

Original Research Paper

# Correlates of Resistance to Gastro-Intestinal Parasites Infection in South African Communal Indigenous Goat Populations

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**Abstract:** The study was conducted to investigate the correlates of resistance to Gastro-Intestinal Parasites (GIPs) infection in South African communal indigenous goat. A total of 288 goats were randomly sampled for fecal and blood collection. Infection intensity was estimated through determining the fecal egg per gram using a modified McMaster technique. Packed Cell Volume (PCV), Hemoglobin (Hgb) and Mean Corpuscular Hemoglobin (MCH) were determined through Auto-Haematology-Analyser BC-2800Vet®. Goat diagnosed free from GIP egg during coprologic evaluation were classified as uninfected, those whose Fecal Egg Count (FEC) were less than 800 as Low Fecal Count (LFEC) phenotype, those with FEC between 800 and 1200 as Intermediate Fecal Egg Count (IFEC) and those that were higher than 1200 as High Fecal Egg Count (HFEC) phenotype. Data were subjected to one-way ANOVA analyses, for dual co-infection, not all comparisons were possible. Pearson's moment correlation test was computed to determine the relationship between variables. The HFEC phenotyped goats were highly ( $p < 0.05$ ) infected by GIPs followed by intermediate and lastly by LFEC phenotype. Higher ( $p < 0.05$ ) Hgb (10.26 g/dL), PCV (28.51%) and MCH (6.12 pg) were observed in uninfected goats compared to IFEC and HFEC phenotypes. A significant effect of infection status on Hgb and PCV was observed, however, MCH was not influenced ( $p > 0.05$ ). There was a negative relationship ( $p < 0.05$ ) between the Hgb and overall FEC, strongyles and *Trichuris* spp. intensity. Negative relationship ( $p < 0.05$ ) between PCV and overall FEC and all the GIPs except for *Moniezia* spp. intensity was evident. The MCH depicted a negative relationship ( $p < 0.05$ ) with *Eimeria* and *Trichuris* spp. intensity. The interactions between concomitant GIPs complicates the clinical outcome of infected goats and should be taken into consideration in any study that investigates disease under field conditions. The FECs, Hgb, PCV and MCH are correlates and potential selection criteria of GIP resistant goats.

**Keywords:** *Capra hircus*, Hemoglobin Concentration, Mean Corpuscular Hemoglobin, Packed Cell Volume, Strongyle, *Trichuris* spp.

## Introduction

Goats (*Capra hircus*) are found to be highly susceptible to Gastro-Intestinal Parasite (GIP) infections (Singh *et al.*, 2017; Mpofu *et al.*, 2020) often leading to clinical diseases and loss of productivity (Risso *et al.*, 2015; Rodríguez *et al.*, 2015) and in extreme conditions, even death (Jegade *et al.*, 2015). The most prevalent GIPs affecting goats in Africa are the *Strongyloides*

*papillosus*, *Moniezia*, *Trichuris*, *Eimeria* spp. and strongyles, especially the *Homonchus contortus*, *Trichostrongylus* spp. belonging to the order Strongylida (Blackie, 2014; Verma *et al.*, 2018; Mpofu *et al.*, 2020). Their prevalence varies with location/agro-ecological zones and ranges up to 90% and have been documented in various studies in Africa (Adeyemi *et al.*, 2017; Zvinorova, 2017; Hassan *et al.*, 2019; Squire *et al.*, 2019; Mpofu *et al.*, 2020). The primary control strategy for the

GIP infections is the use of anthelmintic drugs (Maqbool *et al.*, 2017), which is not sustainable because the GIP, especially the nematodes, develop anthelmintic drug resistance more quickly (Kelley *et al.*, 2016; Erez and Kozan, 2018). The increasing prevalence of anthelmintic resistance in GIPs suggests that reliance on chemotherapy is unsustainable, therefore, alternative control measures to either reduce or eliminate the current dependency on chemotherapy are needed. A relatively simple and cheap method of reducing the effects of GIPs infection would be the selection and breeding of genetically GIP resistant animals (Baker, 1999; Bishop and Stear, 1999).

