INTRODUCTION

Innovations are needed to improve sustainability of livestock production systems, that is, to reduce their environmental impacts while maintaining or increasing their economic viability. Changing feeding practices, both the choice of raw materials or the form of the diet, seems to be one of the promising ways. Indeed, the feed represents the greatest part of the economic and environmental costs of poultry rearing (Boggia et al., 2010).

First, raw materials should be chosen according to their environmental impacts and availability. Increasing the number of usable raw materials improves the flexibility of systems, avoiding reliance on materials whose price fluctuates greatly. Sorghum [Sorghum bicolor (L.) Moench] seems suitable in this respect (Sedghi et al., 2011).

Second, the use of local and simplified diet, such as a crushed, mashed diet or whole grains, can reduce transport and processing costs (Dozier et al., 2006). The value of nonpelleted foods has previously been demonstrated in poultry production (Bennett et al., 2002; Jahan et al., 2006; Gabriel et al., 2008; Mirghelenj and Golian, 2009). It generally increases feed intake and maintains poultry performance (Yo et al., 1997, 1998; Gabriel et al., 2008; Umar Faruk et al., 2010). It can modify the development of the digestive tract, especially the gizzard (Forbes and Covasa, 1995; Carré, 2000; Amerah et al., 2007; Mirghelenj and Golian, 2009; Lu et al., 2011), and improve gut motility, activity, and health (Ferket, 2000; Engberg et al., 2002, 2004; Bjer-
rum et al., 2005). These beneficial effects were attributed to the greater particle size in the simplified diet (Carré, 2000, Engberg et al., 2002).

The aim of this work was to study the effects of the diet presentation (pelleted or simplified) and of the cereal (corn or sorghum) on the performance of geese. Indeed, most of the work on whole grains has been carried out on corn or wheat in broilers. Data on other poultry, such as geese (Auvergne et al., 2006, 2008; Lu et al., 2011), are scarce. Nonetheless, the goose is an interesting animal model because its crop is not a truly differentiated organ (Sturkie, 1986) but its size influences food intake (Savory, 1985). Otherwise, fatty liver production requires high feed ingestion level for which animals should be prepared (Leprettre et al., 1997; Guy et al., 1998), for example, by increasing storage capacity of the food in the proximal part of the digestive tract. The presentation of the diet could play an important role in such a preparation due to relations between particle size, feed hydration, and gut motility.

**MATERIALS AND METHODS**

**Birds and Feeding Program**

This trial was carried out at the Goose Breeding Station (Coulaures, Dordogne, France). In total, 480 one-day-old geese (type Maxipalm) were divided into 4 groups (3 pens of 20 males and 20 females per group). All birds were fed ad libitum with a complete pelleted diet (AME\textsubscript{m} 11.70 MJ/kg, CP 18.00%; manufactured by DFP Nutraliance, Saint-Ybard, Corrèze, France) from 1 d to 51 d. The groups differed in the diet offered to birds between 52 and 102 d of age: a complete pelleted diet containing 500 g of sorghum/kg (CS group; AME\textsubscript{n} 11.29 MJ/kg, CP 16.70%); a mixture containing 500 g of protein-rich pellets and 500 g of sorghum whole seeds/kg (MS group; AME\textsubscript{n} 11.61 MJ/kg, CP 14.30%); a complete pelleted diet containing 500 g of corn/kg (CC group; AME\textsubscript{n} 11.33 MJ/kg, CP 16.40%); or a mixture containing 500 g of protein-rich pellets and 500 g of corn mash/kg (MC group; AME\textsubscript{n} 11.48 MJ/kg, CP 14.50%). The feeding program of growing geese was intended to prepare the birds for force feeding (Guémené and Guy, 2004). For this purpose, birds were fed a restricted diet from 55 to 98 d of age, to progressively adapt them to take in large amounts of food in a short period. The feeding program we used was adapted from Leprettre et al., (1997). Birds were fed ad libitum from 1 to 54 d of age and then had controlled access to food: 4 h/d (2 h in the morning and 2 h in the afternoon) from 55 to 68 d, 2 h/d from 69 to 95 d, and 3 h/d from 96 to 102 d of age.

