system (Rossanigo *et al.*, 1988; Van Hountert and Sykes, 1996). The cellular damages caused by parasites can produce a great release of CCC reducing appetite. However, this is not the only mechanism involved in anorexia induced by parasites as a reduction in appetite is also mentioned in sheep parasited by *Fasciola hepatica* and bovines with *Haemonchus placei* which are parasites not located in the small intestine (Rossanigo *et al.*, 1988).

The cytokines cascade associated to the immune response can also be related to anorexia (Knox *et al.*, 2006). It is known that in laboratory animals the tumoral necrosis factor (TNF) and the interleukin 1 produce anorexia. The hypothalamus is an important place of integration of central and periferical signals involved in the control of ingestion. Several neuropeptides would be involved in the appetite control, such as neuropeptide Y, strong appetite stimulator, and the corticotrophin release factor (CRF) as an inhibitor (Coop and Holmes, 1996). It has been observed that in laboratory mice an increase in the expression of the gene of the neuropeptide Y occurred in a parasitic infection. The fact that no concomitant increase in the food intake occurred

suggests the presence of some inhibitors, amongst which the CRF has been mentioned (Van Hountert and Sykes, 1996).

Armour *et al.* (1974) studied the effect of parasites on the stomach secretion. The injuries in the stomach produced by *O. circumcincta* and *T. axei* alter the normal function of the glands. This decreases the production of hydrochloric acid (HCl), increasing the gastric pH and not allowing the activation of the pepsinogen, with the concomitant absence of protein digestion (Min and Hart, 2003). The decrease in the production of HCl can cause some delay in the abomasal flow, as acidity is an important stimulus for the rumino-reticular contraction (Nari and Fiel, 1994). Studies performed in cattle experimentally infected with *O. ostertagi* have shown a relation between the reductions in food consumption, the increase in the concentration of blood gastrine and the decrease in the food passage. The increase of gastrine reduces the reticular-ruminal motility producing stasis of food and reduction of appetite (Coop and Holmes, 1996).

During infections two classes of proteins are lost with the faeces: the exogenous not absorbed proteins and, most important, the endogenous (the corporal protein) as cells coming from the desquamation of the epithelial cover or as plasmatic proteins of high biological value (specially albumins and globulins) that escape from the blood vessels towards the gastrointestinal lumen through the damaged zone, because of the lack of sealing of the intercellular bridges (Coop and Holmes, 1996; Knox and Steel, 1996; Knox *et al.*, 2006). Some parasites, such as *H. contortus*, can produce an important loss of plasma proteins as a consequence of their haematophagic habits. The infiltration and inflammation of the mucosa produced by some nematodes alters the continuity of the desmosomic unions between the epithelial cells with the concurrent passage of proteins towards the

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lumen of the organ and, eventually, the pepsinogen to the plasma (Romero and Boero, 2001). The absence of pepsin activity due to a pepsinogen loss or to a decrease in the secretion of the HCl necessary to activate pepsinogen into pepsin occurs not in all nematodes but mainly in *Ostertagia*, *Haemonchus* and *Trichostrongylus*. Another source of endogenous protein loss is the increase in the production of mucoproteins (Rossanigo *et al.*, 1988; Coop and Kyriazakis, 2001; Knox *et al.*, 2006). These losses can range from 20 to 125 g of protein per day in infections by *T. colubriformis* in sheep (Coop and Kyriazakis, 1999). In this way, there is a net movement of proteins from the productive processes such as production of meat, bone, milk and wool towards the synthesis of plasmatic proteins, reparation of the gastrointestinal tract and mucus production (Coop and Holmes, 1996; Knox and Steel, 1996; Knox *et al.*, 2006). The protein recycling has an energetic cost (Van Hountert and Sykes, 1996; Coop and Kyriazakis, 1999, 2001), which goes in detriment of the productive performance of the animals. The increase in the mucus production, rich in treonine, serine and proline, can result in a deficiency of these amino acids for other processes. On the other hand, the mucus is resistant to digestion and reabsorption; therefore, once its components are formed, they will not be available for the synthesis of other proteins. The immune response that takes place against the infection requires certain amino acids, especially the sulphured ones and, therefore these will not be available for other processes if they are used for immune purposes. The availability of amino acids for the body tissues can be reduced up to 30% because of the protein loss (Coop and Kyriazakis, 1999).

