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INFLUENCE OF THE MAIN CEREAL AND FEED FORM OF DIET ON PRODUCTIVE PERFORMANCE AND DIGESTIVE TRACT TRAITS IN BROWN-EGG LAYING PULLETS FROM HATCHING TO 17 WEEK

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Se le ciegan los ojos con el polvo,

Oyendo siempre la canción del tiempo

Recuerda, caminando en campo solo,

Nos pusieron descalzos en la tierra

Quemarnos el dolor, pero algo así,

Como un dolor sin sitio destinado

La mañana no siempre nos descubre

Tras el vocablo, el mito o el ensueño

He aprendido que la vida es dura

Pero yo lo soy más!

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ABBREVIATION KEYS

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%: percentage
μm: micro meter
ADFI: average daily feed intake
AMEn: apparent metabolizable energy, nitrogen-corrected
BW: body weight
BWG: body weight gain
Ca: calcium
cm: centimeter
CP: crude protein
Cys: cysteine
d: day
DM: dry mater
FCR: feed conversion ratio
GIT: gastro intestinal tract
GMD: geometric mean diameter
GSD: geometric standard deviation
GLM: general lineal model
g: gram
IU: international unit
kg: kilogram
Lys: lysine
m: meter
mm: millimeter
Met: methionine (Met)
mg: miligram
MPS: mean particle size
N: nitrogen
n: number of replicates per treatment
P: probability
P: phosphorus
RL: relative length (cm/kg BW)
RW: relative weight (g/kg BW)
SI: small intestine
SD: standard deviation
Sem: standard error of the mean
Thr: threonine
Trp: tryptophan
wk: week

Chapter 1: Abstract

ABSTRACT

The influence of the main cereal and feed form of the diet on performance and gastrointestinal tract (**GIT**) traits was studied in brown-egg laying pullets from hatching to 17 wk of age. There were 8 treatments arranged as a 2×4 factorial with 2 main cereals (corn vs. wheat) and 4 feeding programs that consisted in feeding crumbles to pullets from 1 to 5 wk, 1 to 10 wk followed by mash to 17 wk of age, and feeding crumble or mash continuously from 0 to 17 wk of age. Each treatment was replicated 9 times (17 pullets per replicate). From wk 0 to 5 pullets fed wheat had higher BWG ($P < 0.001$) and better FCR ($P < 0.001$) than pullet fed corn but the differences disappeared with age. Pullets fed crumbles continuously showed higher BW gain (14.0 *vs.*13.3 g/d; $P < 0.001$) and better FCR (4.28 *vs.* 4.44; $P < 0.001$) than pullets feed mash continuously, with pullets fed the other 2 treatments being intermediate. When feed form was changed from mash to crumble at any age, pullets performance was improved. Pullets fed corn had heavier GIT and gizzard than pullets fed wheat ($P < 0.001$) but body length, tarsus length and length of the small intestine were not affected. Pullets fed mash from wk 0 to 17 were longer ($P < 0.001$) and higher ($P < 0.001$) relative weight (% BW) of the gizzard and of the GIT but lower ($P < 0.001$) gizzard pH than pullets fed crumbles continuously, with pullets fed the others 2 treatments being intermediate.

We conclude that wheat and corn can be used indistinctly in diets for pullets. Also, feeding crumbles improved growth performance of pullets but reduced the relative weight of the GIT and of the gizzard. The GIT of the pullets adapts quickly to changes in feed form. Feeding crumble improves growth performance without any negative effects on pullet uniformity.

Resumen

El objetivo general de esta Tesis de Máster fue estudiar la influencia del tipo de cereal y la forma de presentación del pienso sobre los parámetros productivos y al desarrollo del tracto digestivo en pollitas de 0 a 17 semanas **(sem)** de vida. El diseño experimental fue complemente al azar con 8 tratamientos organizados de forma factorial con 2 cereales base (trigo vs. maíz) y 4 programas de alimentación, que consistieron en modificar la forma de presentación del pienso (miga vs. harina) según la fase de recría (1-5 sem, 5-10 sem y 10-17 sem de edad). Dos de los tratamientos consistieron en suministrar los piensos durante toda la recría (0 -17 sem) bien en forma de harina o bien en forma de migas. Los otros dos tratamientos consistieron en suministrar el migas de 0 a 5sem o de 0 a 10 sem seguido del suministrar en harina hasta las 17 sem. Se utilizaron 9 réplicas por tratamiento y la unidad experimental fue la jaula con 17 pollitas. De 0 a 5 sem, las pollitas alimentadas con trigo tuvieron una ganancia media diaria (**GMD**) mayor ($P < 0.001$) y un índice de conversión **(IC)** mejor ($P < 0.001$) que las pollitas alimentados con maíz. En el global de la prueba (0 a 17 sem), el tipo de cereal no afectó de forma significativa a ninguno de los parámetros estudiados. La presentación del pienso influyó sobre los parámetros productivos a lo largo del periodo experimental. De hecho, el cambio del pienso de miga a harina se provocó una pérdida de rendimientos productivos en el periodo posterior. De 0 a 17 sem de vida, la GMD fue mayor (14.0 *vs*.13.3 g/d; $P < 0.001$) y el IC fue mejor (4.28 *vs*. 4.44; $P < 0.001$) para las pollitas que consumieron migas durante toda la prueba que para las que consumieron harina con las pollitas que recibieron los 2 tratamientos mostraron resultados intermediaros. El desarrollo del GIT y de la molleja fue mayor con las pollitas alimentadas con piensos basados en maíz que las pollitas alimentadas con piensos basados en trigo. La alimentación en miga redujo el peso relativo del tracto gastrointestinal y de la molleja ($P < 0.001$). El pH del contenido de la molleja fue inferior en las pollitas que recibieron harina durante todo el periodo de recría ($P < 0.01$). A 17 sem de edad La longitud del cuerpo y del tarso fue mayor con las pollitas alimentadas con piensos en forma de harina que para las que consumieron piensos en migas de continua. Por otro lado, las pollitas que recibieron los 2 tratamientos combinados mostraron resultados intermediaros.

En base a los resultados obtenidos, al menos de 40% el trigo suplementado con enzimas puede utilizarse en sustitución de maíz en piensos de pollitas de 0 a 17 sem de edad. Por otro lado, la utilización de piensos en migas mejora la productividad de las pollitas pero podría afectar negativamente el desarrollo del aparato digestivo. Las pollitas adaptan rápidamente su sistema digestivo, consumo de pienso y productividad general, a cambios en la presentación del pienso.

Résumé

L'objectif général de cette Thèse de Master était d'étudier l'influence de type de céréale, et la forme de présentation de l aliment qui pourraient affecter les performances productives et le développement du tube digestif des poulettes brunes pour la production d'œufs commerciaux., 8 traitement organisés de forme factorielle avec 2 types de céréales (maïs contre blé) et 4 programmes de alimentation qui consistent a modifier la forme de présentation de l aliment (farine contre miette) durant les 3 périodes de l élevage (0-5 semaines, 5-10 semaines et 10-17 semaines). Deux de 4 traitements consistent de distribuer l'aliment sous forme de miette ou sous forme de farine durant les trois périodes d'élevage. Les deux autres traitements consistent de combiner la forme de présentation de l'aliment tout le long de la période de l'essai. Un de deux traitements consiste á distribuer l'aliment sous forme de miette seulement durant la première période (0-5 semaine) et l'autre consiste á offrir l'aliment sous forme de miette durant les deux périodes de l`élevage (0-5 semaines, 5-10 semaines) et après tous les régimes ont été offerts sous la forme farineuse et la seule différence entre les régimes était la céréale de base utilisée. Chaque traitement a été répété 6 fois (17 poulettes par répétition). De 0 à 5 semaines, les poulettes alimentées avec des régimes à base de blé ont eu un gain de poids plus élevé (14.0 *vs.*13.3 g/d; $P < 0.001$) et un indice de conversion meilleur ($P < 0.001$) à ceux des poulettes alimentées avec des régimes à base de maïs. Durant la période global le type de céréale n'affecte pas les paramètres productifs. La forme de présentation de l'aliment affecte les paramètres productifs chez les poulettes durant les différentes périodes de l'élevage. Les poulettes alimentées à base de miette durant tout le long de la période de l élevage et ont eu un gain de poids plus élevé (14.0 *vs.*13.3 g/d; $P < 0.001$) et un indice de conversion meilleur que les poulettes alimentées à base de farine (4.28 *vs.* 4.44; $P < 0.001$). On détecte une réduction des paramètres productifs lorsqu'on change la forme de présentation d'aliment (de miette à farine). Le poids relatif (% BW) du gésier et du tube digestif étaient plus élevés ($P < 0.001$) chez les poulettes alimentées avec des régimes à base de maïs que chez les poulettes alimentées avec des régimes à base de blé. Durant la période global, L'utilisation de l'aliment farineux augmente le poids relatif du tube digestif et du gésier ($P < 0.001$) aussi bien que Le pH du contenu de gésier à 17 semaines d'âge n'a pas été affecté par la céréale de base utilisée mais il était inférieur chez les poulettes alimentées à base de farine. Les poulettes alimentées avec le traitement combiné montrant des résultats intermédiaire.