The diets used during the rearing period met NRC requirements (NRC, 1994). Sorghum used for this experiment (Argence variety) was tannin-free. From 102 to 117 d, 33 birds/sex/group were force fed with a mixture of 340 g of corn flour, 240 g of whole corn, 400 g of water, and vitamins (E: 32.00 UI/kg; B\textsubscript{1}: 4.00 mg/kg; K\textsubscript{3}: 2.86 mg/kg) and minerals (FeSO\textsubscript{4}: 55.40 mg; CuSO\textsubscript{4}: 15.00 mg; ZnSO\textsubscript{4}: 40.00 mg; MnSO\textsubscript{4}: 74.00 mg; Ca: 2.13 g, Na: 1.44 g; P: 0.23 g/kg).

The birds used for force feeding were chosen according to their live weight at 102 d to be representative of the live weight variability within groups.

**Housing and Management Conditions**

The birds were housed in pens of 19 m\textsuperscript{2} containing 40 birds (20 males and 20 females). The pens were equipped with 2 drinkers, 3 feeders, and outdoor access (91.5 m\textsuperscript{2}/pen). Geese had outdoor access between 0700 h and 1800 h from 41 to 102 d of age. The room temperature was maintained at 28°C from the first week after hatching and was subsequently gradually reduced to 22°C at 40 d of age, after which no heat was provided.

**Measurements and Analytical Methods**

Birds were weighed individually at 1, 52, 69, 84, 96, and 102 d after 18 h of fasting and at 117 d after 8 h of fasting. Feed intake per pen was measured at 54, 62, 68, 76, 83, 91, 95, and 102 d. In the MS and MC groups, the content of the feed refusal (that is, the relative amounts of uneaten sorghum whole seeds vs. protein-rich pellets or corn mash vs. protein-rich pellets) were also measured. During force feeding, the quantity of corn distributed was measured for each meal. Mortality was recorded daily. Birds were slaughtered at 69 d and 96 d of age (6 geese per sex and group) to study gizzard development and carcass traits according to the WPSA method. The weights of gut (small intestine, duodenum, jejunum, ileum, and cecum), gizzard, liver, carcass (eviscerated carcass with skin), and abdominal fat were measured as well as breast and thigh weights (without skin and subcutaneous fat). Also, birds (33 geese per sex and group) were slaughtered after force feeding, at 117 d, to measure the weight of breast with skin, gizzard, and fatty liver. Birds were killed according to the European council regulations (EU Council Directive, 2009).

Geese have no truly differentiated crop; however, the feeding method used involves partly expanding the esophagus to form a pocket, which we will call the crop. At 102 d, the volume of the crop (13 geese per sex and group selected on their live weight at 102 d) was measured after 18 h of fasting. A balloon was introduced into the esophagus and inflated to a constant pressure (70 mmHg). The volume of air introduced was measured by displacement of a water column.

The chemical composition of the experimental diets was analyzed by INZO (Château-Thierry, France) and shown in Table 1. The physical characteristics of the experimental diets are shown in Table 2. Length and diameter of the pellets were measured on 200 samples. Particle size was measured using successive sieves of decreasing mesh on dry material for corn mash and sorghum whole seeds or wet material for the complete
pelleted diets and protein-rich pellets (Lebas and Lamberley, 1999). The hydration capacity was measured by the method of Giger-Reverdin (2000). First, 2 g of feed-stuff were mixed with 10 mL of distilled water. After 8 h at room temperature, the mixture was centrifuged (966 × g for 10 min at 20°C) before weighing the pellet to determine the water-holding capacity (WHC). Second, 25 mL of distilled water were added to 2 g of feedstuff. After 8 h at room temperature, the increased volume of the feedstuff due to hydration was measured to determine the swelling capacity (SC).

