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Effects of mannan oligosaccharide dietary supplementation on mortality, growth performance and carcass traits in meat Guinea pigs

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ABSTRACT
The effects of mannan oligosaccharide (MOS) as a dietary supplement on growth performance, carcass traits and mortality in meat guinea pigs were compared to a commonly used antimicrobial growth promoter (AGP, Zn-Bacitracin). The four experimental treatments were as follow: Control group (no additives); MOS 1 (1.5 g kg−1); MOS 2 (2 g kg−1) and AGP (0.1 g kg−1). The guinea pigs were housed in 40 floor pens containing a deep litter of woodchips ($n = 100$ animals in each trial; 10 animals per pen). Guinea pigs were all weaned on day 28 and their body weight was measured weekly. All animals were slaughtered at the end of fattening period (day 77) and carcass traits were evaluated. Significant differences against the control group were observed for traits studied ($P < 0.05$). Between MOS groups and AGP no significant differences were observed. In conclusion, the use of MOS could be a suitable replacement for antibiotic growth promoter to raise guinea pigs.

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KEYWORDS
Carcass; growth; Guinea pig; mannan oligosaccharides; mortality

1. Introduction

Guinea pigs (*Cavia porcellus*) are commonly used in scientific research for example to test experimental therapies in Ebola virus (Wong et al. 2018). However, in developing countries such as some South America and sub-Saharan Africa, as well as the Philippines, the meat of guinea pigs is an economic source of animal protein for the poorer and malnourished humans (Lammers et al. 2009).

Guinea pig meat production has many advantages. Guinea pigs have a small size and it can be kept on a small plot. In addition, a guinea pigs farm could be a valuable place to work for vulnerable groups as women or others unable find work. Also, such animals are mainly fed with forage and they are not a direct competitor to human beings for food resources like corn or wheat (Grongnet et al. 2013).

Antibiotics are used in both animals and humans. In livestock production, some drugs are used to treat sick animals, but large amounts have been used in feed to promote growth and increase feed efficiency (Dibner and Richards 2005). This misuse of antibiotics can cause an accumulation of residues in animals (meat, milk and eggs) and consequently, the increase of antibiotic resistance and allergies (Gonzalez and Angeles 2017). For these reasons, the World Health Organization and multiple countries have restricted the use of antimicrobials for growth promotion (AGP) and disease prevention in food animal production (WHO 2004; Maron et al. 2013).

Prebiotics could be substitutive of AGP used as feed additives in livestock (Papatsiros et al. 2013; Brown et al. 2017). Mannan oligosaccharide (MOS) is a prebiotic derived from the cell wall of yeast *Saccharomyces cerevisiae* (Sohn et al. 2000). MOS has shown positive effects in growth traits and immune response in animals as weanling pigs (Zhao et al. 2012; Valpotić et al. 2017), nursery pigs (Halas and Nochta 2012), pigs (Valpotić et al. 2018), dairy cattle (Tewoldebrhan et al. 2017), beef (Silva et al. 2017), poultry (Hooge 2004) or trout (Mínguez et al. 2016).

The objective of this study was to examine the effect of MOS compared to AGP (Zn-Bacitracin) as a dietary supplement on mortality, growth and carcass traits of meat guinea pigs.

2. Material and methods

Animals were reared and slaughtered in compliance with the regulations for the care and use of animals in research in the 'Código Orgánico del Ambiente' (ROS No 983, Ecuador).

2.1. Animals

The present study included 400 Criolla breed guinea pigs (Sánchez-Macías et al. 2018) distributed into two commercial farms (200 animals in each farm). The farms were located in Gualaceo (2°53′33.5″ S, 78°46′41.3″ O) and Cuenca (2°54′08″ S 79°00′19″ O), both in the province of Azuay (Ecuador). In each farm, the same experimental design was performed. Young guinea pigs were weaned on the 28th day, individually identified using small ear tags. The experimental groups (50 animals per group and farm) were created by balancing the weight at weaning, since an unbalanced initial weight could originate uneven feed intake within groups. The experimental treatments groups were: (1) Control Group (CG, commercial basal diet: Cuyes Engorde, BioALIMENTAR Cía. Ltda); (2) MOS

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1.5 (Bio-Mos® at 1.5 g kg−1); (3) MOS 2 (Bio-Mos® at 2 g kg−1) and (4) AGP (Zn-Bacitracin at 0.1 g kg−1).