Nous concluons que 40% de blé peut substituer le maïs dans les régimes de poulette avec une légère réduction du gain de poids vif. Aussi, l'utilisation de l'aliment granulé depuis 0 jusqu'à 17 semaines d'âge a augmenté le gain de poids vif et le pH du gésier. La présentation de l'aliment granulé a réduit le poids relatif du gésier et la longueur du tube digestif à 17 semaines d'âge.

Chapter 2:

Literature review and Objectives

2.1. Literature review and objectives

2.1.1. Introduction

The egg industry changes and evolves quickly due to increased demand for quality, technology changes, and pressures from consumers and government regulators. Also, the egg industry continues to grow as the egg offers consumers a source of protein at low cost. Egg production and consumption continues to grow in most countries around the world as the international trade of eggs is relatively insignificant because of handling difficulties with some exceptions mainly in the European Union. The demand for processed egg products continues will probably to increase (FAO Stat, 2011).

Spain is one of the most important egg producers in Europe with more than 35 millions of industrial laying hens, and more than 883 thousand tones of egg produced per year (FAO Stat, 2011). Egg size is especially important in Spain because consumers show a clear preference for large eggs (Grobas et al., 1999). The profitability of the egg industry depends mostly of 3 factors; number of eggs per hen housed, size of the eggs produced, and percentage of eggs that reach the table of the final consumer. To improve egg rate and the quality of the eggs, one of the most critical points is the management and the nutrition of the pullets during the rearing phase. Pullets should reach sexual maturity with a BW and uniformity as recommended by the genetic companies that market them. In fact, the rate of egg production and the percentage of large eggs are positively related to feed intake and the BW of pullets during the rearing period.

Summers and Lesson (1983) found that heavier pullets laid significantly more and heavier eggs than did lighter pullets at the beginning of the egg production cycle. Age of sexual maturity of pullets can be advanced considerably by breeding programs, light stimulation, or nutrition, and by a combination of the three. Decreasing the age of sexual maturity increases the number of eggs laid with the potential disadvantage of the production of a greater proportion of small eggs. Changing feeding practices, including the choice of raw materials and the form, seems to be promising ways to reduce cost of production. Indeed, the feed represents the greatest part of the economic cost of eggs production (Boggia et al., 2010).

Two major factors affecting productive performance of laying hens are BW and uniformity at the onset of the egg-laying cycle (Akanbi and Goodman., 1982; Bish et al., 1985). An adequate BW is well correlated with the rate of production and the percentage of large eggs (Summers and Leeson, 1994). In fact, one of the main challenges in rearing pullets is to produce birds with good feed intake at 18 wks of age. A high feed intake during the rearing phase will results in a well developed digestive tract that will allow fulfilling the nutritional requirements of the pullets, especially in the critical period of the onset of lay production. Consequently, a main objective for rearing pullets is to obtain flocks with desirable BW and uniformity at a target age (Hy-Line Brown, 2012).

The authors had not found any report on the effects of the main cereal of the diet and feed form on performance and digestive tract traits of brown-egg laying in pullets from 0 to 17 wk of age. Information in this respect is needed to help the nutritionist to formulate diets and select the best feeding program which allows to maximize feed intake and BW of the pullets at the same time allows a better uniformity of the flock at the beginning of the egg production cycle.

2.1.2. Effect of main cereal of the diets on productive performance

Cereals are the most widely used energy sources in poultry feeds, and the majority of the energy is derived from the starch fraction. In addition, cereals provide also a part of the protein and amino acids required by the birds. Therefore, Starch digestion depends on factors such as the soluble cell-wall polysaccharide content, the nature of grain starch, the presence of anti-nutritional factors in the grain, and the digestive capacity of the animal (Classen et al., 1996). Starch utilization depends on the cereal used because the structure of the starch varies with the source considered. The structure and chemical characteristics of the ingredients of the diet affect the physicochemical properties of the digesta (Lentle and Janssen, 2008) and microflora growth in the gastrointestinal tract (GIT). Corn (Zea mays L.) and soft wheat (Triticum aestivum L.) are 2 cereals commonly used as energy sources in poultry diets.

In some countries, barley (Hordeum vulgare L.) is also an attractive commercial alternative. Corn has less protein and dietary fiber and more starch than wheat. The chemical composition and nutritive value of corn is quite uniform compared with those of wheat, the nutritive value of wheat varies depending on factors such as cultivar, agronomic practices, weather conditions, and length of storage period (Pirgozliev et al., 2003; Gutierrez-Alamo et al., 2008; Frikha et al., 2010). Several reports have compared the effects of including these 2 cereals in the diet on productive performance of broilers (Ruiz et al., 1987; Mathlouthi et al., 2002) and laying hens (Lázaro et al., 2003a; Safaa et al., 2009). In general, these studies suggest that wheat is a good alternative to corn in these species. Amerah et al. (2007) concluded that coarse grinding of a wheat-based diet may facilitate digestion of energy substrates, enhancing values of apparent metabolizable energy (**AME**). Ruiz et al. (1987) reported similar BW gain (**BWG)** and feed conversion ratio (**FCR**) in broilers fed mash when corn was substituted by wheat.

Similarly, Liebert et al. (2005) observed that performance was not affected when corn was substituted by wheat as the main ingredient in diets of Lohmann Brown hens from 22 to 61 wk of age, Lázaro et al. (2003a) found that the substitution of corn by wheat did not affect ADFI, hen productivity, or egg quality of SCWL hens from 20 to 44 wk of age. Feeding wheat might increase the incidence of sticky droppings, reduces the extent of digestion and absorption of nutrients, and impairs broiler and hen performance (Annison and Choct, 1991; Lazáro et al., 2003a). Moreover, Mathlouthi et al. (2002) reported similar performance when 60% corn of a broiler diet was substituted by a mixture of 40% wheat and 20% barley supplemented with enzymes.

In general, the data indicate that wheat supplemented with enzymes can be used in substitution of maize in poultry diets without any significant impact on productive performance. Enzyme supplementation improves performance and nutrient digestibility of broilers fed diets containing high levels of grains rich in NSP. The reason is not totally clear but has been related to a decrease in intestinal viscosity, which may improve nutrient digestibility and increase feed intake (Petterson et al., 1991; Salih et al., 1991; Lázaro et al., 2003a,b).

Pérez-Bonilla et al. (2011) observed that performance was not affected when corn was substituted by wheat as the main ingredient in diets of Lohmann Brown hens from 22 to 52 wk of age. The number of reports comparing the effects of corn and wheat in diets for pullets from hatching to 17 wk of age is very limited. Frikha et al. (2009a) reported that pullets performance was not affected by the main cereal (corn *vs.* wheat) of the diets in birds from 1 to 45 d of age.

However, pullets fed the corn diets from hatching to 120 d of age had higher BWG than pullets fed the wheat diets but no differences were observed for ADFI or FCR. In contrast, Kim et al. (1976) reported that SCWL hens fed a diet based on corn consumed more feed and produced bigger eggs than hens fed a diet based on wheat from 21 to 43 wk of age. On the other hand, Moran et al. (1993) observed better productive performance with wheat than with corn in broilers fed pellet form from 1 to 42 d of age.

2.1.3. Effect of feed form on productive performance

The physical form of feed (mash, pellets, and crumbles) is a crucial factor in meat yield of broiler and in hen egg production. Feed constitutes about 65-70 % of the total cost of broiler production. Numerous reports have been published over the years comparing the effects of feed form on hen, and boilers performance (Quentin et al., 2004; Cerrate et al., 2009), but the available information in pullets is scarce.

Pelleting consists in the application of heat and vapor to the mash feed inside the conditioner which leads to a mild cooking of the diet. The steam is applied for a short period of time and with a temperature of no more than 80ºC to avoid inactivation of the enzymes and vitamins added to the diet. When a feed is pelleted, a reduction in the size of mash particles is required to improve the quality of the feed. Therefore, the process minimizes the differences in the initial particle size of the ingredients. After grinding, the feed passes through a pellet press provided with a die of variable diameter and thickness depending on the target species

During the pelleting process, the feed is steam-heated to soften the feed particles and then, it is pressed causing an additional mechanical pressure (Engberg et al., 2002; Svihus et al., 2004). Grinding, steam and pressure applied to the meal help to agglomerate the particles of the diet with a concomitant improvement in bulk density and feed texture which in turn will facilitate feed intake. In addition, pelleted feeds have the advantage of better uniformity which reduces the natural selection of the feed particles by the animal. Wilson et al. (2001) investigated the relationship between crumble size and growth performance in broilers chicks and observed no differences in BWG between coarse crumbles (> 4mm) and medium crumbles (1.5- 4mm) but fine crumbles (< 1.5mm) result in lower in lower BW gain.

Serrano et al. (2012) reported that chickens fed crumble or pellets from 1 to 21 d of age, had higher BWG than chicks fed mash. Also, chicks fed pellets had better FCR than chicks fed crumbles, and both were better than chicks fed mash. In contrast, Hamilton and Proudfoot (1995) found that BW at 20 wk of age was higher for Leghorn pullets receiving mash diets compared with those receiving pellets or crumbled diets. Feeding pellets increased BWG and reduced FCR compared with feeding mash (Amerah et al., 2007). Reece et al. (1984) observed that best feed conversion was obtained with a feeding of high energy level with high protein profile in crumble form of feed.