Although the infections can cause local changes that alter the gastrointestinal digestion and absorption functions, there are compensatory increases in the distal

places of the lesions so there will not necessarily be an altered nitrogen faecal excretion. Moreover, the enteric protein losses are balanced by an early increase in the hepatic synthesis of albumin. Afterwards, however, this synthesis declines and the protein losses produce hypoproteinemia (Nari and Fiel, 1994).

The hypoproteinemia and the nitrogen loss affect the protein deposition in the growing animal, retarding the body development (Rossanigo *et al.*, 1988). The reduction in the ingestion, incomplete absorption in the intestine and increase protein turn-over, decrease the raw materials for the productive processes (Nari and Fiel, 1994; Knox and Steel, 1996). The intestinal protein synthesis is increased as well as the plasmatic and structural protein synthesis, while muscle, milk and wool protein synthesis are reduced (Knox and Steel, 1996).

The average of exogenous proteins that are absorbed is not much less than in non-parasited animals as the intestine region not affected is more active and compensates for the lack of absorption of the affected part (Rossanigo *et al.*, 1988; Knox *et al.*, 2006). Rossanigo *et al.* (1988) state that the poor absorption and the protein losses would not be enough to explain the low performance. This increases the importance given to anorexia in the parasitosis as the main cause of the lower productive performance.

It is estimated that to make up for the protein losses of the infection 17 g/day of metabolizable protein above the maintenance requirements are needed, therefore the effects of the parasitosis will be worsened in times of protein shortage in the pastures, during pregnancy and lactation (Knox *et al.*, 2006).

Gastroenteritis caused by helminths can have severe consequences in the bone growth. The absorption and retention of phosphorus is severely reduced. There exists an endogen loss of calcium and a reduction

in the absorption of this mineral due to a lower demand as the growth of the bones is reduced (Van Hountert and Sykes, 1996; Knox *et al.*, 2006).

Van Hountert and Sykes (1996) state that the absorption of magnesium is not altered, while Knox *et al.* (2006) mentions a decrease in the absorption of this mineral in gastrointestinal parasitoses.

In the abomasal infections there is a reduction in the copper absorption (Coop and Holmes, 1996; Van Hountert and Sykes, 1996). The infection by *O. circumcincta* in sheep affects the metabolism of copper, especially because of the increase of the abomasal pH. The reduction of the abomasal acidity reduces the copper solubility and therefore the captivity of the mineral by the liver (Coop and Holmes, 1996).

EFFECTS OF THE NUTRITION ON PARASITES

The effect of nutrition over the parasite-host relationship is an alternative to chemoprophylaxis. Nutrition can influence the development and consequences of parasitism in three different ways: it can increase the ability of the host to overcome the adverse consequences of parasitism; it can increase the ability of the host to contain and overcome the parasitism limiting the establishment, growth rate, fecundity and/or persistence of the parasites population; last of all, it can directly affect the parasites population through the ingestion of natural antiparasitological compounds (Coop and Kyriazakis, 2001).

It is known that the raise in the dietary protein enhances the resistance to the infections through an increase in the immunity to parasites, not allowing them to establish, reproduce and survive or at least reducing the consequences of the subclinical parasitosis. In times of protein shortage, the supplement in the diet can reduce the number of gastrointestinal nematodes in growing animals and peri-

parturent females. Nutrition has the "power" to regulate the rate of acquisition and expression of immunity. This way, immunonutrition plays an important role in control strategies, alone or associated with other non-chemical strategies. Many studies that relate the effects of nutrition to the immunity are based on the metabolizable protein, as many of the immune system components are proteins in nature (Kyriazakis and Houdijk, 2006), for instance the immunoglobulins, mucoproteins and the interleukins. Once the requirements for growth are satisfied, the immune response becomes more effective with the addition of supplementary protein. This would explain the relative immaturity in the parasited young animals that have greater demands (Coop and Holmes, 1996).

There is abundant evidence concerning the importance of increasing the protein level more than the energetic one (Coop and Kyriazakis, 1999, 2001), even though in animals severely affected by famine the increase in the energetic level will certainly help to overcome the infection. In an experience done in sheep, it was observed that given two isoenergetic foods, the two sheep infected with *T. colubriformis* chose the one with the greater protein content, while the control animals did not do such selection (Coop and Kyriazakis, 2001).