**Statistical Analysis**

Data were analyzed using the GLM procedure of PASW Statistics 18 (version 18.0.2, SPSS Inc., Chicago, IL). All data were analyzed including the effects of cereal (2 levels: corn or sorghum), presentation (2 levels: complete pelleted diet or mixture diet), sex (2 levels: male and female), and their interaction in the model, except for feed intake and the feed conversion ratio (FCR) measured during the rearing period where the sex was not included in the model because males and females were mixed in each pen. The effect of the sex was significant for many of the variables measured, but interactions between sex, cereal, and presentation effects were never significant. Therefore, we have not reported the means of the variables for each sex in the present paper because the sexual dimorphism was previously described by Guy et al. (1998). The physical characteristics (length, diameter, WHC, and SC) of the experimental food were also analyzed using GLM procedures using the diet effect in the model (6 levels: CS, CC, protein-rich pellets to complement sorghum, Table 1. Ingredients and chemical composition of the experimental diets

<table>
<thead>
<tr>
<th>Item</th>
<th>Group1</th>
<th>Group2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete pelleted diets</td>
<td>Mixture diets</td>
</tr>
<tr>
<td></td>
<td>CC</td>
<td>MS</td>
</tr>
<tr>
<td>Ingredient (g/kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>500.0</td>
<td>—</td>
</tr>
<tr>
<td>Sorghum</td>
<td>500.0</td>
<td>1,000.0</td>
</tr>
<tr>
<td>Wheat</td>
<td>162.5</td>
<td>193.2</td>
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<tr>
<td>Rapeseed meal</td>
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<td>30.0</td>
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<tr>
<td>Soybean meal</td>
<td>145.0</td>
<td>117.5</td>
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<tr>
<td>Wheat middling</td>
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<td>Calcium carbonate</td>
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<tr>
<td>Salt</td>
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<tr>
<td>Dicalcium phosphate</td>
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<td>Sodium bicarbonate</td>
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<tr>
<td>Methionine</td>
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<tr>
<td>Lysine</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Threonine</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Additive</td>
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<td>2.0</td>
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<td>Vitamin and mineral premix2</td>
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<tr>
<td>DM</td>
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<td>87.6</td>
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<tr>
<td>CP</td>
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<td>16.7</td>
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<tr>
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<tr>
<td>Fat</td>
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</tr>
<tr>
<td>Cellulose</td>
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<td>3.9</td>
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<td>Starch (% DM)</td>
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</tr>
<tr>
<td>Sugar (% DM)</td>
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<td>4.2</td>
</tr>
<tr>
<td>Methionine + Cystine</td>
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<tr>
<td>Lysine</td>
<td>0.87</td>
<td>0.90</td>
</tr>
<tr>
<td>Threonine</td>
<td>0.58</td>
<td>0.59</td>
</tr>
<tr>
<td>ADF3 (MJ/kg)</td>
<td>11.3</td>
<td>11.3</td>
</tr>
<tr>
<td>NDF4</td>
<td>14.6</td>
<td>14.2</td>
</tr>
<tr>
<td>ADF4</td>
<td>4.9</td>
<td>5.4</td>
</tr>
<tr>
<td>ADL4</td>
<td>1.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Plant cell walls4</td>
<td>14.5</td>
<td>14.0</td>
</tr>
</tbody>
</table>

1CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash (CM) and 50% of protein-rich pellets (PRC); MS: mixture diet containing 50% of sorghum whole seeds (SWS) and 50% of protein-rich pellets (PRS).

2Vitamins, A: 9,990 UI/kg; D₃: 1,998 UI/kg; E: 10.0 UI/kg; B₁: 2.0 mg/kg; K₁: 1.0 mg/kg; B₂: 2.5 mg/kg; B₃: 5.1 mg/kg; B₆: 1.0 mg/kg; PP: 24.9 mg/kg; B₉: 0.3 mg/kg; choline: 300 mg/kg. Oligo elements, Cu: 9.3 mg/kg; Fe: 29.0 mg/kg; I: 0.99 mg/kg; Co: 0.16 mg/kg; Mn: 70 mg/kg; Zn: 47 mg/kg; Se: 0.20 mg/kg; clay (sepiolite): 2 g/kg.

3AMEₚ was calculated from Fisher and Mc Nab (1987).

4Calculated from Sauvant et al. (2004). NDF = neutral detergent fiber; ADF = acid detergent fiber; and ADL = acid detergent lignin.
protein-rich pellets to complement corn, sorghum whole seeds, and corn mash). When significant, differences between groups were compared using the Duncan test.