In broilers, Serrano et al. (2013) indicated that the observed improvement in FCR with pelleting was mostly due to a reduction in feed wastage. Dozier et al. (2010) reported that chickens fed pelleted diets grew faster and consumed more feed from 15 to 28 d, 15 to 42 d, and 1 to 42 d of age than mash feeds. The improvement in broiler performance due to pelleting relates to less time devoted to eating translating to reduced energy spent for pretension (Moran et al., 1989). Advantages of feeding pelleted diets include better flow ability with mechanical feeding systems, decreased feed wastage, and an enhanced rate and efficiency of growth (Briggs et al., 1999; McKinney et al., 2004). The information available of the influence of changing the feed form during the rearing period on pullet performance is scarce and contradictory.

From 46 to 85 d of age, Frikha et al. (2009a) reported that pullets were fed pellets previously, had higher BWG than pullets that were fed mash. However, from 46 to 120 d of age, no differences in productive performance were observed between treatments. Gous and Morris (2001) found that pullets fed crumbles from 1 to 4 wk of age and then pellets from 5 to 20 wk consumed 2% less feed but were 6% heavier than pullets fed mash and improved FCR with respect to pullets fed mash. In addition, Frikha et al. (2009b) observed that pullets fed pellets from 1 to 45 d of age, consumed more feed and had higher BW gain than those fed mash.

2.1.4. Effect of cereal type of the diets on digestive tract traits

Diet composition influences the development of the gastrointestinal tract (**GIT**) and the utilization of nutrients in post hatch chicks (Noy and Sklan, 1999). Two nutritional alternatives proposed to improve GIT development and growth in young chicks are the use of easily digested ingredients (Noy and Sklan, 1999) and heat processing of the cereal portion of the diet (Gracia et al., 2003). Nir et al. (1995) found that the pH of gizzard digesta increased the cereal was finely milled. In contrast, Frikha et al. (2009a) observed that the gizzard pH was not affected by type of diet in pullets fed maize and wheat diets at 120d of age. Gonzalez-Alvarado et al. (2008) found that birds fed corn had heavier digestive tracts with larger gizzard that had greater digesta contents and lower gizzard pH, than birds fed rice. Our data agreed with those of Rama et al. (2000) who observed heavier gizzards in hens fed corn than in hens fed rice.

Also, Frikha et al. (2009a) observed that pullets fed the corn diets at 45 d of age had higher relative weight of the gizzard than pullets fed the wheat diets. Moreover, Amerah et al. (2008) in broilers. The higher weight of the gizzard in pullets fed corn might be related to differences in the hardness of the endosperm that is harder and more difficult to grind for corn than for wheat (Dobraszczyk et al., 2002). Nir et al. (1994b) observed a heavier relative weight (**RW**, g/kg of BW) of the gizzard in 21-d-old broilers fed maize than in those fed wheat. In contrast, Frikha et al. (2010) observed that the RW of the gizzard was not affected by the main cereal (corn vs wheat) of the diet in pullets at 45 d of age.

At this age, pullets fed maize tended to have heavier digestive tracts, proventriculus and longer small intestines **(SI)** than pullets fed wheat. At 120 d of age, pullets fed maize had shorter SI, jejunum and ceca than pullets fed wheat. Unfortunately, no data is available comparing the influence of cereal on the size and length of the GIT in pullets.

2.1.5. Effect of feed form on digestive tract traits

The gizzard (a mechanical type of stomach) has very strong muscular walls that grind the feed. Depending on the type of feed ingested. The development of the gizzard musculature is greatest in carnivorous and herbivorous species in which its action may govern nutrient intake. Hence, the efficiency of feed conversion by poultry is known to be significantly influenced by the action of the gizzard (Gionfriddo and Best, 1999; Svihus et al., 2011). A thorough understanding of the mechanical action of the gizzard is essential for gaining insight into strategies that optimize foraging in avian species as well as into the formulation of feeds to optimize digestive efficiency.

In spite of the ability of the avian gizzard to retain deliberately ingested (Alonso et al., 1985; Soler and Soler, 1993) large, hard, nonnutrient particles for long periods (Gionfriddo and Best, 1999). In chickens, the gizzard weight relative to BW depends both on the genetic origin of birds (Peron et al., 2006; Garcia et al., 2007; Rougiere and Carre, 2010; Arroyo et al., 2012) and on diet characteristics, with coarse particles being a stimulating factor for gizzard development. In addition, gizzard action increases the peristaltic movements of the GIT and the gastro-duodenal refluxes, improving the mixing of the nutrients containing in the feed with digestive enzymes (Duke et al., 1992).

Diet composition, feed form affects the development of the gastrointestinal tract (**GIT**) in poultry (Zang et al., 2009; González-Alvarado et al., 2010). The form of the diet may also affect gizzard development. A well developed gizzard can modulate gut motility in a favorable manner (Ferket, 2000) and may inhibit the growth of pathogenic bacteria in the small intestine (Bjerrum et al., 2005).

Jensen and Becker (1965) suggested that the pelleting process to some extent gelatinized starch. Also, pelleting of diets can reduce their particle size substantially (Engberg et al., 2002). The combination of particle size reduction and starch gelatinization may expose feed particles more efficiently to enzymatic digestion, which may explain the improved AME and the apparent crude protein (**CP)**. Mateos et al. (2002) and González-Alvarado et al. (2008) suggested that a more functional gizzard might result in more reflux and better mixing of the digesta and endogenous enzymes in the GIT.

Therefore, a well-developed gizzard might increase nutrient digestibility and help to maintain a healthy microbiota population in the GIT (Gabriel et al., 2008; Santos et al., 2008). Choi et al. (1986) and Nir et al. (1994a, b) observed that feeding crumbles or pellets reduced the relative weight (g/kg of BW) of the gizzard compared with feeding mash. Nir et al. (1994b) observed that feeding crumbles or pellets to broilers reduced gizzard weight with respect to feeding mash. In pullets, Frikha et al. (2009b) observed that feeding pellets to pullets reduced the RW of the gizzard, proventriculus and digestive tract at 45 d of age. Also, the relative length (**RL**) of the small intestine (**SI**), jejunum, ileum and ceca was reduced at this age.

However, at 120 d of age, the only differences observed were for the RW of gizzard and proventriculus that were heavier for pullets previously fed mash than for those fed pellets. Gizzard pH at 120 d of age was not affected by diet. Frikha et al. (2009a), the digestive tract and the gizzard were heavier in pullets fed mash at 45 d of age than in pullets fed pellets. In addition, the small intestine and the ceca were longer in pullets fed mash than in those fed pellets. The information available comparing effect of changing feed form on productive performance and digestive tract traits development (**GIT**), in broilers is abundant but scarce in pullets.

2.2. Objectives

The present Master Thesis has been carried in collaboration between department of animal production (UPM) and Cantos it is the largest egg producing company of Spain with more than 5 millions hens. The general aim of this Master Thesis was to study the influence of the main cereal of the diet and programs feeding according to feed form of diets on productive performance and development of the GIT of brown-egg laying pullets from hatching to 17 week of age.

2.3. Reference

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Chapter 3:

Influence of the main cereal and feed form of the diet on performance and digestive traits of brown-egg laying pullets from hatching to 17 wk

3.1. INTRODUCTION

Corn and wheat are the most common used cereals in poultry diets. Corn has less protein (7.7 vs. 11.2%) but more energy (3,260 *vs.* 3,150 kcal AMEn /kg) than wheat **(**Fundación Española Desarrollo Nutrición Animal**,** 2010**)**. However, chemical composition and energy availability is more variable for wheat than for corn (Kim et al., 1976; Mollah et al., 1983; Gutierrez-Alamo et al., 2008) which reduces the interest of wheat as an ingredient in poultry feeding. Several reports have compared diets based on corn or wheat on productive performance of broilers (Crouch et al., 1997; Mathlouthi et al., 2002) and laying hens (Lazáro et al., 2003a; Pérez-Bonilla et al., 2011). In most cases, authors concluded that wheat can be used in substitution of corn without any negative effects on performance, provided that the diet is supplemented with enzymes.

However, Frikha et al. (2009b) reported that pullets fed wheat diets from hatching to 120 d of age had lower BWG than pullets fed corn diets, although no differences were observed for ADFI or FCR. Also, they observed that at 6 wk of age the gizzard was heavier in 6 wk-old pullets fed corn than in pullets fed wheat. The authors had not found any other report on the effects of the main cereal of the diet on performance and gastrointestinal tract **(GIT)** traits of brown-egg laying pullets from hatching to 17 wk of age fed mash or crumbles diets.

Under commercial conditions, broilers are frequently fed crumbles from 1 to 3 wk and then pellets to slaughter, a practice that results in improved BW gain **(BWG)** and FCR (Amerah et al., 2007; Cerrate et al., 2008; Serrano et al., 2012, 2013). However, the information available on the effects of feed form on pullet performance is scarce. Frikha et al. (2009b) reported that from hatching to 120 d of age, BWG and ADFI were higher in pullets that were fed pellets from 1 to 45 d of age than for pullets that were fed mash. In addition, from 46 to 85 d of age pullets that were fed pellets previously showed higher BWG than pullets that were fed mash.