The natural variation in resistance to GIP infections is under genetic control (Benavides *et al.*, 2016; Aboshady *et al.*, 2020). The resistance is associated with variation in the key genes that control the immune system (Stear *et al.*, 2004; Bressani *et al.*, 2014). Several potential indicators such as parasitological, immunological and pathological (hematological parameters) phenotypic markers can be used to evaluate resistance to GIPs (Dominik, 2005). Parameters such as Fecal Egg Count (FEC) (Hayward *et al.*, 2014) and Packed Cell Volume (PCV) (Saddiqi *et al.*, 2012; Zvinorova, 2017) have been found to be repeatable, heritable, responsive to selection and simplest indicators of blood-sucking parasites. The FEC heritability as a measure of resistance ranges between 0.14 and 0.40 depending on both nematode species and breed surveyed (Gruner *et al.*, 2004; Bishop and Morris, 2007). Resistant goats tend to have lower FECs, by approximately 50% (González *et al.*, 2011; Zvinorova, 2017) than the susceptible goats. The FECs should not be used as a stand-alone diagnostic tool to determine the severity of parasite infection (Hepworth *et al.*, 2006; Saddiqi *et al.*, 2012), other resistance phenotypic indicators should also form part of the diagnostic tool for resistance. Most of the GIPs (especially strongyles) are active blood suckers, the heavy parasitic burden often results in anemia (Burden *et al.*, 2010). Packed cell volume, hemoglobin (Hgb) concentration and Mean Corpuscular Hemoglobin (MCH) are substantive indices in the diagnosis of anemia (Awodi *et al.*, 2005; Chineke *et al.*, 2006; Peters *et al.*, 2011), therefore, can be used as response phenotypic predictors of GIPs infection intensity and whether an animal is resistant or not. Animals with lower values are considered anemic (Aster, 2004; Peters *et al.*, 2011) as the clinical sign of high parasite infection. However, there is a paucity of information on the use of Hgb concentration and MCH as phenotypic predictors for GIP infection intensity in ruminants.

There is currently a paucity of information on the resistance and resilience status of the South African communal goats to GIPs as well as reliable phenotypic markers, correlates of such resistance and resilience. With a view to identifying reliable phenotypic markers

that can be used as selection criteria for the GIP resistant animals, this research was therefore conducted to investigate the correlates of resistance to GIPs infection in South African communal goat populations.

## Materials and Methods

### *Ethical Approval*

The study was approved by the Animal Research Ethic Committee of the Faculty of Science, Tshwane University of Technology [FCRE 2017/10/01 (02) (SCI)].

### *Study Site*

A total of 288 South African indigenous goats (male = 101 and female = 274) were randomly sampled in a longitudinal study during winter (June – July) and summer (November – December) in communal areas of the Kwa-Zulu Natal, Limpopo and Mpumalanga provinces, South Africa. The sample size was determined using Equation 1 (Thrusfield, 1997), the required sample size was calculated to be 288 goats for each set of the season. The animals were kept under extensive grazing systems where during the day they were released to graze on communal lands and kraaled at night. Goats were naturally infected with the GIP when grazing and there was no artificial infection of the GIP to goats. The flocks considered were those with no history of GIP treatment. The flocks were classified by age as an adult (>2 years), young goat (1-2 years) and suckling kids (<1 year) as described by Kheirandish *et al.* (2014):

$$n = \frac{1.96^2 pq}{L^2} \quad (1)$$

where,  $n$  = sample size,  $p$  = expected prevalence,  $q = 1-p$  and  $L$  = limits of error on the prevalence. Because the prevalence in the local goat population was unknown, the hypothesized prevalence of 75% was used with a 5% limit of error of the prevalence.

### *Sample Collection*

About 10 g of fecal and 10 mL blood samples of each sampled animal were obtained directly from the rectum and the jugular vein, respectively. The collected fecal samples were placed into airtight containers and labelled, whilst, the blood samples were collected by venipuncture into the EDTA VACUETTE® tubes and labeled. Samples were kept between 2-4°C in cooler boxes prior and later refrigerated prior to analyses and transported to the laboratory for further coprological and hematological examination within 24 h.