The expression of the resistance to gastrointestinal nematodes competes with other functions when there is scarceness of nutrients. It is expected that the animals will privilege the maintenance of the corporal protein in moments of shortage of food, as it ensures the survival in the short term. This includes reparation and replacement of damaged tissues. Although the immune system was earlier considered as part of the "maintenance" there are studies that demonstrate that there are aspects of the immunity that are sensitive to dietary changes. Once the maintenance necessities are covered, growth, reproduction and

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immunity to parasites will be privileged. In young animals infected for the first time, the acquisition of immunity will be privileged over growth; otherwise they would die from the parasitosis before they can reach maturity age. Once immunity is acquired, growth and reproduction are privileged over immunity, as these functions will guarantee the preservation of the genetic material (Coop and Kyriazakis, 2001; Houdijk *et al.*, 2003; Kyriazakis and Houdijk, 2006). The initial establishment of nematodes and the acquisition of immunity in young animals are not influenced by supplementation, as they already have more priority than growth. On the other hand, the expression of immunity is very much affected by the protein content of the diet (Coop and Kyriazakis, 2001). Once the growth rate begins to decline, the immune function can be fulfilled in an efficient manner (Coop and Holmes, 1996). The increase in the metabolizable protein in sheep infected with *O. circumcincta* increased the milk production at the beginning while the reduction in the parasite burden took place only at the end (Houdijk *et al.*, 2000; Kyriazakis and Houdijk, 2006).

The immune break down in the periparturient females and during the beginning of lactation is explained by the priority that reproduction has over immunity and in moments of insufficiency of food the former is privileged. These females have great protein demands and the supplementation in these stages reduces the epg (Coop and Kyriazakis, 2001). That is to say, the immune break down is caused by the greater importance that reproduction has over immunity. Therefore, if immunity is "penalized" in moments of deficiency, these functions will be benefited when supplemented with proteins, reducing the epg, burden and fecundity of parasites. The protein supplementation in these cases is clearly remarked as a good antiparasitical non-chemical control method. In an experimental study it was observed that when removing one of the

lambs in twin-sheep the count of epg and the parasite burden was reduced in one week and in more than 50%, reaching the lowest levels of the supplemented sheep (Houdijk *et al.*, 2006).

The degree of genetic resistance of the host can influence the response to food supplementation (Coop and Holmes, 1996; Kahna *et al.*, 2000). The benefits of a superior genotype are not lost in a diet poor in proteins while a diet rich in proteins can help a sensitive genotype to overcome the infection (Coop and Holmes, 1996). In a study of Bricarello *et al.* (2005) it was demonstrated that breeds of sheep that were genetically more resistant reacted better than the sensitive breeds to an increase in the dietary protein when they were experimentally infected with *H. contortus*. Although both breeds resisted better the infection when increasing the protein in the diet, the resistant breed was the only one that showed a reduction in the parasite burden.

The nutritional levels that are poor in energy and proteins affect the immune response mediated by cells. Both the number and the morphology of the effector cells are severely affected. In the nutritional levels abruptly reduced as in those kept permanently low, a reduction in the phagocytosis, in the complement system and in the opsonisation can be observed. The alteration of the humoral immunity in malnutrition cases is the indirect result of the depression in the cellular response (Nari and Fiel, 1994). In parasite infections, the role of the T helper lymphocytes seems to be important in the immune response (Koski and Scott, 2001).

In an experimental work conducted by Gennari *et al.* (1995), the group of calves that consumed a diet with high protein content showed a lower parasite burden, less clinical signs and less biochemical and hematological alterations than the group of animals maintained with a low protein level.

Similar observations were made by Knox and Steel (1996) and by Coop and Kyriazakis (2001). The first authors observed, however, that more than the protein content in the diet what seemed to have more influence would be the immunity level previously acquired. Despite this, the level of proteins in the diet would indeed be important in sheep parasited by *F. hepatica* and *H. contortus*.

The reduction of immunity around parturition has nutritional bases. As the immune functions are expected to use metabolizable protein, a breakdown of immunity is produced in shortage moments. Females around parturition privilege milk production to the expression in immunity (Houdijk *et al.*, 2003, 2005). In a work conducted by Houdijk *et al.* (2003), it was observed that increasing the protein value from 190 to 330 g/day in lactating ewes infected with *O. circumcincta* the count of epg declined but not the total parasite burden, while in 2005 the same author performed an experiment in which an increase in the supplementation with metabolizable protein in sheep in the period next to parturition reduced the count of epg in the faeces and the parasite burden. A 5% difference in the dry matter intake was observed, with the associated reduction in the ingestion of metabolizable energy when comparing animals fed with food with high and low protein value. The milk production improved with the first increase of metabolizable proteins (from 184 to 273 g/day) but not with the last ones (from 273 to 376 g/day). The epg count declined as the protein supplementation increased (Houdijk *et al.*, 2003). The resistance to *H. contortus* can be altered if the proteins offer is less than 30 g/kg of dry matter, which produces weight loss at the beginning and later an immunological break down (Coop and Holmes, 1996).