The authors have not found any report on the effects of length of time of feeding crumbles to pullets on productive performance and GIT development. The aim of this research was to evaluate the effects of feeding crumbles or mash for different lengths of the rearing period on productive performance and GIT development of brown-egg laying pullets fed diets based on corn or wheat.

3.2. MATERIALS AND METHODS

3.2.1 Husbandry, Diets, Feeding Program, and Experiment Design

The experimental procedures used in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial Estado, 2007).

In total, 1,224 one-day old Lohmann Brown Classic pullets obtained from a commercial hatchery were used in this experiment. On arrival at the experimental farm, pullets were weighed individually and distributed at random in groups of 17 in 72 cages (80 cm x 68 cm, Facco, Venezia, Italy) in a windowless environmentally controlled room. Pullets were beak-trimmed at 8 d of age and vaccinated against main diseases (Infectious Bronchitis Disease, Marek Disease, Infectious Bursal Disease, Newcastle Disease, and Salmonella spp.) and managed according to accepted commercial practices (Lohmann, 2012).

The environmental conditions during the experiment were controlled automatically according to age. Room temperature was maintained at 32°C during the first 3 d of life and then, the temperature was reduced gradually until reaching 24°C at 42 d. The light program consisted of 24 h of light for the first week of life and then, light was decreased 2h per week 1 to 7 wk of age. From 7 wk to the end of the experiment a constant 12 h light period was maintained.

The feeding program consisted of 3 feeds supplied from 1 to 5 wk, 5 to 10 wk, and 10 to 17 wk of age. Within each period, diets were formulated to have similar nutrient content (Fundación Española Desarrollo Nutrición Animal, 2010) and met or exceeded the nutritional recommendations of NRC (1998) for pullets. The main difference in ingredient composition among the experimental diets within each feeding period, was the main cereal used (Table 1). The cereals were ground to pass through a 4 mm screen from 1 to 5 wk and through a 5 mm screen from 5 to 17 wk of age.

The experiment was completely randomized with 8 treatments forming a 2×4 factorial with 2 cereals (corn vs. wheat) and 4 feeding programs that consisted in changing feed form from crumble to mash at 5, or 10 wk of age, followed by mash to 17 wk of age and feeding crumble or mash continuously from 0 to 17 wk of age.

3.2.2. Growth Performance

Individual BW of the pullets and feed consumption by replicate were recorded at 5, 10, and 17 wk of age. Mortality was recorded as produced. The data were used to calculate BWG, ADFI, and FCR by period and for the entire experimental period. The uniformity of BW of the pullets was assessed by replicate as the percentage of pullets that were within ± 1.25 SD of the mean average BW as indicated by Frikha et al. (2009b). The 1.25 SD range was selected to fit commercial target (Hy-Line Brown, 2012) for BW homogeneity of the flock (80% of pullets within ± 10% of the average BW).

3.2.3. Gastrointestinal Tract Traits

After each of the 3 productive performance controls, 2 birds per replicate were randomly selected, weighed individually, and slaughtered by CO_2 asphyxiation. The GIT, from the beginning of the proventriculus to the cloaca, including digesta content, spleen, liver, and pancreas, were removed and weighed (Table 5). Then, the gizzard was excised and the pH of the content was measured (Table 6) in all these birds using a digital pH meter fitted with a fine-tip glass electrode (model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jimenez-Moreno et al. (2009). Then, the organ was emptied from any digesta content, cleaned, dried with desiccant paper, and weighed.

The weights of the full GIT (including the weight of the spleen, the liver and the pancreas) and the empty gizzard were expressed relative to BW **(% BW).** The length of the duodenum (from the gizzard to the pancreobiliary ducts), jejunum (from pancreobiliary ducts to Meckel's diverticulum), ileum (from Meckel's diverticulum to ileo-cecal junction), and of the 2 ceca (from the ostium to the tip of the right and left ceca) were also measured (Table 7).

Before removing the digestive tract, the length of the pullets, from the tip of the beak to the end of the longest phalanx, was measured in extended birds using a flexible tape with a precision of 1 mm, and expressed relative to BW **(cm/kg BW)**, Tarsus length (measured in the middle point of the bone) was also determined using a digital caliper (Table 8). All traits were measured in duplicate and the average value of the two determinations was used for further statistical analysis.

3.2.4. Laboratory analysis

Representative samples of the diets were ground in a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) fitted with a 1-mm screen and analyzed in triplicate for moisture by the oven-drying (method 930.01), ash by a muffle furnace (method 942.05), and nitrogen by combustion (method 990.03) using a Leco equipment (model FP-528, Leco Corporation, St. Joseph, MI) as described by AOAC International (2000). Gross energy was measured in an adiabatic bomb calorimeter (model 356, Parr Instrument Company, Moline, IL). Particle size of the mash and crumble diets, expressed as geometric mean diameter (**GMD**), was determined in 3 subsamples of 100 g each using a shaker (Filtra S.A., Barcelona, Spain) provided with 8 sieves ranging in mesh from 5000 to 40 μm as indicated by ASAE (1995). The chemical analysis of the experimental diets is shown in Table 2.

3.2.5. Statistical analysis

Data on growth and GIT and on body measurements were analyzed as a completely randomized design with main cereal and feed form as main effects using the GLM procedure of SAS (SAS Institute, 1990).

When the model was significant, treatment means were separated using the Tukey test. Differences between treatment means were considered significant at ***P* < 0.05**. Results in tables are presented as means.

3.3. RESULTS

3.3.1. Growth Performance

Main cereal: From hatching to 17 wk of age, the main cereal of the diet did not affect productive performance of the pullets (Table 3). However, from 0 to 5 wk, pullets fed wheat had higher BWG (8.9 vs. 9.2 g/d; *P* < 0.001) and better FCR (2.10 *vs.* 2.18; *P* < 0.05) than pullets fed corn (Table 3).

In contrast, from wk 10 to 17 pullets fed corn had higher BWG (10.6 vs. 10.3 g/d; *P* < 0.001) than pullets fed wheat but no differences were observed for FCR; From wk 5 to 10, an interaction between type of cereal and feed form was detected for FCR; pullets fed mash had poorer FCR than pullets fed crumbles with the corn diets (*P* < 0.05 for the interaction) but no effects were detected with the wheat diets (Figure1).

Feed form: Pullets that were fed mash or crumbles continuously from wk 0 to 17 of age ate more feed (59.9, 59.3 *vs.* 57.5; *P* < 0.01) than pullets that were changed from crumbles to mash at 5 wk of age. Pullets fed crumbles from 0 to 17 wk of age had higher BWG than pullets fed any of the other treatment (14.0 *vs.* 13.4, 13.3 and 13.3g/d, respectively; *P* < 0.001). Also, pullets fed crumbles continuously had better FCR (4.28 *vs*. 4.44; *P* < 0.001) than pullets feed mash continuously, with pullets fed the other treatments being intermediate. From 0 to 5 wk of age, pullets fed crumbles had lower ADFI (*P* < 0.001) but had higher BWG (*P* < 0.001) and better FCR (*P* < 0.001) than pullet fed mash (Table 3).

From wk 5 to 10 of age, BWG (17.3 *vs.* 16.2 g/d; *P* < 0.001) and ADFI (58.4 vs. 55.8 g; *P* < 0.001) were higher and FCR (3.38 *vs.* 3.45; *P* < 0.05) was better for pullets fed crumbles than for pullets fed mash in the previous period.

At this age, pullets that were changed from crumble to mash, consumed less feed (*P* < 0.001) and had lower BWG (*P* < 0.001), and poor FCR (*P* < 0.05) as a compared with pullets fed crumbles continuously. From 10 to 17 wk of age, pullets that were fed crumbles continuously consumed more feed (70.9 *vs.* 67.0; *P* < 0.001) and had better FCR (6.47 *vs.* 6.91; *P* < 0.05) than pullets that were changed from crumble to mash at 10 wk. Pullet uniformity was not affected by dietary treatment at any age (Table 4).

3.3.2. Gastrointestinal Tract Traits

No interaction between main cereal of the diet and feed form was detected for any measurement of GIT traits and therefore, only main effects are presented.

Main cereal: At the end of the experiment, pullets fed corn had heavier (*P* < 0.01) GIT than pullets fed wheat (Table 5). At 5 and 10 wk of age, the main cereal of the diet had no effect on GIT weight. At 17 wk of age, gizzard weight (4.1 *vs.* 3.7 %; *P* < 0.001) and gizzard digesta content (26.3 *vs.* 24.5; *P* < 0.05) were higher in pullets fed corn than in pullets fed wheat but no differences were observed for gizzard pH except for gizzard weight at 5 wk of age was higher for pullets fed corn (4.9 *vs.* 4.6 %; *P* < 0.01) than for pullets fed wheat (Table 6). Main cereal of the diet did not affect SI or ceca weight at any age (Table7).