Mortality, during rearing and force-feeding periods, was analyzed using the chi-squared test. Differences were treated as significant when $P \leq 0.05$.

**RESULTS**

**Physical Characteristics of Experimental Diets**

The diameter of the pellets was similar for all the experimental diets (4.2 ± 0.1 mm; NS) but they were shorter in the protein-rich pellets complementing the sorghum whole seeds than in the protein-rich pellets complementing the corn mash (9.0 ± 2.2 mm vs. 10.2 ± 2.2 mm, $P < 0.05$). The proportion of large particles (>2.0 mm) was higher in the mixture diets (75% and 80% in MS and MC, respectively) than in the complete pelleted diets (26% and 31%, in CC and CS respectively; Table 2) mainly due to the diameter of the whole sorghum seeds (3.3 ± 0.8 mm) and the proportion of very large particles (>4.0 mm) in corn mash (19%). Conversely, for the same reason, the proportion of small particles (<0.5 mm) was less in the complete pelleted diets (52% and 48% in CC and CS, respectively) than in the mixture diets (3% and 5%, in MC and MS, respectively).

Measurements of hydration capacity, WHC, and SC showed differences between the experimental foods ($P < 0.001$). The 4 pelleted diets showed greater hydration capacity than the 2 unpelleted foods (−67% for WHC and −79% for SC; $P < 0.001$; Table 2). Sorghum whole seeds had a lower hydration capacity than corn mash (−40% for WHC and −30% for SC; $P < 0.05$).

**Feed Intake During the Rearing Period**

There was no significant interaction between the cereal and the presentation effect and no effect of the cereal on feed intake, except between 69 and 76 d when feed intake was 9% lower in birds fed corn rather than sorghum ($P < 0.05$). Conversely, the presentation of the diet had a significant effect from 69 d to 102 d (Table 3). In general, during the first 2 wk of the trial (52–68 d), the feed intake was not affected by cereal or presentation of the diet (325 ± 3.6 g/d; NS). On the other hand, during the last part of the trial (69–102 d), intake was higher in birds fed the mixture compared with the complete pellets (251 ± 12 vs. 272 ± 8 g/d; $P < 0.001$). Over the whole period, the feed intake tended to be lower in the CC group than in the others (14,227 g vs. 15,296 g, $P = 0.10$).

During the first 3 days of the trial, the birds fed the mixture diet preferred the protein-rich pellets to the cereal (59% of protein rich pellets vs. 41% of corn mash, and 61% of protein-rich pellets vs. 39% of sorghum whole seeds). After this period, the consumption of the 2 compounds of the mixture diets was balanced (between 52 and 48% depending on the periods). Over the whole period of rearing (52–102 d), more of the protein-rich pellets were consumed than the cereal (53% vs. 47%) in both MC and MS groups.

**Mortality and Bird Growth During the Rearing Period**

The mortality during the rearing period (52–102 d) was significantly higher in the CS group than in the others (11.6% vs. 1.0%; $P < 0.001$). This effect was due to a colibacillosis in one of the 3 pens, which resulted in
the death of 6 birds between 63 and 68 d rather than a cereal or a presentation of diet effect.

The BW was similar in the 4 groups at 1 d (106 ± 0.4 g), 52 d (4,549 ± 19 g), and 69 d (5,466 ± 25 g; NS; Table 4). Between 84 and 102 d, BW was 3.8% lower in birds fed the complete pelleted diets than with the mixture diet (\( P < 0.001 \)). Interaction between cereal and presentation was significant at 96 d when the lowest BW was observed in the CC group. The cereal, presentation of the diet, or their interaction had significant effects on ADG of the birds from 69 d. Birds fed sorghum or the mixture diets gained more (at the beginning of the trial) or lost less (at the end of the trial) than birds fed corn or the complete pelleted diets (\( P < 0.05 \) to 0.001 depending on the period; Table 4).

Over the whole rearing period, ADG was 17% lower in birds fed the complete pelleted diets than the mixture diets (\( P < 0.001 \)).