Experimental diets were manufactured by combining the commercial basal diet with the different additives. Bio-Mos® is a mannan oligosaccharide (MOS) derived from the outer cell wall of yeast *Saccharomyces cerivisae* produced by Alltech Inc. (Nicholasville, Kentucky, USA) and the 0.1 g kg−1 Zn-Bacitracin were obtained adding 2 g kg−1 of Bacikern 50 (Laboratorios Calier, SA). Pellets were supplied with fresh alfalfa (*Medicago sativa*) everyday as forage. Fresh water was always available. Fresh alfalfa from a first-year crop was in the flowering onset stage at the start of the fattening period. Each week, alfalfa samples were drawn to determine dry matter, which averaged 23.2% throughout the period. Chemical composition of the pellet and fresh alfalfa is shown in Table 1. Dry matter of the fresh alfalfa and the forage refused was determined by oven-drying at 102 ± 2°C for 24 h (no. 934.01; AOAC 2008). It was not necessary to carry out a feed adaptation period since the diet offered before weaning was similar to the experimental one (basal diet supplemented with alfalfa).

The guinea pigs were housed in collective pens (10 animals per pen) with a deep litter of woodchips. The dimensions of the pens were 2 × 1×0.4 m., (length × width × height) equipped with a central feeder and nipple drinker. This allows enough space for guinea pig production (Mínguez et al. 2019). The cages were separated by sex to avoid pregnant females at the age of slaughter, as mounts begin around 1 month old, and ejaculation occurs around 2 months (Harkness et al. 2013). The overall fattening period was seven weeks, from the 13th of April to the 1st of June 2016.

On day 77, animals were slaughtered according to the methods reported in Sánchez-Macías et al. (2016). Before slaughtering, guinea pigs were fasting 14 h in the cage. After this period, guinea pigs were taken to the slaughterhouse located close to the farms (about 2 h of transport period). Experimental groups were randomized among loads of guinea pigs to avoid differences occurring due to waiting times at the slaughterhouse.

2.2. Traits measured

Individual weights and feed consumption were recorded weekly. The growth traits studied were the individual body weight (BW, g), the individual average daily gain (ADG, g/day), the average daily feed intake of solid pellet (FI, g/day), the dry matter intake of forage (DMI, g/day), and the feed conversion ratio (FCR). The cage was the experimental unit for FI, DMI and FCR.

The carcass traits studied followed the criteria and terminology proposed by Sánchez-Macías et al. (2016). The carcass traits studied were live weight at slaughter (LWS, g at 77 days), full gastrointestinal tract weight (FGTW, g), hot carcass weight (HCW, g with the head), cold carcass weight with head after 15 h at 4°C (CCW, g). Dressing-out carcass yield (DCY) and drip loss percentage (DLP) were also calculated according to the following equations:

$$DCY = \frac{CCW}{LWS} \times 100$$

$$DLP = \frac{HCW - CCW}{HCW} \times 100$$

2.3. Statistical analysis

Estimates of the differences between all treatment groups were obtained by generalized least squares, using the programme R Project (R Core Team 2013).

The model used in this analysis was:

$$Y_{klm} = T_k + F_l + S_m + e_{klm}$$

where: Y_{klm} is a record of the trait; T_k is the effect of the treatment (four levels); F_l is the effect of the farm (two levels), S_m is the effect of sex and e_{klm} is the residual effect.

The model for the analysis of BW and ADG included the weaning weight as covariate; LWS was used as covariate on carcass traits. Mortality were evaluated by Fisher's exact test due to low values of dead animals (McDonald 2014). Contrasts between groups on mortality were made with 'rcompanion' package. Significance was claimed at a Type I error rate of $\alpha = 0.05$.

3. Results

Summary statistics for growth and carcass traits are shown in Tables 2 and 3 respectively.

Least squares means for growth traits are shown in Table 4. Non-significant differences in the traits studied were observed

Table 1. Chemical composition and additives of the forage (*Medicago sativa L.*) and the different pellet diets[3].