Feed form: Feed form affected the relative weight of the GIT and of the gizzard at all ages (Tables 5 and 6, respectively). At 17 wk of age, the GIT and gizzard were heavier in pullets fed mash continuously than in pullets fed crumbles continuously, with pullets changed from crumble to mash diets at 5 or 10 wk of age being intermediate (*P* < 0.001).

At 5 wk and 10 wk of age, pullets fed mash had heavier GIT and gizzard (*P* < 0.01) than pullets fed crumbles (Table 5). An increase in the relative weight of the GIT and gizzard was observed at all times in which pullets were changed from crumble to mash feeds (Tables 5 and 6, respectively).

Gizzard digesta content was higher and gizzard pH was lower (*P* < 0.01) in all of the 3 feeding periods considered in pullets fed mash than in pullets fed crumbles continuously (Table 6). At 5 and 10 wk of age, pullets fed mash continuously had heavier (*P* < 0.01) gizzards than pullets fed crumbles continuously. The digest content of the gizzard was increased (*P* < 0.01) and gizzard pH (*P* < 0.01) was reduced in pullets fed mash as compared with pullets fed crumbles.

At 17 wk of age, neither the SI or the ceca length were affected by feed form but the jejunum was shorter (*P* < 0.05) in pullets fed crumbles continuously than in pullets fed mash continuously, with pullets from the others treatment being intermediate (Table 7). At 5 wk of age the SI was shorter at 5 wk (*P* = 0.09) and at 10 wk (*P* < 0.001) of age in pullets fed crumbles than in pullets fed mash continuously with most of the differences observed for the ileum and jejunum length.

3.3.3. Body and Tarsus Measurements

No interaction between main cereal and feed form of the diet was detected for any measurement for body and tarsus and therefore, only main effects are presented (Table 8).

Main cereal: The main cereal of the diet did not affect the relative length of the pullets or of the tarsus at 5 or 10 wk of age. However, at 17 wk of age pullets fed corn tended to be longer (48.9 *vs.* 48.1 cm/kg BW; *P* < 0.01) than pullets fed wheat.

Feed form: At 17 wk of age, pullets fed mash continuously were longer and had longer tarsus than pullets fed crumbles continuously (*P* < 0.05) with most of the differences observed already at 5 wk of age. At this age, Pullets fed mash were longer

(P < 0.01) and had longer (P < 0.01) tarsus than pullets fed crumbles. At 10 wk of age, pullets fed mash had longer tarsus (P < 0.01) than pullets fed crumbles, but no differences in pullet length were detected.

3.4. DISCUSSION

The gross energy, crude protein, and ash content of the experimental diets within each feeding period were similar to calculated values, indicating that the ingredients were mixed correctly. The GMD of the diets, within each feeding period, was similar for the corn and the wheat based diets and was lower from 0 to 5 wk of age than from 5 to 10 wk or 10 to 17 wk, consistent with the lower screen used to grind the cereals of the starter feeds (Table 2).

3.4.1. Growth Performance

Main cereal: For the entire experimental period, the main cereal of the diet did not affect productive performance of the pullets. Therefore wheat supplemented with enzymes can be used as a substitute of corn in diets for pullets. These results agree with data from studies conducted in broilers (Ruiz et al., 1987; Mathlouthi et al., 2002), pullets (Frikha et al., 2010), and laying hens (Ciftci et al., 2003; Lázaro et al., 2003a; Safaa et al., 2009; Pérez Bonilla et al., 2011). The information provided confirms that wheat composition is more variable than that of corn and therefore, poultry might respond differently to different wheat varieties. For example, Crouch et al. (1997) compared corn and two varieties of wheat at 40% of inclusion in mash diets for broilers and found that BWG and FCR were hindered with one of the two wheats but not with the other.

Pullets fed wheat supplemented with enzymes had higher BWG at 5 wk of age and had better FCR from wk 0 to 10 of age than pullets fed corn consistent with data of Moran et al. (1993) who observed better growth performance with wheat than with corn from 1 to 42 d of age in broilers. These authors observed that the inclusion of adequate enzymes improved more performance of broilers that were fed low-quality wheat than of those fed the high quality traits. Frikha et al. (2009b) compared wheat and corn as main cereal of the diets in pullets from 1 to 17 wk of age.

In the first experiment, the authors reported better performance at 17 wk of age with corn whereas no differences were detected in the second experiment. Ruiz et al. (1987) reported similar BWG and feed conversion ratio in broilers fed mash when corn was substituted by wheat. The reason for the differences in BWG for pullets fed wheat than for pullets fed corn among experiment is unknown. Wheat contains a high and variable amount of nonstarch polysaccharides **(NSP),** which are known to increase digesta viscosity and reduce productive performance in poultry (Làzaro et al., 2003a, b; Garcia et al., 2008).

Làzaro et al. (2003a, 2004) reported that enzymes reduced digesta viscosity and improve nutrient digestibility and feed intake in laying hens and broilers fed high NSP cereals. In laying hens, most reports indicate that wheat conveniently supplemented with enzymes can be used successfully as the main ingredient of the diet (Liebert et al., 2005; Safaa et al., 2009; Perez-Bonilla et al., 2011).

From 10 to 17 wk of age, pullets fed corn had higher BWG ($P < 0.01$) than pullets fed wheat but no differences were observed for ADFI or FCR, data that agree with results of Frikha et al. (2009b) in pullets from 1 to 120 d of age. Ouart et al. (1986) indicated that ADFI and FCR of SCWL hens from 68 to 71 wk of age were not affected when 37% corn was substituted by wheat. Pérez-Bonilla et al. (2011) observed that ADFI and FCR of brown-egg laying hens from 22 to 54 wk of age were similar when fed corn than when fed wheat based diets.

Similarly, Mathlouthi et al. (2002) reported same performance when 60 % corn of a broiler diet was substituted by a mixture of 40 % wheat and 20 % barley supplemented with enzymes. In contrast, Kim et al. (1976) found that SCWL hens fed a diet based on corn consumed more feed and produced heavier eggs than hens fed diet based on wheat from 21 to 43 wk of age, although BW was not affected.

Feed form: For the entire experiment, Pullets fed crumbles continuously had higher BWG and better FCR than pullets feed mash continuously, with pullets changed from crumble to mash at 5 or 10 wk of age being intermediate. The effects of feeding crumbles or pellets to broilers on growth performance have been studied in detail (Cerrate et al., 2008, 2009; Serrano et al., 2012, 2013). Crumbling increases feed density and improves the texture of the feed which might increase ADFI in broilers. In addition, because of its small particle size pelleting facilitates the contact and access of endogenous enzymes to nutrients.

In this addition, Gracia et et al. (2003) reported that heat processing modifies starch, protein, and fiber structure of the cereal and improves accessibility of enzymes to nutrients facilitating its digestibility. However, the mild temperatures applied during the pelleting process might not affect at any high extent nutrient digestibility. Abdollahi et al. (2011) observed that from 4 to 21 d of age BWG was 10.3% higher in broilers fed pellets than in broilers fed mash. In pullets, Gous and Morris (2011) reported that pullets fed crumbles from 1 to 4 wk and then pellets from 5 to 20 wk of age consumed 2% less feed and were 6% heavier at 20 wk than pullets fed mash. In contrast, Hamilton and Proudfoot (1995) found that BW at 20 wk of age was higher for Leghorn hens fed mash diets as compared with hens fed crumbled diets.

For the entire experiment period, pullets that were fed crumbles from 1 to 5 wk of age had lower ADFI than pullets that were fed crumbles or mash continuously with pullets fed crumbles from 1 to 10 wk of age being intermediate.

In fact, ADFI was reduced at any time pullets were changed from crumbles to mash feed. The reason for the lower ADFI any time that pullets were changed from crumbles to mash feed is not known. Feed wastage was not measured in this research but probably it was higher for mash than for crumbles as has been reported in piglets (Medel et al., 2004; Berrocoso et al., 2013) and broilers (Serrano et al., 2013). Serrano et al. (2012) reported that from 21 to 42 d of age, broilers fed pellets that were fed mash previously, had higher ADFI than broilers that were fed crumbles or pellets.

Body weight uniformity was not affected by the main cereal or feed form at any age in the rearing phase, results agree with Frikha et al. (2009b) who did not observed any effect on BW uniformity at any age in pullets fed corn or wheat in pellet or mash form.

3.4.2. Gastrointestinal Tract Traits

Main cereal: At 17 wk of age, GIT and gizzard were heavier for pullets fed corn than for pullet fed wheat. At 5 wk of age, pullets fed corn had heavier gizzards than those fed wheat, results that agree with data of Amerah et al. (2008) in broilers. Also, pullet fed corn had higher gizzard digest contents than pullets fed wheat, consistent with the GMD of the 2 diets. The higher weight of the gizzard in pullets fed corn might be related to the GMD of the diets as well as differences in the structure of the endosperm that is harder and more difficult to grind for corn than for wheat (Dombrink-Kurtzman and Bietz, 1993; Dobraszczyk et al., 2002). The percentage of fine particles (< 160 μm) was higher for the wheat than for the corn diets. Fine particles passes faster through the gizzard than coarse particles (Hetland et al., 2002; Svihus and Hetland, 2002) and consequently, gizzard contents should be reduced when wheat replaces corn.