Between 52 and 69 d of age, the FCR was 6% higher in birds fed sorghum rather than corn (\( P < 0.05 \)) without effect of presentation (Table 5). However, after 69 d, the cereal did not influence the FCR whereas the mixture diets lowered the FCR compared with complete pelleted diets (11.41 vs. 12.67; \( P < 0.05 \), Table 5).

**Body Traits at the End of the Rearing Period**

At 69 d of age, the relative weights of carcass (−1.8%) and abdominal fat (−8%) were lower in birds fed sorghum instead of corn (\( P < 0.05 \); Table 6). At 96 d of age, the relative weight of the breast was higher in birds fed corn and complete pelleted diets (\( P < 0.05 \) for cereal and presentation effect), while the relative weight of gut was lower in birds fed the complete pelleted diets (−8.5%; \( P < 0.001 \)). The weight of liver tended to be higher and the weight of gizzard tended to be lower in birds fed the mixture diet (\( P < 0.1 \)). The other body traits were similar in the 4 groups at both slaughter stages.

**Crop Volume**

The cereal had no influence on the crop volume before the force-feeding period, but the crop was 10% smaller in birds fed corn rather than sorghum (\( P < 0.001 \)).

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### Table 3. Individual feed intake during the rearing period\(^1\)

<table>
<thead>
<tr>
<th>Period</th>
<th>Feeding access</th>
<th>Group(^2)</th>
<th>SEM</th>
<th>Significance(^3)</th>
<th>CC</th>
<th>CS</th>
<th>MC</th>
<th>MS</th>
<th>C</th>
<th>P</th>
<th>C×P</th>
</tr>
</thead>
<tbody>
<tr>
<td>52–54 d (g/d)</td>
<td>Ad libitum</td>
<td>CC</td>
<td>280</td>
<td>294</td>
<td>287</td>
<td>295</td>
<td>6.4</td>
<td>0.453</td>
<td>0.759</td>
<td>0.847</td>
<td></td>
</tr>
<tr>
<td>55–62 d (g/d)</td>
<td>2 h + 2 h</td>
<td>CS</td>
<td>298</td>
<td>317</td>
<td>325</td>
<td>327</td>
<td>5.1</td>
<td>0.276</td>
<td>0.072</td>
<td>0.374</td>
<td></td>
</tr>
<tr>
<td>63–68 d (g/d)</td>
<td>2 h + 2 h</td>
<td>MC</td>
<td>357</td>
<td>364</td>
<td>356</td>
<td>340</td>
<td>4.2</td>
<td>0.578</td>
<td>0.146</td>
<td>0.200</td>
<td></td>
</tr>
<tr>
<td>69–76 d (g/d)</td>
<td>2 h</td>
<td>MS</td>
<td>203</td>
<td>235</td>
<td>240</td>
<td>250</td>
<td>6.3</td>
<td>0.041</td>
<td>0.016</td>
<td>0.236</td>
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<tr>
<td>77–83 d (g/d)</td>
<td>2 h</td>
<td>C</td>
<td>277</td>
<td>297</td>
<td>307</td>
<td>310</td>
<td>5.3</td>
<td>0.212</td>
<td>0.032</td>
<td>0.313</td>
<td></td>
</tr>
<tr>
<td>84–91 d (g/d)</td>
<td>2 h</td>
<td>P</td>
<td>240</td>
<td>250</td>
<td>271</td>
<td>263</td>
<td>5.0</td>
<td>0.846</td>
<td>0.029</td>
<td>0.330</td>
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</tr>
<tr>
<td>92–95 d (g/d)</td>
<td>2 h</td>
<td>C×P</td>
<td>287</td>
<td>310</td>
<td>313</td>
<td>316</td>
<td>4.7</td>
<td>0.105</td>
<td>0.055</td>
<td>0.194</td>
<td></td>
</tr>
<tr>
<td>96–102 d (g/d)</td>
<td>3 h</td>
<td>C</td>
<td>236</td>
<td>229</td>
<td>247</td>
<td>244</td>
<td>2.9</td>
<td>0.310</td>
<td>0.016</td>
<td>0.590</td>
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</tr>
<tr>
<td>52–102 d (g)</td>
<td></td>
<td></td>
<td>14,227</td>
<td>15,021</td>
<td>15,442</td>
<td>15,424</td>
<td>175.8</td>
<td>0.117</td>
<td>0.006</td>
<td>0.103</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) The individual feed intake was calculated from the intake per pen (n = 3 pens/group) and the number of birds in the pen during the observation period (40 birds per pen at the beginning of the experimental period).