The increase in the offer of proteins seems to affect the expulsion of already established adults rather than to avoid the

acquisition of the infection with *T. colubriformis* (Kahna *et al.*, 2000). Besides, the establishment of the abomasal and intestinal larvae seems to be independent from the protein offer (Coop and Holmes, 1996; Kahna *et al.*, 2000). Chronical haemonchosis during periods of poor alimentation would indicate that there exists an association between nutrition and the already established infections. Animals to which the protein level of the diet was improved showed a clinical improvement; they reduced the epg count and were more resistant to re-infection than those that were kept on a basal diet (Coop and Holmes, 1996).

The emergence of the "arrested" larvae in the abomasum could have nutritional basis, as it occurs in a moment when the forage offer is poorer, which leads to a lower expression of immunity (Coop and Kyriazakis, 2001).

The protein supplementation affects various effectors of the immune response. In parasited animals that are supplemented with proteins, the number of eosinophils and other leukocytes, mast cells and proteases from the mast cells increase in the mucosa of the gastrointestinal tract. Some components of the immune response such as mucoproteins, leukotrienes, cytokines and immunoglobulins have a disproportionate demand of certain amino acids. The intestinal mucus is rich in serine, threonine and proline, while leukotrienes are rich in cysteine. Sheep that were parasited with *T. colubriformis*, when fed with methionine protected of ruminal degradation, showed an increase in the immune response by the increase in the mast cells and leukocytes (Coop and Kyriazakis, 2001).

There is enough evidence to consider that the macro-minerals and the trace elements influence the parasite-host relationship. As it was previously mentioned, the intestinal infections with nematodes reduce the absorption of phosphorus, the retention of phosphorus

and the mineralization of the skeleton. The increase of this mineral in the diet of lambs that received L3 of *T. vitrinus* raised the weight gain. The burden of *T. vitrinus* and the egg count was greater in the animals that received the low phosphorus diet (Coop and Holmes, 1996). The administration of phosphorous to *T. vitrinus*-parasited sheep reduced the egg count in 55% and the total parasite burden in 89% (Coop and Kyriazakis, 2001). Other studies have shown that the administration of copper before the infection with *H. contortus* and *O. circumcincta* reduced the establishment of the nematodes in 96 and 56%, respectively, although no effect was observed in the establishment of *T. colubriformis* (Coop and Holmes, 1996; Coop and Kyriazakis, 1999). According to Dimander (2003), the administration of copper capsules to sheep reduced the establishment and development of parasites in the abomasum. The ionic copper released by the acid of the mucosa would be the responsible of the anthelmintic effect. However, no increase in the parasite burden was observed in hypocupremic animals (Coop and Kyriazakis, 1999). The addition of molybdenum to the diet of sheep infected with *T. vitrinus* or *H. contortus* reduced the populations of these parasites in 23 and 78%, respectively. Molybdenum is an oligoelement that affects the parasite populations disturbing the metabolism of the parasites or indirectly increasing the immune response of the mucosa (Coop and Holmes, 1996; Coop and Kyriazakis, 2001).

The selenium deficiency does not seem to affect the resistance to parasites while the deficiency of cobalt induces greater egg counts and increased levels of pepsinogen in lambs infected with *O. circumcincta* (Coop and Holmes, 1996). Zinc is known to be an essential element that affects the development and integrity of the immune system (Brãzao *et al.*, 2008; Coop and Kyriazakis, 2001).

The optimization of the ruminal function increases the microbial protein production

and offers greater amounts of protein to digest and absorb in the intestine. The inefficient ruminal function produces an increase in the heat production, which reduces the intake of food. The supplementation of low quality food with urea as a non-proteinaceous nitrogen source can reduce the level of infection and the effects of the nematodes. This response is somehow due to the urea stimulation effect over appetite. Urea also increases the microbial protein production and the degradation of organic matter by the ruminal micro-organisms (Coop and Holmes, 1996; Knox *et al.*, 2006). The pathogenicity of *H. contortus* can be reduced by adding urea (60 g/kg of dry matter) to the basal ration. Coop and Kyriazakis (2001) observed that parasited animals whose diets were supplemented with urea showed less parasite burdens and less biochemical and hematological alterations. Although the response is lower than that obtained with high quality protein, it is to be considered in places where obtaining such proteins is impossible.