Feed form: In the current experiment, the relative weight of the GIT and the gizzard increased when pullets were changed from crumbles to mash feeds. The data indicate that crumbling might have a negative effect on the development of the GIT of pullets whether they are fed corn or wheat.

Also, the relative digest content of the gizzard was higher when the diets were fed in mash than when feed in crumble form, results that agree with data of Frikha et al. (2009b).

Nir et al. (1994) observed that feeding crumbles or pellets to broilers reduced the relative weight of the gizzard as compared with feeding mash. The GMD of the feed is smaller with crumbles than with mash which results in faster transit time throughout the GIT. Similar results have been published by Jiménez-Moreno et al. (2008) in broilers.

On the other hand, gizzard pH was lower for pullets fed mash than for pullets fed crumbles, results that agree with data of Frikha et al. (2009b) in pullets fed similar type of diets. In contrast, Dahlke et al. (2003) in broilers did not observe any effect on gizzard pH when pelleted diets based on corn, varying in GMD from 340 μm to 1,120 μm, were used. In the current research, the changes in feed form from crumbles to mash at 5 and 10 wk of age might have reduced the negative effects of pelleting on gizzard pH.

At 10 wk of age, feeding mash increased the relative length of all the segments of the small intestine, except that of the ileum and the ceca, results that agree in part with data of Frikha et al. (2009a) who reported that feeding pellets from 1 to 45 d of age reduced the RL of the jejunum and ileum in Hy-Line Brown pullets. However, at 17 wk of age the only differences observed was for the RL of the jejunum that was higher for pullets fed mash continuously than in pullets fed crumbles continuously, with pullets changed from crumble to mash at 5 or 10 wk of age being intermediate, results that agree with data of Nir et al. (1995) found that pelleting reduced by 15% the RL of the jejunum and ileum of broilers. Similar results have been reported by Amerah et al. (2007).

3.4.3. Body and Tarsus Measurement

In the current experiment, The main cereal of the diet did not affect the relative length of the pullets and of the tarsus but pullets fed mash continuously were longer and had longer tarsus than pullet mash continuously results that agree with data of Amerah et al. (2007) reported that the improvement in broiler performance observed with pelleting was associated with a decrease in the RL of the GIT. To our knowledge, this is the first report indicating that feeding crumbles to pullets from hatching to 17 wk of age reduced the relative length of the pullets, the tarsus and the weight of the GIT but increased gizzard pH.

3.5. CONCLUSION

We conclude that, the main cereal of the diet did not affect pullet performance from 0 to 17 wk of age. In addition, Pullets fed corn had heavier GIT and gizzards than pullets fed wheat. Crumbling of the diet from 0 to 17 wk of age improved growth performance of the pullets at any age, but reduced the relative weight and pH of the gizzard. When pullets were changed from crumble to mash feeds, growth performances was reduced in the subsequent rearing period, but improves the relative weight of the GIT and of the gizzard as compared with those of pullets fed crumbles continuously. Also, The GIT of the pullets adapts quickly to changes in feed form.

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Table 1. Ingredient composition and calculated nutritive value of the experimental diets[1] (% as fed basis, unless otherwise indicated)

	1 to 5 wk		5 to 10 wk		10 to 17 wk	
	Corn	Wheat	Corn	Wheat	Corn	Wheat
Ingredient						
Dented corn	40.0	14.2	40.0	-	40.0	-
Soft wheat	14.2	40.0	-	40.0	-	40.0
Soybean meal (45.7% CP)	33.2	31.7	18.5	15.6	12.28	9.25
Barley	-	-	24.1	27.0	20.0	22.84
Wheat middling	-	-	-	-	12.0	12.0
Sunflower meal (27.5% CP)	6.0	7.54	12.7	12.7	11.54	11.65
Soybean oil	2.71	2.92	1.0	1.0	1.0	1.0
Dicalcium phosphate	2.07	2.04	1.21	1.15	0.90	0.70
Calcium carbonate	1.04	0.82	1.40	1.40	1.36	1.56
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-lys-HCL (78%)	-	-	0.13	0.2	0.01	0.08
DL-met, (99%)	0.13	0.13	0.11	0.10	0.06	0.07
Vitamin and mineral premix[2]	0.3	0.3	0.5	0.5	0.5	0.5
Calculted analysis						
EMAn (Kcal/kg)	2,860	2,860	2,690	2,690	2,620	2,620
Crude fiber	4.4	4.8	6.1	6.3	6.3	6.5
Crude protein	21.4	22.1	17.9	18.0	15.7	16.0
Total ash	6.3	6.2	6.4	6.0	6.2	6.2
Digestible AA						
Ile	0.79	0.82	0.62	0.63	0.53	0.53
Lys	0.96	0.96	0.85	0.85	0.60	0.61
Met	0.35	0.35	0.40	0.38	0.30	0.30
Met+cys	0.64	0.66	0.60	0.65	0.53	0.56
Thr	0.68	0.68	0.75	0.70	0.47	0.45
Trp	0.22	0.24	0.18	0.19	0.16	0.17
Val	0.88	0.90	0.73	0.73	0.64	0.60
Calcium	1.07	1.03	0.99	0.97	0.9	0.9
Total phosphorus	0.82	0.84	0.66	0.66	0.6	0.6
Digestible phosphorus	0.43	0.44	0.31	0.32	0.28	0.27

[1]Diets were offered either as mash or crumbles.

[2]Provided the following (per kilogram of diet): vitamin A (trans-retinyl acetate), 6000 IU; vitamin D3 (cholecalciferol), 1,200 IU; vitamin E (all-rac-tocopherol-acetate), 5 mg; vitamin K3 (bisulphatemenadione complex), 1.5 mg; riboflavin ,3.5 mg; betayne ,67.5 mg; thiamin (thiamine-mononitrate) ,1 mg; vitamin B12 (cyanocobalamin), 15 mcg; Se (Na_2SeO_3) 0.1 mg; I (KI), 1.9 mg; Cu ($CuSO_4$ $5H_2O$), 4 mg; Fe ($FeCO_3$), 18 mg; Mn (MnO), 66 mg; and Zn (ZnO), 37 mg. Roxazyme, 200 mg [1,600 U of Endo-1,4-β-glucanase (EC 3.2.1.4), 5,200 U of Endo-1,3(4)-β-glucanase (EC 3.2.1.6),and 5,200 U of Endo-1,4- β-xylanase (EC 3.2.1.8)] Natuphos 5000, 80 mg (400 phytase units of phytase) supplied by BASF supplied by DSM S.A., Madrid, Spain.

Table 2. Determined analysis (%, as-fed basis, unless stated otherwise), particle size distribution (%), and geometric mean diameter (GMD) of the experimental diets[3]

	1 to 5 week				5 to 10 week				10 to 17 week			
	Corn		Wheat		Corn		Wheat		Corn		Wheat	
	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash
GE (kcal/kg)	4,000	3,970	4,075	3,995	3,931	3,931	3,881	3,890	3.952	4.038	3.951	4.015
DM	93.7	93.0	93.4	94.1	91.7	93.7	91.2	93.2	91.8	92.6	91.7	93.2
CP	20.1	20.0	20.4	20.4	17.8	18.1	17.4	17.7	15.2	15.7	15.9	16.2
Total ash	7.7	7.9	7.0	7.5	6.1	6.1	7.5	5.3	6.2	6.8	6.4	5.6
Particle size distribution[1]												
>2,500	9.2	20.0	10.4	6.7	22.8	23.0	28.6	16.2	17.8	20.1	20.2	19.0
1,250	51.2	27.7	53.9	29.6	61.2	30.2	51.5	39.0	65.2	29.0	57.9	36.7
630	26.2	23.0	21.6	21.6	12.4	26.1	13.2	26.5	14.6	26.4	15.5	24.0
315	8.7	14.0	6.6	27.7	2.3	10.9	3.2	11.1	1.7	14.0	3.4	11.5
160	2.7	10.1	6.0	11.4	0.5	7.4	2.0	5.0	0.5	9.0	1.1	6.0
<80	1.5	2.1	1.3	2.8	0.3	2.1	1.0	2.0	0.3	1.4	1.2	2.0
GMD±GSD[2]	1,255± 2.0	735± 2.6	1,295± 2.0	799± 2.3	1,792± 1.7	1,204± 2.4	1,741± 2.0	1,204± 2.2	1,734± 1.6	1,118± 2.4	1,645± 1.9	1,199± 20.3

[1] Sieve diameter, µm. The percentage of particles smaller than 40 µm and bigger than 5000 µm was negligible for all diets.
[2]GSD=Log normalSD.
[3]Analyzed in triplicate samples.