\(^2\) CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash and 50% of protein-rich pellets; MS: mixture diet containing 50% of sorghum whole seeds and 50% of protein-rich pellets.

\(^3\) C: cereal; P: presentation of the diet.

### Table 4. Live weight and ADG during the rearing period

<table>
<thead>
<tr>
<th>Item</th>
<th>Groups(^1)</th>
<th>SEM</th>
<th>Significance(^2)</th>
<th>CC</th>
<th>P</th>
<th>S</th>
<th>C×P</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW (g)</td>
<td>CC</td>
<td>CS</td>
<td>MC</td>
<td>MS</td>
<td>0.4</td>
<td>0.357</td>
<td>0.785</td>
</tr>
<tr>
<td>1 d</td>
<td>107</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>19.5</td>
<td>0.434</td>
<td>0.507</td>
</tr>
<tr>
<td>52 d</td>
<td>4,512</td>
<td>4,562</td>
<td>4,558</td>
<td>4,562</td>
<td>24.9</td>
<td>0.818</td>
<td>0.372</td>
</tr>
<tr>
<td>69 d</td>
<td>5,421</td>
<td>5,448</td>
<td>5,529</td>
<td>5,466</td>
<td>29.3</td>
<td>0.563</td>
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<tr>
<td>84 d</td>
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<td>5,664</td>
<td>5,829</td>
<td>5,777</td>
<td>31.0</td>
<td>0.178</td>
<td>&lt;0.001</td>
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<tr>
<td>96 d</td>
<td>5,646(^b)</td>
<td>5,819(^b)</td>
<td>6,004(^c)</td>
<td>5,976(^c)</td>
<td>34.1</td>
<td>0.550</td>
<td>&lt;0.001</td>
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<tr>
<td>102 d</td>
<td>5,673</td>
<td>5,728</td>
<td>5,913</td>
<td>5,931</td>
<td>0.8</td>
<td>0.130</td>
<td>0.218</td>
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<td>ADG (g/d)</td>
<td>52–69 d</td>
<td>53.6</td>
<td>52.6</td>
<td>57.1</td>
<td>53.2</td>
<td>0.0</td>
<td>0.021</td>
</tr>
<tr>
<td>69–84 d</td>
<td>8.6</td>
<td>13.7</td>
<td>20.7</td>
<td>21.2</td>
<td>0.6</td>
<td>0.003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>84–96 d</td>
<td>7.4</td>
<td>12.7</td>
<td>14.5</td>
<td>16.6</td>
<td>0.6</td>
<td>0.003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>96–102 d</td>
<td>4.9(^1)</td>
<td>−12.7(^ b)</td>
<td>−7.0(^ b)</td>
<td>−1.9(^ c)</td>
<td>0.9</td>
<td>&lt;0.001</td>
<td>0.709</td>
</tr>
<tr>
<td>52–102 d</td>
<td>23.3</td>
<td>22.8</td>
<td>27.8</td>
<td>27.6</td>
<td>0.5</td>
<td>0.703</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^a\) Within a row, means with no common superscript differed at \( P < 0.05 \).

\(^b\) CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash and 50% of protein-rich pellets; MS: mixture diet containing 50% of sorghum whole seeds and 50% of protein-rich pellets.

\(^c\) C: cereal; P: presentation of the diet; S: sex.
smaller in birds fed the mixture of protein-rich pellets and cereal than in those given the complete pelleted diet ($P < 0.05$; Table 7). It was also smaller in males than in females ($42.2 \text{ mL} \cdot \text{g}^{-1}$ vs. $48.1 \text{ mL} \cdot \text{g}^{-1}$; $P < 0.001$).