### *Fecal Sample Analyses*

The fecal samples were subjected to a quantitative examination of the GIPs. The FEC measured as egg

(EPG) or Oocyst Per Gram (OPG) was determined through a modified McMaster technique as described by Hansen and Perry (1994) in the positive fecal samples. Briefly, approximately 2 g of feces were placed in a beaker. Then 50 mL of floatation fluid was poured into the beaker containing 2 g of feces and mixed thoroughly. The resulting fecal suspension was poured through a tea strainer into another beaker. After rough shaking, 200  $\mu$ L was withdrawn and run into the counting chambers. About 1 minute between preparation and counting was allowed for the eggs or oocysts to float to the top of the slide, placed on a microscope slide and examined under the microscope ( $\times 10$ ). Three (3) samples were counted for each animal and the mean EPG or OPG of feces was calculated. The floatation fluid used was NaCl. The GIPs were identified under a compound microscope ( $\times 10$ ) based on the morphological appearance and size of helminth eggs and protozoa cysts and trophozoites (Foriet, 1999; Zajac and Conboy, 2006). The fecal samples were ground into five drops of bloat guard to prevent bubbles when counting the eggs, each count was multiplied by 100 and give an estimation number of eggs in the animal system (Aumont *et al.*, 2003). Fecal cultures were prepared by incubating 2-3 g of feces between 26-28°C for 7 days at 80% humidity after which infective larvae were collected using a modified Baerman technique. L3-stage nematodes were identified according to the protocol proposed by Van Wyk *et al.* (2004). *Eimeria* species were identified following the sporulation of oocysts within the feces in a thin layer of 2.5% potassium dichromate for 1 week between 26-28°C. The identification of *Eimeria* species was based on morphological characteristics of oocysts (size, shape, color and presence or absence of a micropyle and its cap). The PCV, Hgb concentration and MCH were estimated using an Auto Haematology Analyzer BC-2800Vet® (Shenzhen Mindray Bio-Medical Electronics Co., Ltd, Hamburg, Germany).

### Study Design

To be consistent with epidemiological terminologies, in this study, the intensity is defined as the total number of worms in a host digestive system, the intensity is zero when a host has no GIP (Cattadori *et al.*, 2008) and this contrasts with the definition suggested by Bush *et al.* (1997). After the sample analysis, animals were categorically assigned into four respective response phenotypes namely, uninfected group, Low FEC (LFEC), Intermediate FEC (IFEC) and High FEC (HFEC) phenotype based on their individual FEC as described by Asha and Chebo (2015) with slight modification. Goats diagnosed free from any of the GIP egg or oocyst during the coprological evaluation were classified as uninfected, those whose FEC did not exceed 800 as LFEC phenotype, those that exceed 1200, as HFEC phenotype

and those with FEC between 800 and 1200 as IFEC. For dual co-infection, very few animals were co-infected with *Eimeria* and *Moniezia* spp., *S. papillosus* and *Moniezia* spp., *Moniezia* and *Trichuris* spp., not all comparisons were possible, only three dual co-infections were possible in addition to three single infections.

### Statistical Analysis

The FECs for all GIPs found were transformed through a base 10 logarithm ( $\log_{10}\text{FEC}+25$ ) to approximate a normal distribution. The transformed data were used for statistical analysis. The infection intensity and hematological parameters data were subjected to one-way ANOVA analyses through the MiniTab 17 (2017). The FEC transformed data and the results were then back-transformed by taking anti-logarithms and presented as geometric means. Means were separated using Fisher's Protected LSD test ( $p < 0.05$ ). Pearson's moment correlation test was computed to determine the relationship between the hematological parameters and FECs of individual GIPs ( $p < 0.05$ ).

### Results

The mean FEC and hematological parameters of South African communal goats segregated into LFEC, IFEC and HFEC phenotypes are presented in Table 1. The results indicate a highly significant difference ( $p < 0.05$ ) in the FECs for strongyles, *S. papillosus*, *Trichuris*, *Eimeria* and *Moniezia*, spp. within the phenotypes. The pattern of the FECs intensity depicted that HFEC phenotyped goats were highly ( $p < 0.05$ ) infected by the strongyles, *S. papillosus*, *Trichuris*, *Eimeria* and *Moniezia*, spp. followed by intermediate and lastly by LFEC phenotype.