Table 3. Influence of main cereal and feed form of the diet on growth performance of brown-egg pullets from 0 to 17 wk of age

	Feed form[1]			0-5 week			5-10 week			10-17 week			0-17 week		
Cereal	0-5 week	5-10 week	10-17 week	ADFI[2]	BWG[3]	FCR[4]	ADFI	BWG	FCR	ADFI	BWG	FCR	ADFI	BWG	FCR
Corn	C	C	C	19.1	9.0	2.13	58.2	17.3	3.36^{b}	69.6	10.9	6.39	59.2	13.9	4.26
	C	C	M	18.8	9.0	2.10	58.4	17.3	3.38^{b}	68.3	9.8	6.96	58.6	13.4	4.38
	C	M	M	19.0	9.0	2.11	56.1	16.0	3.51^{ab}	69.4	10.5	6.63	58.3	13.3	4.40
	M	M	M	20.2	8.5	2.37	57.1	16.1	3.55^{a}	70.1	11.1	6.36	59.4	13.4	4.44
Wheat	C	C	C	19.3	9.5	2.04	58.5	17.3	3.39^{ab}	72.2	11.0	6.56	60.6	14.1	4.30
	C	C	M	18.9	9.3	2.04	58.0	17.2	3.37^{b}	65.7	9.6	6.87	57.2	13.3	4.29
	C	M	M	18.7	9.4	2.00	55.8	16.4	3.40^{ab}	66.2	9.9	6.70	56.6	13.3	4.27
	M	M	M	20.2	8.8	2.31	54.6	16.3	3.36^{b}	71.4	10.6	6.75	59.2	13.3	4.44
Main effect															
Cereal															
Corn				19.3	8.9^{a}	2.18^{a}	57.4	16.7	3.45^{a}	69.3	10.6^{a}	6.58	58.9	13.5	4.37
Wheat				19.3	9.2^{b}	2.10^{b}	56.7	16.8	3.38^{b}	68.9	10.3^{b}	6.72	58.4	13.5	4.33
Feed form															
	C	C	C	19.2^{b}	9.2^{a}	2.08^{b}	58.4^{a}	17.3^{a}	3.38^{b}	70.9^{a}	11.0^{a}	6.47^{b}	59.9^{a}	14.0^{a}	4.28^{b}
	C	C	M	18.9^{b}	9.1^{a}	2.07^{b}	58.2^{a}	17.2^{a}	3.37^{b}	67.0^{b}	9.7^{b}	6.91^{a}	57.9^{ab}	13.4^{b}	4.33^{ab}
	C	M	M	18.8^{b}	9.2^{a}	2.05^{b}	56.0^{b}	16.2^{b}	3.45^{a}	67.8^{ab}	10.2^{b}	6.66^{ab}	57.5^{b}	13.3^{b}	4.33^{ab}
	M	M	M	20.2^{a}	8.6^{b}	2.34^{a}	55.8^{b}	16.2^{b}	3.45^{a}	70.8^{ab}	10.8^{a}	6.56^{ab}	59.3^{a}	13.3^{b}	4.46^{a}
SEM[5]				0.675	0.297	0.09	1.80	0.527	**0.105**	4.33	0.60	0.415	2.34	0.340	0.137
				Probability											
Feed form				0.001	0.001	0.001	0.001	0.001	0.034	0.012	0.001	0.014	0.007	0.001	0.005
Cereal				0.885	0.001	0.003	0.110	0.361	0.006	0.652	0.035	0.169	0.406	0.868	0.207
cereal *Feed form				0.820	0.608	0.784	0.121	0.450	**0.010**	0.125	0.308	0.357	0.189	0.686	0.236

[a-b] Within a column, means without a common superscript differ ($P < 0.05$).
[1]C=crumble; M=mash..
[2]Average daily feed intake.
[3]Body weight gain.
[4]Feed conversion ratio.
[5]SEM (9 replicates of 17 pullets per treatment).

Figure 1. Interaction cereal*feed form on feed conversion (FCR) from **5 to 10** week of age

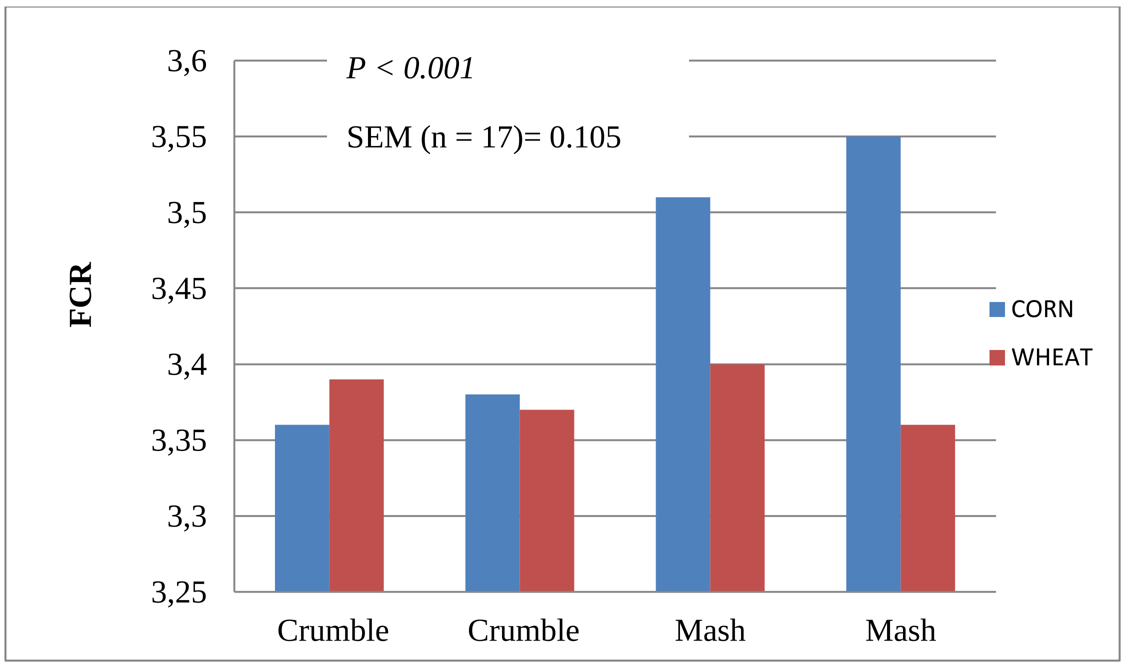

Table 4. Influence of main cereal and feed form of the diet on BW uniformity

	Feed form[1]			Uniformity		
Cereal	0-5 week	5-10 week	10-17 week	5 week	10 week	17 week
Corn	C	C	C	66.5	82.2	87.1
	C	C	M	77.6	89.6	90.5
	C	M	M	69.3	80.0	87.2
	M	M	M	66.1	81.7	89.8
Wheat	C	C	C	73.2	84.4	89.7
	C	C	M	71.9	80.7	88.9
	C	M	M	76.5	87.4	90.6
	M	M	M	69.3	83.1	92.4
Main effect						
Cereal						
Corn				68.9	83.4	88.7
Wheat				72.7	83.9	90.4
Feed form						
	C	C	C	70.0[ab]	83.3	88.4
	C	C	M	74.7[a]	85.2	89.7
	C	M	M	72.9[ab]	83.7	88.9
	M	M	M	65.7[a]	82.4	91.1
SEM[2]				9.98	11.18	10.14
				Probability		
Feed form				0.050	0.950	0.970
Cereal				0.110	0.890	0.310
cereal*Feed form				0.150	0.110	0.760

[a-b-c] Within a column, means without a common superscript differ (P < 0.05).
[1]C=crumbles; M=mash.
[2]SEM (9 replicates of 17 pullets per treatment).

Table 5. Influence of main cereal and feed form of the diet on the relative weight (% BW) of the gastrointestinal tract (GIT) of the pullets

Cereal	Feed form[1]			5 week		10 week		17 week	
	0-5 week	5-10 week	10-17 week	BW[2]	GIT[3]	BW	GIT	BW	GIT
Corn	C	C	C	335	20.6	967	13.7	1,339	11.4
	C	C	M	348	20.8	970	13.7	1,314	12.1
	C	M	M	329	21.0	891	15.1	1,314	12.4
	M	M	M	301	22.4	888	15.9	1,290	13.0
Wheat	C	C	C	339	20.3	968	14.2	1,409	10.5
	C	C	M	338	20.2	969	14.2	1,328	11.6
	C	M	M	335	21.1	926	15.4	1,301	12.2
	M	M	M	325	21.9	926	15.5	1,318	12.5
Main effect									
Cereal									
Corn				329	21.2	929	14.6	1,314	12.2[a]
Wheat				335	20.8	947	14.8	1,339	11.7[b]
Feed form									
	C	C	C	337[a]	20.4[b]	969[a]	13.9[b]	1,374[a]	11.0[c]
	C	C	M	344[a]	20.5[b]	970[a]	14.0[b]	1,321[ab]	11.9[b]
	C	M	M	333[ab]	21.0[ab]	909[b]	15.2[a]	1,307[b]	12.3[ab]
	M	M	M	314[ab]	22.2[a]	907[b]	15.7[a]	1,304[b]	12.7[a]
SEM[4]				22.43	1.45	54.01	0.81	61.35	0.66
				Probability					
Cereal				0.252	0.317	0.171	0.256	0.092	0.002
Feed form				0.001	0.002	0.001	0.001	0.003	0.001
cereal *Feed form				0.174	0.912	0.573	0.259	0.241	0.462

[a-b-c] Within a column, means without a common superscript differ ($P < 0.05$).
[1]C= crumble; M= mash.
[2]Body weight.
[3] Includes the weights of the digestive tract (from the beginning of the proventriculus to cloaca, with digesta content), the liver, and the pancreas.
[4]SEM (9 replicates of 2 pullets each per treatment).