	Forage	Control[c]	MOS 1.5	MOS 2	AGP
Dry matter (% as fed)	21.9	87.0	87.0	87.0	87.0
Neutral detergent fibre, % in DM	38.3	33.0	33.0	33.0	33.0
Acid detergent fibre, % in DM	30.7	22.0	22.0	22.0	22.0
Crude protein, % in DM	19.8	15.0	15.0	15.0	15.0
Crude fibre, % in DM	27.2	8.0	8.0	8.0	8.0
Ether extract, % in DM	2.8	4.0	4.0	4.0	4.0
Gross Energy, MJ/Kg	18.7	17	17	17	17
MOS[a]	–	–	1.5	2.0	–
AGP[b]	–	–	–	–	0.1

[a]MOS = Mannan Oligosaccharide (Bio-Mos®, Alltech, USA).
MOS-1.5 and MOS-2.0 = groups supplemented with MOS (Bio-Mos®, Alltech, USA) at 1.5 and 2.0 g/kg, respectively.
[b]AGP = 0.1 g kg^{-1} Zn-Bacitracin obtained adding 2 g kg−1 of Bacikern 50 (Laboratorios Calier, SA).
[c]Value based on the information by manufacture.

Table 2. Descriptive statistics for growth traits.

Items[a]	Mean	SD[b]	Maximum	Minimum
BW_{28}	507.6	48.9	712.3	454.0
BW_{77}	1105.0	83.3	1342.7	895.5
ADG_{77-28}	11.4	1.0	14.5	8.1
FI_{77-28}	38.8	3.8	45.0	33.2
DMI_{77-28}	14.4	2.9	18.2	9.9
FCR_{77-28}	3.8	0.7	3.0	4.6

[a]BW_{28}= body weight at weaning (day 28, g).
BW_{77}= body weight at slaughter (day 77, g).
ADG_{77-28}= average daily gain for the whole fattening period (g/d).
FI_{77-28}= individual feed intake for the whole fattening period (g/d).
DMI_{77-28}= dry mater intake of forage (*Medicago sativa*) for the whole fattening period (g/d).
FCR_{77-28}= feed conversion ratio for the whole fattening period.
[b]SD = standard deviation

Table 3. Descriptive statistics for carcass traits.

Items[a]	Mean	SD[b]	Maximum	Minimum
LWS	955.3	90.3	1230.0	623.9
FGTW	269.2	23.4	357.2	178.5
HCW	676.3	89.2	945.0	402.7
CCW	672.4	89.1	935.6	399.0
DLP	3.0	0.7	5.9	1.1
DCY	70.3	2.4	78.7	63.1

[a]LWS = live weight at slaughter after transport and fasting (g).
FGTW = full gastrointestinal tract weight (g).
HCW = hot carcass weight (g).
CCW = cold carcass weight (g).
DL*P* = drip loss percentage (%).
DCY = dressing out carcass yield percentage (%).
[b]SD = standard deviation.

between MOS groups and AGP group. Significant differences against the CG were observed regarding the other groups for ADG (CG vs MOS 1, $P = 0.03$; CG vs MOS 2, $P = 0.03$; CG vs AGP, $P = 0.02$) and FI (CG vs MOS 1, $P = 0.02$; CG vs MOS 2, $P = 0.02$; CG vs AGP, $P = 0.01$).

For carcass traits, non-significant differences were found for carcass traits (Table 5). Although the differences were non-significant, it can be observed a trend in favour of the MOS and AGP groups traits against de CG. During the whole fattening period, the total guinea pig mortality was 7.5%. The values of mortality were 4%, 5% and 5% for MOS 1.5, MOS 2 and AGP groups, respectively (non-significant differences). However, mortality in the CG (16%) was significant higher compared to the other groups (CG vs MOS, 1$P = 0.01$; CG vs MOS 2, $P = 0.02$; CG vs AGP, $P = 0.02$). Besides, the major number of deaths in this CG occurred in the first two weeks.

4. Discussion

In food and nutrition research, prebiotics have become particularly interesting due to the health benefits both animals and humans (Xiao et al. 2015). A prebiotic is generally defined as a selectively fermented dietary ingredient that confers a health benefit on the host in association with modulation of the intestinal microbiota or microbial activity (Roberfroid 2007). As a consequence, prebiotics play an important role in cecotrophic animals like guinea pigs.

In the guinea pig, indigestible sugars as fructo-oligosaccharides have shown a good physiological effect in the improvement of the nitrogen (N) utilization and decreased acid detergent fiber (ADF) digestibility (Kawasaki et al. 2017) yet the literature on MOS is scarce.

Table 4. Least square means (standard error) of the dietary supplementation diet on growth traits.