Results also indicated that the difference between the Hgb concentration, PCV and MCH was highly significant ( $p < 0.05$ ) between the phenotypes. The uninfected goats had higher Hgb concentration (10.26 g/dL), PCV (28.51%) and MCH (6.12 pg) compared to the intermediate (Hgb concentration: 9.17 g/dL, PCV: 25.45%, MCH: 5.20 pg) and HFEC (Hgb concentration: 8.40 g/dL, PCV: 23.15%, MCH: 5.20 pg) phenotypes. However, the PCV and MCH of the uninfected group were similar ( $p > 0.05$ ) to that of the LFEC phenotyped goats. The Hgb concentration of LFEC (8.17 g/dL) and HFEC (8.40 g/dL) phenotypes was similar ( $p > 0.05$ ). The HFEC phenotyped goats had lower values of the Hgb concentration (8.40 g/dL), PCV (23.15%) and MCH (4.81 pg), respectively.

The impact of infection status (single vs co-infection) on hematological parameters of South African communal goats are presented in Table 2. There was a significant ( $p < 0.05$ ) effect of the infection status on the Hgb concentration and PCV, however, the MCH was not influenced ( $p > 0.05$ ). Goats co-infected with strongyles

and *Moniezia* spp., strongyles and *Trichuris* spp. resulted in lower ( $p < 0.05$ ) Hgb concentration (strongyles and *Moniezia* spp.: 8.71 and strongyles and *Trichuris* spp.: 8.64), PCV (strongyles and *Moniezia* spp.: 32.71 and strongyles and *Trichuris* spp.: 26.89) and MCH (strongyles and *Moniezia* spp.: 31.24 and strongyles and *Trichuris* spp.: 31.19) compared to those co-infected with strongyles and *S. papillosus* and the single infections.

Pearson's moment correlation test between the GIPs intensity and the hematological parameters in South African communal goats are presented in Table 3. There was a significant negative relationship between the Hgb concentration and overall FEC ( $r_p = -0.45$ ,  $p < 0.01$ ), strongyles ( $r_p = -0.52$ ,  $p < 0.01$ ) and *Trichuris* spp. ( $r_p = -0.66$ ,  $p < 0.001$ ). However, the Hgb concentration depicted insignificant negative relationship with *S. papillosus* ( $r_p = -$

0.06,  $p > 0.05$ ), *Eimeria* spp. ( $r_p = -0.07$ ,  $p > 0.05$ ) and the positive insignificant relationship with *Moniezia* spp. ( $r_p = 0.02$ ,  $p > 0.05$ ). There was also a significant negative relationship between the PCV and overall FEC ( $r_p = -0.55$ ,  $p < 0.01$ ), strongyles ( $r_p = -0.70$ ,  $p < 0.001$ ), *Trichuris* ( $r_p = -0.59$ ,  $p < 0.01$ ), *S. papillosus* ( $r_p = -0.39$ ,  $p < 0.05$ ) and *Eimeria* spp. ( $r_p = -0.26$ ,  $p < 0.05$ ), however, insignificant positive relationship between the PCV and *Moniezia* spp. ( $r_p = 0.17$ ,  $p > 0.05$ ) was observed. The MCH depicted also a significant negative relationship with overall FEC ( $r_p = -0.13$ ,  $p < 0.05$ ), *Eimeria* ( $r_p = -0.50$ ,  $p < 0.01$ ) and *Trichuris* spp. ( $r_p = -0.21$ ,  $p < 0.05$ ). A significant positive relationship between MCH and *Moniezia* spp. ( $r_p = 0.19$ ,  $p < 0.05$ ) was observed, however, the insignificant negative relationship was also noticed between the MCH and strongyles ( $r_p = -0.12$ ,  $p > 0.05$ ) and *S. papillosus* ( $r_p = -0.14$ ,  $p > 0.05$ ).

**Table 1:** Mean ( $\pm$  SE) egg per gram of gastro-intestinal parasites and hematological parameters of South African communal indigenous goats