Table 6. Influence of main cereal and feed form of the diets on the relative weight (% BW) of the gizzard, gizzard digest content (% gizzard weight) and gizzard pH of the pullets

Cereal	Feed form[1]			5 week			10 week			17 week		
	0-5 week	5- 10 week	10- 17 week	Weight (% BW)	Gizzard content	pH	Weight (% BW)	Gizzard content	pH	Weight (% BW)	Gizzard content	pH
Corn	C	C	C	4.6	31.3	3.42	2.7	16.3	3.96	3.2	19.6	3.63
	C	C	M	4.5	29.8	3.38	2.5	15.0	3.73	4.1	28.4	3.33
	C	M	M	4.6	28.1	3.51	4.9	31.9	2.77	4.4	28.7	3.06
	M	M	M	5.9	34.3	3.01	5.0	32.6	2.61	4.6	28.5	3.21
Wheat	C	C	C	3.9	27.1	3.44	3.0	21.3	3.71	2.5	15.0	4.11
	C	C	M	4.1	27.5	3.33	3.0	18.8	3.68	3.7	27.1	3.20
	C	M	M	4.5	28.6	3.26	4.7	30.3	2.65	4.2	29.3	3.16
	M	M	M	5.7	34.1	2.83	4.9	30.2	2.75	4.2	26.6	3.14
Main effect												
Cereal												
Corn				4.9[a]	30.9	3.30	3.8	24.0	3.3	4.1[a]	26.3[a]	3.31
Wheat				4.6[b]	29.3	3.20	3.9	25.2	3.2	3.7[b]	24.5[b]	3.40
Feed form												
	C	C	C	4.3[b]	29.2[b]	3.40[a]	2.9[b]	18.8[b]	3.84[a]	2.8[c]	17.3[b]	3.87[a]
	C	C	M	4.3[b]	28.7[b]	3.30[a]	2.8[b]	16.9[b]	3.70[a]	3.9[b]	27.8[a]	3.26[b]
	C	M	M	4.6[b]	28.4[b]	3.40[a]	4.8[a]	31.1[a]	2.71[b]	4.2[a]	29.0[a]	3.11[b]
	M	M	M	5.8[a]	34.1[a]	2.90[b]	5.0[a]	31.4[a]	2.68[b]	4.4[a]	27.5[a]	3.17[b]
SEM[2]				0.53	5.09	0.35	0.457	4.902	0.38	0.57	3.56	0.46
				Probability								
Cereal				0.007	0.196	0.215	0.280	0.256	0.467	0.001	0.034	0.389
Feed form				0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
cereal *Feed form				0.395	0.506	0.676	0.052	0.259	0.483	0.163	0.183	0.211

[a-b-c] Within a column, means without a common superscript differ ($P < 0.05$).

[1]C= crumble; M= mash.

[2]SEM (9 replicates of 2 pullets each per treatment).

Table 7. Influence of main cereal and Feed form of the diets on the relative length (cm/ kg BW) of the organs of the SI and ceca of pullets

	Feed form[1]			5 week					10 week					17 week				
Cereal	0-5week	5-10week	10-17week	Duod[2]	Jejun[3]	Ileum	SI[4]	Ceca	Duod	Jejun	Ileum	SI	Ceca	Duod	Jejun	Ileum	SI	Ceca
Corn	C	C	C	30.9	158.6	128.0	317.5	33.0	10.8	61.7	48.5	121.0	13.4	7.9	45.5	36.9	90.3	12.9
	C	C	M	28.5	152.6	124.7	305.8	32.1	10.9	61.8	50.5	123.3	13.5	7.7	45.7	37.2	90.7	12.3
	C	M	M	30.0	160.9	132.4	323.2	33.0	11.8	66.1	50.4	128.4	13.7	8.0	47.4	38.1	93.5	12.3
	M	M	M	33.0	171.0	142.7	346.7	35.5	11.8	67.7	53.3	132.8	14.1	7.7	48.7	39.5	95.9	13.2
Wheat	C	C	C	30.7	155.3	127.2	313.2	32.8	10.5	61.4	49.6	121.5	13.0	7.2	44.0	36.4	87.6	12.3
	C	C	M	29.9	157.3	128.9	316.1	32.7	10.9	62.3	49.9	123.1	13.2	7.8	48.1	37.7	93.7	12.9
	C	M	M	30.0	157.4	127.1	314.5	33.1	11.6	65.1	50.2	126.9	14.1	7.8	47.6	38.4	93.9	13.2
	M	M	M	31.5	165.4	128.3	325.2	33.7	11.2	64.2	48.1	123.5	13.6	7.7	48.6	38.1	94.4	12.9
Main effects																		
Cereal																		
Corn				30.6	160.8	132.0	323.3	33.4	11.3	64.3	50.7	126.4	13.7	7.8	46.8	37.9	92.6	12.7
Wheat				30.5	158.8	127.9	317.3	33.1	11.1	63.3	49.4	123.7	13.5	7.6	47.1	37.7	92.4	12.8
Feed form																		
	C	C	C	30.8[ab]	157.0	127.6	315.4	32.9	10.7[b]	61.5[b]	49.0	121.3[b]	13.2[b]	7.5	44.7[b]	36.7	88.9	12.6
	C	C	M	29.2[b]	154.9	126.8	311.0	32.4	10.9[b]	62.1[b]	50.2	123.2[b]	13.4[ab]	7.8	46.9[ab]	37.5	92.2	12.6
	C	M	M	30.0[ab]	159.1	129.8	318.9	33.0	11.7[a]	65.6[a]	50.3	127.6[a]	13.9[a]	7.9	47.5[ab]	38.2	93.7	12.7
	M	M	M	32.3[a]	168.2	135.5	335.9	34.6	11.5[a]	66.0[a]	50.7	128.1[a]	13.9[a]	7.7	48.7[a]	38.8	95.2	13.7
SEM[5]				3.0	15.63	13.88	31.17	3.21	0.98	4.82	5.16	9.58	1.09	0.88	4.03	4.1	8.14	1.04
				Probability														
Cereal				0.944	0.610	0.217	0.415	0.711	0.088	0.183	0.538	0.105	0.254	0.282	0.769	0.773	0.906	0.648
Feed form				0.025	0.07	0.241	0.095	0.212	0.001	<0.001	0.498	0.005	0.015	0.625	0.037	0.434	0.134	0.498
Cereal* Feed form				0.584	0.774	0.232	0.501	0.677	0.706	0.348	0.645	0.120	0.365	0.516	0.555	0.891	0.743	0.129

[1]C=crumble; M=mash.
[2]Duodenum.
[3]Jejunum.
[4]Small intestine.
[5] SEM (9 replicates 2 pullets each per treatment).

Table 8. Influence of main cereal and feed form of the diets on the relative length (cm/ kg BW) of the pullets and the tarsus.

	Feed form[1]			5 week		10 week		17 week	
Cereal	0-5 week	5-10 week	10-17 week	Pullet[2] length	Tarsus[3] length	Pullet length	Tarsus length	Pullet length	Tarsus length
Corn	C	C	C	117.1	179.8	60.3	73.0	47.9	63.1
	C	C	M	112.3	179.1	60.4	74.1	49.1	63.7
	C	M	M	117.3	183.9	64.2	78.4	49.0	64.4
	M	M	M	125.2	194.8	64.3	78.7	49.4	64.9
Wheat	C	C	C	114.1	178.3	60.6	74.4	46.1	60.2
	C	C	M	114.5	178.3	60.9	73.3	48.6	64.8
	C	M	M	114.9	181.0	62.2	75.4	49.0	65.1
	M	M	M	118.2	185.6	62.2	76.0	48.8	65.5
Main effects									
Cereal									
Corn				118.0	184.4	62.3	76.1	48.9	64.0
Wheat				115.4	180.8	61.5	74.8	48.1	63.9
Feed form									
	C	C	C	115.5^{b}	179.0^{b}	60.5	73.7^{b}	47.0^{b}	61.7^{b}
	C	C	M	113.4^{b}	178.8^{b}	60.7	73.7^{b}	48.9^{a}	64.2^{ab}
	C	M	M	116.1^{ab}	182.5^{ab}	63.2	76.9^{ab}	49.0^{a}	64.8^{ab}
	M	M	M	121.7^{a}	190.2^{a}	62.2	77.4^{a}	49.1^{a}	65.2^{a}
SEM[4]				6.61	10.75	8.955	3.831	1.74	3.60
				Probability					
Cereal				0.106	0.159	0.693	0.158	0.073	0.870
Feed form				0.003	0.007	0.653	0.004	0.014	0.020
Feed form*cereal				0.232	0.635	0.952	0.291	0.478	0.323

[1]C=crumble; M=mash.
[2]Measured from the tip of the beak to the end of the longest phalanx.
[3]Measured with a caliper above the spur.
[4] SEM (9 replicates of 2 pullets each per treatment).