	Item[1]				
Groups[2]	BW	ADG	FI	DMI	FCR
Control	990.1(101.1)[a]	6.1(1.3)[a]	30.2 (4.2)[a]	12.6(3.3)[a]	3.9 (1.2)[a]
MOS 1.5	1152.3(99.4)[a]	11.7(1.1)[b]	47.3(4.0)[b]	15.1(3.1)[a]	3.7 (1.1)[a]
MOS 2.0	1163.2(100.2)[a]	11.9(1.1)[b]	47.9(4.1)[b]	14.9(3.2)[a]	3.7 (1.1)[a]
AGP	1203.4(99.3)[a]	12.1(1.1)[b]	48.2(4.0)[b]	15.8(3.2)[a]	3.8 (1.1)[a]

[1]BW = body weight (g) at the end of the complete fattening period.
ADG = average daily gain (g/d).
FI = individual feed intake (g/d).
DMI = dry mater intake of forage (*Medicago sativa*) (g/d).
FCR = feed conversion ratio.
[2]Control = group without supplement.
MOS-1.5 and MOS-2.0 = groups supplemented with MOS (Bio-Mos®, Alltech, USA) at 1.5 and 2.0 g/kg, respectively.
[ab]Mean in the same column with the same superscript do not differ significantly (significant difference at $P < 0.05$).

4.1. Growth traits

The mean of the slaughter weight obtained was within the range of commercial weight in Ecuador (0.7–1.1 Kg; Hoffman and Cawthorn 2013) and this value is consistent with Mínguez and Calvo (2018) who reported a range of 0.9–1.150 kg. Thus, our results could be of potential interest to be applied in practice in other commercial farms.

In livestock species, the use of MOS has been developed as an alternative to AGP in recent years (Collins et al. 2009) but the results have been contradictory.

In rabbits, a typical cecum fermenter, Pinheiro et al. (2004) and Mourao et al. (2006) reported no significant differences on weight gain, feed intake, FCR and mortality between MOS groups (1, 1.5 and 2 g kg-1) and AGP group (0.1 g Zn-Bacitracin). Attia et al. (2015) compared animals supplemented with MOS (0.083 g/rabbit.day) vs. a Zn-Bacitracin group (0.083 g/rabbit.-day) and they observed that MOS group had a favourable FCR at 32–56 days of age. In studies with others AGP, Fonseca et al. (2004) compared 2 g kg-1 of MOS with oxitetracyclin but no significant differences were reported on growth performance. Attia et al. (2014) did not observed significant differences between MOS and bee pollen, propolis or inulin.

In pigs, White et al. (2002) and Hancock et al. (2003) compared different doses of MOS with carbadox as AGP. They did not observe significant differences between groups for ADG, FI and FCR. However, Davis et al. (2002), Castillo et al. (2008) and LeMieux et al. (2010) observed a good performance on growth traits when compared MOS with a basal diet, cooper sulphate and organic zinc respectively. The results appear to be better in earlier-weaned piglets because the intestine is less developed due stress of weaning, adaptation to solid feed during the weaning period, dietary factor and so on. For these reason, the weaning is associated with a higher rate of gut epithelial atrophy than at a later age (Poeikhampha and Bunchasak 2011). In agreement with this hypothesis, Miguel et al. (2004) showed in a meta-analysis involving studies with 54 comparisons that the MOS supplementation had improved the growth rate mainly in the first 2 weeks of nursery.

In broiler, Hooge (2004), Silva et al. (2010) and Haldar et al. (2011) showed a good growth performance with a MOS supplementation, whereas, in Yang et al. (2008) and Baurhoo et al. (2007) no significant benefits were observed. In laying hens, Bozkurt et al. (2012) and Hashim et al. (2013) did not observed improving efficiency in growth performance and egg production but it seems that MOS improves egg quality (Koiyama et al. 2017). In turkeys, Stanczuk et al. (2005) did not find significant differences in animals supplemented with MOS, whereas Sims et al. (2004), reported an improvement on live weight.

Furthermore, supplementation with MOS improved the growth performance in dairy cattle (Uyeno et al. 2015) and beef (Tassinari et al. 2007).

In aquaculture, MOS has been studied in most species. A vast body of literature shows that the use of MOS increases the

Table 5. Least square means (standard error) of the dietary supplementation diet on carcass traits.