Parameters	Uninfected goats	Fecal egg count response phenotypes		
		Low FEC	Intermediate FEC	High FEC
Overall FEC	0	504.66 <sup>c</sup> $\pm$ 14.1	1021.85 <sup>b</sup> $\pm$ 19.8	1654.13 <sup>a</sup> $\pm$ 20.7
Strongyles	0	208.05 <sup>c</sup> $\pm$ 14.4	415.97 <sup>b</sup> $\pm$ 20.2	560.55 <sup>a</sup> $\pm$ 21.1
<i>Strongyloides papillosus</i>	0	75.42 <sup>c</sup> $\pm$ 11.0	129.41 <sup>b</sup> $\pm$ 15.6	257.80 <sup>a</sup> $\pm$ 16.2
<i>Trichuris</i>	0	79.66 <sup>c</sup> $\pm$ 12.1	152.10 <sup>b</sup> $\pm$ 17.0	243.12 <sup>a</sup> $\pm$ 17.8
<i>Eimeria</i>	0	69.92 <sup>c</sup> $\pm$ 11.4	165.55 <sup>b</sup> $\pm$ 16.1	300.00 <sup>a</sup> $\pm$ 16.8
<i>Moniezia</i>	0	71.61 <sup>c</sup> $\pm$ 9.27	158.82 <sup>b</sup> $\pm$ 13.1	292.66 <sup>a</sup> $\pm$ 13.6
Hemoglobin concentration (g/dL)	10.26 <sup>a</sup> $\pm$ 0.19	8.71 <sup>bc</sup> $\pm$ 0.28	9.17 <sup>b</sup> $\pm$ 0.27	8.40 <sup>c</sup> $\pm$ 0.28
PCV (%)	28.51 <sup>a</sup> $\pm$ 0.41	27.95 <sup>a</sup> $\pm$ 0.57	25.45 <sup>b</sup> $\pm$ 0.60	23.15 <sup>b</sup> $\pm$ 0.59
MCH (pg)	6.12 <sup>a</sup> $\pm$ 0.17	5.63 <sup>ab</sup> $\pm$ 0.24	5.20 <sup>bc</sup> $\pm$ 0.25	4.81 <sup>c</sup> $\pm$ 0.25

<sup>a, b, c</sup> Row means with different superscripts differs significantly ( $p < 0.05$ ); FEC: Fecal Egg Count; PCV: Packed Cell Volume; MCH: Mean Corpuscular Hemoglobin

**Table 2:** Impact of infection status (single vs dual co-infection) on hematological parameters of communal indigenous goats

Infection status	Hematological parameters		
	Hemoglobin concentration (g/dL)	PCV (%)	MCH (pg)
Strongyles	9.84 <sup>a</sup> $\pm$ 0.36	25.63 <sup>a</sup> $\pm$ 1.52	6.11 <sup>a</sup> $\pm$ 0.59
<i>Strongyloides papillosus</i>	9.69 <sup>a</sup> $\pm$ 0.74	25.22 <sup>a</sup> $\pm$ 1.52	6.10 <sup>a</sup> $\pm$ 1.01
<i>Trichuris</i>	9.28 <sup>a</sup> $\pm$ 0.62	23.31 <sup>b</sup> $\pm$ 1.27	6.09 <sup>ab</sup> $\pm$ 0.87
Strongyles/ <i>Strongyloides papillosus</i>	9.94 <sup>a</sup> $\pm$ 0.50	25.78 <sup>a</sup> $\pm$ 1.02	6.05 <sup>b</sup> $\pm$ 0.73
Strongyles/ <i>Trichuris</i>	8.64 <sup>a</sup> $\pm$ 0.54	22.89 <sup>b</sup> $\pm$ 1.12	6.04 <sup>b</sup> $\pm$ 0.78
<i>Strongyloides papillosus</i> / <i>Trichuris</i>	8.98 <sup>a</sup> $\pm$ 0.74	22.19 <sup>b</sup> $\pm$ 1.52	6.08 <sup>ab</sup> $\pm$ 0.87

<sup>a, b</sup> Row means with different superscripts differs significantly ( $p < 0.05$ ); FEC: Fecal Egg Count; PCV: Packed Cell Volume; MCH: Mean Corpuscular Hemoglobin

**Table 3:** Pearson's moment correlation test between the gastro-intestinal parasites intensity and the hematological parameters in South African communal goats

	Hemoglobin concentration (g/dL)	PCV (%)	Mean corpuscular hemoglobin (pg)
Overall FEC	-0.45**	-0.55**	-0.13*
Strongyles	-0.52**	-0.70**	-0.12 <sup>NS</sup>
<i>S. papillosus</i>	-0.06 <sup>NS</sup>	-0.39*	-0.14 <sup>NS</sup>
<i>Trichuris</i>	-0.66***	-0.59**	-0.21*
<i>Eimeria</i>	-0.07 <sup>NS</sup>	-0.26*	-0.50**
<i>Moniezia</i>	0.02 <sup>NS</sup>	0.17 <sup>NS</sup>	0.19*