Plants used to feed animals can affect their health not only as an alimentary source but also as a source of certain antiparasitic substances. It is well known that tannins can produce this effect; however, similar results can be obtained with a variety of other substances. *Xylopia aethiopica*, a tree found in Nigeria, is an example of this. An extract of its seeds is used as a vermifuge of round worms. Doses of 0.8 g/kg, 1.0 g/kg, 1.2 g/kg, 1.4 g/kg, 1.7 g/kg and 2.0 g/kg of such extract produce deparasitization of 21%, 47%, 51%, 50%, 63% and 76% respectively in treated rats, compared to controls (Suleiman *et al.*, 2005).

Tannins are found in many of the plants that are part of the diet of herbivores and their concentration can affect the parasite population (Athanasiadou *et al.*, 2005; Coop and Kyriazakis, 200; Nguyen *et al.*, 2005; Tzamaloukas *et al.*, 2005). Their concentration ranges from 5% in some tropical leguminous to 50% of the dry matter in some

other tropical plants (Coop and Kyriazakis, 2001). These substances are related to the plants' defences against insects and herbivores, and can cause either beneficial or undesirable effects on those animals that feed on them (Athanasidou *et al.*, 2000; Coop and Kyriazakis, 2001). The major benefit of the tannins of the plants is the protection of proteins against the ruminal degradation, enabling the digestion and absorption in the abomasum and intestine (Coop and Kyriazakis, 2001; Nguyena *et al.*, 2005). They are usually divided into hydrolysable and condensed tannins (CT), although there are other types. The CT are relatively stable in the digestive tract of the animals and they rarely have toxic effects and are, therefore, used to control parasite populations (Coop and Kyriazakis, 2001). The CT are the most frequent type of tannin found in leguminous and trees (Min *et al.*, 2003). The tannins bind themselves to proteins and other compounds in a reversible way in relation to the pH (Coop and Kyriazakis, 2001; Muturi *et al.*, 2005). They can form complexes with proteins, polysaccharides, nuclear acids and minerals. Although they interact with carbohydrates, particularly with starch, their affinity for carbohydrates is lower than for proteins. The complexes with proteins are influenced by the pH and the molecular weight of both. They bind to proteins in a pH close to neutrality, which is the case of the rumen, dissociating themselves in the acid pH of the abomasum to be digested (Muturi *et al.*, 2005). The complexes also dissociate in the intestine due to the bile acids that act as surfactants (Athanasidou *et al.*, 2000). This reaction can be used to reduce the protein degradation in the rumen without reducing the microbial protein synthesized. The tannins in *Lotus corniculatus* and *Hedysarum coronarium* can be used to increase the absorption of essential amino acids in the intestine. Yet, not all of the tannins found in plants produce such increase. This would be related to the structure of the tannins themselves (Coop

and Kyriazakis, 2001; Min and Hart, 2003).

The tannins in the plants have both direct and indirect effects over the gastrointestinal parasites (Coop and Kyriazakis, 2001; Min and Hart, 2003; Hoste *et al.*, 2006). The direct effects could be caused by the tannin-parasite interaction, affecting the parasite's physiology. The tannins extracted from several forages reduce the total nematode burden, the migration, the viability of the larvae and the egg count. They can also interfere with the hatching of the eggs and the development of infective larval stages (Athanasidou *et al.*, 2001, 2005; Nguyena *et al.*, 2005). The CT of *quebracho* had a direct anthelmintic effect when they were given to sheep parasited by *T. colubriformis*. A reduction in the adult parasite burden, in the egg count and in the parasite females' fecundity *per capita* was observed (Athanasidou *et al.*, 2000).

Indirectly, tannins act improving the protein nutrition by binding themselves to the proteins of the plants in the rumen and preventing the microbial degradation, thus increasing the offer of amino acids to the duodenum (Athanasidou *et al.*, 2000; Coop and Kyriazakis, 2001; Nguyena *et al.*, 2005). The administration of quebracho extract during three days (8% of the intake) reduced the egg count, the adult burden and the fecundity of *T. colubriformis* (Athanasidou *et al.*, 2001). The ideal tannin concentration would be somewhere around 20-40g/kg of dry matter, level in which they bind themselves to the diet proteins during chewing. A tannin concentration higher than 50g/kg of dry matter can transform them into anti-nutritional factors with adverse effects both on food ingestion and on ruminal function (Nguyena *et al.*, 2005). Lambs infected with *T. colubriformis* had higher daily live weight gains, lower egg counts and lower parasite burdens when they pastured the Mediterranean leguminous *H. coronarium* (12% CT) than when they pastured leguminous without CT. Similarly, lambs naturally exposed to nematodes had