	Items[1]					
Groups[2]	LWS	FGTW	HCW	CCW	DLP	DCY
Control	890.5(94.2)[a]	229.6(24.2)[a]	640.1 (91.4)[a]	637.3(94.2)[a]	3.2 (1.2)[a]	69.3(3.0)[a]
MOS 1.5	962.3(92.7)[a]	250.7(23.9)[a]	681.7(91.0)[a]	680.1(91.0)[a]	3.3 (1.1)[a]	67.3(2.9)[a]
MOS 2.0	970.2(93.1)[a]	249.1(23.3)[a]	688.2(91.2)[a]	683.6(90.9)[a]	3.1 (1.0)[a]	66.9(2.9)[a]
AGP	972.4(91.3)[a]	245.6(23.5)[a]	684.6(90.9)[a]	681.7(90.5)[a]	3.2 (1.1)[a]	72.7(2.8)[a]

[1]LWS = live weight at slaughter after transport and fasting (g).
FGTW = full gastrointestinal tract weight (g).
HCW = hot carcass weight (g).
CCW = cold carcass weight (g).
DL*P* = drip loss percentage (%).
DCY = dressing out carcass yield percentage (%).
[2]Control = group without supplement.
MOS-1.5 and MOS-2.0 = groups supplemented with MOS (Bio-Mos®, Alltech, USA) at 1.5 and 2.0 g/kg, respectively
[ab]Mean in the same column with the same superscript do not differ significantly (significant difference at $P < 0.05$).

growth performance in fish and shellfish (Torrecillas et al. 2014). In Ecuador, where our study was conducted, Mínguez et al. (2016) used MOS with a good result in rainbow trout.

4.2. Carcass traits

The supplementation of MOS has a significant impact on gut morphology in different species. An increased villous height, crypt depth ratio and a bigger absorptive surface had been observed in animals supplemented with MOS (Halas and Nochta 2012; Song et al. 2014). Also, Bovera et al. (2012) showed that rabbits fed with a supplementation of 1.5 g/kg of MOS had a greater empty gastrointestinal tract than CG.

According with our results, in other livestock species, as birds (Bozkurt et al. 2008; Ghosh et al. 2008; Konca et al. 2009; Sarica et al. 2009), rabbits (Bovera et al. 2012; Attia et al. 2015) or pigs (Wenner et al. 2013), the supplementing of MOS did not improve carcass traits.

4.3. Mortality

The values observed on mortality are in agreement with other studies (Pascual et al. 2017; Mínguez and Calvo 2018; Mínguez et al. 2019).

In livestock production, post-weaning period is critical for mortality due to gastrointestinal problems associated with the weaning transition especially in caecotrophy species (Fortun-Lamothe and Boullier 2007). These gastrointestinal conditions are in agreement with our findings, given that the majority deaths of CG occurred in the two weeks following weaning. MOS decreases the load of pathogenic bacteria through (1) binding bacterial type-1 fimbriae (2) increasing goblet cells which produce bactericidal mucin and (3) providing favourable environment for the growth of beneficial bacteria leading to competitive exclusion (Chacher et al. 2017). For this reason, the use of MOS to reduced mortality has been studied over the last several decades in different species with good results. Numerous studies with rats (Kudoch et al. 1999), dogs (Swanson et al. 2002), pigs (Valpotić et al. 2017), cows (Franklin et al. 2005), trout (Staykov et al. 2007) and chickens (Shadhishara and Devegowda 2003) show that dietary MOS produces an activation of the immune defence.

4.4. Farm effect

The absence of differences observed in the farm effect may be due to two reasons. First, farms are located closely (25 km of distance with similar climatic conditions), and second, animals were kept under the same management conditions.

4.5. Sex effect

Sex effect was non-significant in our study. Our results agree with Mínguez et al. (2019), Sánchez-Macías et al. (2018) and Mínguez and Calvo (2018). Several studies of rabbits indicating that sex does not influence on growth (Orengo et al. 2009) or carcass traits at the commercial slaughter age (Hernández et al. 2006), since sexual dimorphism arises later than slaughter.

5. Conclusion

The use of MOS could be of a good substitute of traditional AGP used in livestock. In meat guinea pig production, MOS can be a good dietary supplement. The results indicated that MOS groups showed better growth performance and lower mortality than CG (without additives). While the use of MOS could increase the feed cost, the dose to be consumed is shallow. Consequently, this additional cost ($0.01/kg of food in Ecuador) is not significant in contrast to the potential benefits on growth performance and mortality reduction.

Disclosure statement

No potential conflict of interest was reported by the authors.

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