\* $p > 0.05$ , \*\* $p > 0.01$ , \*\*\* $p > 0.001$ , NS: Not Significant ( $p > 0.05$ ); FEC: Fecal Egg Count

## Discussion

The intensity of infection for the strongyles, *S. papillosus*, *Trichuris*, *Eimeria* and *Moniezia*, spp. was found to be lower in the LFEC phenotype than in the intermediate FEC and HFEC phenotype. This could be attributed to the fact that resistance to one GIP species was accompanied by resistance to some other GIPs or vice-versa (Behnke *et al.*, 2006). However, similar results had been previously reported, where there was a positive relationship between resistance to different GIPs in Nigerian West African Dwarf goats (Behnke *et al.*, 2006) and INRA sheep (Gruner *et al.*, 2003). Major effects of higher GIP infections on animals are severe anemia (Burden *et al.*, 2010) along with other hematological (Rasool *et al.*, 1995) and biochemical disturbances (Moudgil *et al.*, 2017). Furthermore, the hematological parameters were also lower in the HFEC phenotype compared to the uninfected group and LFEC phenotype, attributed to a greater load of GIPs sucking a substantial amount of blood, therefore, lowering these parameters. These findings accord with previous reports that the higher GIP infection intensity especially *H. contortus* leads to lower PCV (Ameen *et al.*, 2010; Saddiqi *et al.*, 2010; 2012; Moudgil *et al.*, 2017) and Hgb concentration (Audu *et al.*, 2018) in animals. Noteworthy, *H. contortus* infection in West African Dwarf goats resulted in a normochromic normocytic anemia attributed to blood loss caused by this GIP (Ameen *et al.*, 2010). However, contrary to the present findings, Ameen *et al.* (2010) observed similar normal Hgb concentrations and increased MCH values between the infected and uninfected West African Dwarf goats. The difference could be attributed to the breed and age of goat and more importantly, the prepatent period and duration of infection which consequently determines the response to infection. In parasitological sense, the prepatent period in GIPs infection is defined as the time elapsed between the infection and the first appearance of eggs in the feces (Hansen and Perry, 1994), which varies with the infection route, sex, age and degree of acquired resistance of the host (Ameen *et al.*, 2010). Animals may acquire immunity/resistance to the parasite through the frequent challenge (Shah-Fischer and Say, 1989; Singh *et al.*, 2015). Furthermore, Radostits *et al.* (2010) reported a difference in hematological parameters between weeks of post-infection in ruminants. Anemic goats with normal MCH values are referred to as normocytic normochromic. Therefore, the normocytic normochromic anemia observed here is consistent with other reports of anemia in cattle with strongyles infection (Audu *et al.*, 2018).

The reduction in the MCH of the HFEC phenotyped goats could be due to direct reduction in the level of Hgb concentration observed which might be ascribed to deficiency of iron (Cole *et al.*, 1997; Khan *et al.*, 2010)

attributed to blood loss due to GIPs infection (Soulsby, 1986; Katoch and Mandial, 2003; Radostits *et al.*, 2010). The depletion of iron hypothesized might also be due to the rapid depletion of iron stores by the bone marrow for Hgb production (Schalm, 1975; Khan *et al.*, 2010). The observed similar PCV and MCH of the uninfected group and LFEC phenotyped goats depicts that low infection intensity by the GIPs does not alter these hematological parameters. Reduced hematological parameters in IFEC and HFEC phenotyped compared to uninfected goats were also observed in cattle infected by the GIPs, especially the *Bunostomum* and *Trichostrongylus* spp. (Singh *et al.*, 2014).