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a better performance and lower parasite burdens when pasturing *H. coronarium* or *L. pedunculatus* with 8% and 9% CT, respectively, than leguminous without CT (*Lolium perenne* and *Trifolium repens*). Recent experiments suggest that the addition of *quebracho* tannins to diets with low protein levels can improve the diet quality and reduce the consequences of parasitism (Coop and Kyriazakis, 2001).

Besides the beneficial effects, the CT have undesirable ones: they reduce the voluntary intake and digestibility, due to the enzymatic and microbial inhibition (Coop and Kyriazakis, 2001). The reduction in the intake could be due to the poor palatability of the plants containing tannins. The presence of tannins can reduce the action of trypsin and amylase in the small intestine of the ruminants. This does not always happen, however, because both the presence and the structure of the tannins influence their biological activity (Nguyena *et al.*, 2005). Quebracho extract increases the water content in the faeces, reduces the digestibility of food and increases the faecal volume. This was observed when administered in high protein diets (220 g/kg humid matter), not happening in low proteins diets (97 g/kg humid matter) (Athanasiadou *et al.*, 2000).

The polyunsaturated fatty acids (PUFA), especially omega-3 (Ω -3) and omega-6 (Ω -6), are diet compounds with important immunomodulating effects. The diet with a supplement rich in Ω 3 (fish oil) can influence the cellular mediators of the response to the parasitic infections. The reduction in the Ω -6/ Ω -3 relation can be an immunonutritional strategy to improve the reaction to parasites. The eicosanoids are key molecules in the regulation of the inflammatory response of the intestinal mucosa. In the early age, the Ω -3 can stimulate a better immune response against the gastrointestinal nematodes promoting a more balanced secretion of the Th1 and Th2 mediators. The inclusion of Ω -3 can reduce the severity of infection. They

are also thought to reduce the maturation of the nematodes, as a greater number of immature worms can be observed in diets containing these compounds, which suggests that they can inhibit the maturation of the L3. The weight gain in animals that consume Ω -3 was greater than that of the controls in some experiments (Muturi *et al.*, 2005). The supplementation with fish oil increased the levels of proteinases of the mast cells and the number of circulating eosinophils. These changes, however, were not accompanied by the increase of specific and non-specific antibodies, which suggests a minor role in the serum response to gastrointestinal parasites (Coop and Kyriazakis, 1999).

CONCLUSIONS

Animal protein has generally been considered an essential component of human diet and animal production a crucial activity. This is even more evident these days if we think of the world spread protein malnutrition and its consequences.

Nutrition and parasites are two of the various difficulties animal producers have to face in order to optimize performance. Even though they might seem different areas of animal production, the relation between parasites and nutrition is extremely close and delicate. This interaction may produce negative consequences for the animals but its understanding, rationally used, can represent a very interesting alternative to improve animal production.

Nutrition is an essential feature in any production system. Not only does a good nutrition enhance *per se* the animal's general status and productive parameters but it also, by improving the immune response and decreasing the presence and consequences of parasites, helps to avoid the economic losses.

Parasites have a negative effect on animal health, producing deaths or reducing their performance, and therefore are a major

threat of animal production.

The resistance of parasites to antihelminthic drugs and the concern about the presence of residues in production animals is leading scientists to look for non-pharmacological means of control (Athanasidou *et al.*, 2001). The rotation with agriculture production (Stuedemann *et al.*, 2003) and between sheep and bovines, that reduce the larvae burden in the pasture, and the selection of genetically resistant animals (considering the egg count) are some non-chemical alternatives in the anthelmintic management (Romero and Boero, 2001; Larsson *et al.*, 2006; Marley *et al.*, 2006). Supplementary feeding can improve the nutritional level of the animal and has the additional benefit of reducing the exposure to infective larvae on pasture by replacing herbage intake with

supplement (Larsson *et al.*, 2006).

Both the amount and the quality of the consumed food are closely connected to the presentation of the parasitosis in ruminants. Knowing the ways in which nutrition and parasite infections are related, it is easily understood that the important problem that the parasitic diseases and their consequences represent in animal production can be resolved or reduced by an adequate and rational nutritional management.

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