The findings that the infection status (single vs co-infection) influences the hemoglobin and PCV concurs with earlier reports (Graham *et al.*, 2007; Vaumourin *et al.*, 2015) that interaction between concomitant parasites complicate the clinical outcome of the infected hosts and should be taken into consideration in any study that investigates disease under field conditions and disease management programme. Several mechanisms of direct and indirect interaction between co-infecting parasites have been proposed, but results remain ambiguous (Petney and Andrews, 1998; Murphy *et al.*, 2013; Vaumourin *et al.*, 2015). These interactions may be synergistic or antagonistic, wherein, one parasite can improve the immune response to a second parasite through cross-immunity (negative interaction) (Tabel *et al.*, 2013), or alternatively cause immuno-suppression (positive interaction) (Cox, 2001; Pedersen and Fenton, 2007). Such interactions can have important impacts on animal health since they can modify host susceptibility, infection duration and transmission risks (Petney and Andrews, 1998; Graham *et al.*, 2007; Vaumourin *et al.*, 2015). The literature on the structural or functional changes in animals with mixed infections is scanty (Brown *et al.*, 1989; Poulin, 2007) or making a logical judgment on the basis of circumstantial evidence and prior conclusions by comparing single to mixed infections than assessing the contributions of the single strains in the mixed infection.

*Eimeria* spp. single infection caused a slight decrease of PCV and hemoglobin of the goat population which was not clinically significant from those free of any GIP and may be due to the level of dehydration due to diarrhea. It would be interesting to investigate the association between *Eimeria* infection and other clinical parameters such as the presence or absence of diarrhea, in this population.

In the present study, the PCV strongly correlated with the FECs for the strongyles, *S. papillosus*, *Trichuris* and *Eimeria* spp. depicting that it can be used as a predictor of infection intensity by these GIPs. The present findings that the PCV has a negative significant correlation with overall FEC and strongyles confirms earlier reports (Kaplan, 2004; Scheuerle *et al.*, 2010). The present findings also concur with previous reports that the FEC

(Hayward *et al.*, 2014) and PCV (Saddiqi *et al.*, 2012; Zvinorova, 2017) are the most important phenotypic indicators of infection intensity and host resistance. Low values of PCV are commonly associated with high FEC attributed to the adult parasites sucking a substantial amount of blood from the abomasum (Saddiqi *et al.*, 2010; 2012). Practically, resistant animals show low FEC and high PCV.

The strongyles are recognized as active blood suckers in the stomach and intestine, subsequently, its infection causes a decrease in the value of Hgb concentration and PCV (Kumar *et al.*, 2015). The average blood loss due to *H. contortus* infection is 0.03 ml/parasite/day (Bordoloi *et al.*, 2012). The insignificant relationship between the MCH and the strongyles and *S. papillosus* intensity observed in the present study depicts that MCH is not a valuable indicator for the intensity and resistance against the strongyles and *S. papillosus*. The present findings that there is an insignificant relationship between the MCH and the strongyles and *S. papillosus* intensity concurs with earlier report wherein the lack of significance decrease in the MCH of infected animals (sheep) compared to uninfected animals had also been reported (Kumar *et al.*, 2015).

The findings that the MCH has a moderate and negative significant correlation with the intensity for the *Eimeria* depicts that the MCH is of great value and can be used as a valuable predictor for the *Eimeria* intensity in South African communal goats. Also, the observed moderate and negative significant correlation between the Hgb concentration and FECs for strongyles and *Trichuris* spp. depicts that hemoglobin concentration is also of great importance and can be used as a good predictor of infection intensity for these GIPs. The observed strong and insignificant relationship between the *Moniezia* spp. infection intensity with the Hgb concentration and PCV significantly underscore the value of these hematological parameters as potential parameters for assessing the intensity of *Moniezia* spp. in goats. However, there is a paucity of information on the use of Hgb concentration and MCH as phenotypic predictors for GIP infection intensity in animals.

## Conclusion

The results suggest that interactions between concomitant GIP complicates the clinical outcome of the infected goats and should be taken into consideration in any study that investigates disease under field conditions and disease management programme. The results suggest that the PCV and infection intensity are reliable measures for resistance against strongyles, *S. papillosus*, *Trichuris* and *Eimeria* spp. The Hgb concentration and infection intensity can be used as response phenotypic predictors for resistance against strongyles and *Trichuris*

spp. The MCH and infection intensity can be used as response phenotypic predictors for resistance against *Eimeria*, *Trichuris* and *Moniezia* spp. Thus, these response phenotypic predictors can be used as selection criteria for the GIP resistant South African communal indigenous goats.

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## Author's Contributions

**Takalani Judas Mpofu:** Participated in all experiments, coordinated the data-analysis and contributed to the writing of the manuscript.

**Khathutshelo Agree Nephawe and Bohani Mtileni:** Involved in the design of the study, coordinated all the work and constructive revision of manuscript.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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