**Bird Performance During and After Force Feeding**

Mortality during the force-feeding period was similar in the 4 groups (26/264 = 9.8%; NS) and tended to be higher in males than in females (12.9% vs. 6.8%; $P = 0.098$). Cereal, presentation, and their interaction did not influence mortality in females; however, mortality was increased in males fed the mixture diets compared with complete pelleted diets (13/66 vs. 4/66; $P < 0.05$).

Cereal and presentation had no effect on feed intake, weight gain, FCR during the force-feeding period, or on body traits at the end of force feeding (Table 7). The amount of food given during force feeding was greater in males than in females (13,832 g vs. 12,734 g; $P < 0.001$; data not shown) because males were heavier than females, but weight gain during force feeding was similar in both sexes.

**DISCUSSION**

The aim of this work was to study the effects of the cereal (corn or sorghum) and of the diet presentation (pelleted or simplified feed) on the performance of geese to propose a more sustainable goose feeding system. The results showed that 1) tannin-free sorghum could be used in goose feeding during the rearing period because it did not decrease the performance at the end of the rearing period or after force feeding, compared with corn; 2) a simplified diet, in the form of a mixture of cereal and protein-rich pellets, seems promising for geese feeding because it increased their BW and reduced the amount of food given during force feeding was greater in males than in females (13,832 g vs. 12,734 g; $P < 0.001$; data not shown) because males were heavier than females, but weight gain during force feeding was similar in both sexes.

### Table 5. Feed conversion ratio (FCR) during the rearing period

<table>
<thead>
<tr>
<th>Period (d)</th>
<th>CC</th>
<th>CS</th>
<th>MC</th>
<th>MS</th>
<th>SEM</th>
<th>C</th>
<th>P</th>
<th>C×P</th>
</tr>
</thead>
<tbody>
<tr>
<td>52–69</td>
<td>5.9</td>
<td>6.3</td>
<td>5.8</td>
<td>6.2</td>
<td>0.09</td>
<td>0.046</td>
<td>0.517</td>
<td>0.966</td>
</tr>
<tr>
<td>52–84</td>
<td>8.6</td>
<td>8.7</td>
<td>7.6</td>
<td>8.0</td>
<td>0.19</td>
<td>0.464</td>
<td>0.036</td>
<td>0.781</td>
</tr>
<tr>
<td>52–96</td>
<td>11.2</td>
<td>10.8</td>
<td>9.5</td>
<td>9.7</td>
<td>0.26</td>
<td>0.866</td>
<td>0.006</td>
<td>0.486</td>
</tr>
<tr>
<td>52–102</td>
<td>12.3</td>
<td>13.1</td>
<td>11.6</td>
<td>11.2</td>
<td>0.30</td>
<td>0.726</td>
<td>0.031</td>
<td>0.221</td>
</tr>
</tbody>
</table>

1FCR per bird was determined using measured live weight (individual measure) and estimated feed intake (measure per pen).

2CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash and 50% of protein-rich pellets; MS: mixture diet containing 50% of sorghum whole seeds and 50% of protein-rich pellets.

3C: cereal; P: presentation of the diet.

### Table 6. Geese carcass composition at 69 and 96 d of age

<table>
<thead>
<tr>
<th>Item</th>
<th>Group</th>
<th>SEM</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>CS</td>
<td>MC</td>
</tr>
<tr>
<td>69 d of age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (g)</td>
<td>5,368</td>
<td>5,394</td>
<td>5,531</td>
</tr>
<tr>
<td>Carcass (g)</td>
<td>3,116</td>
<td>3,134</td>
<td>3,191</td>
</tr>
<tr>
<td>Carcass (% of BW)</td>
<td>58.0</td>
<td>57.3</td>
<td>57.6</td>
</tr>
<tr>
<td>Gut (% of BW)</td>
<td>5.4</td>
<td>5.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Gizzard (% of BW)</td>
<td>3.8</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Liver (% of BW)</td>
<td>1.7</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Abdominal fat (% of BW)</td>
<td>3.0</td>
<td>2.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Breast (% of carcass)</td>
<td>7.3</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Thigh with bones (% of carcass)</td>
<td>10.5</td>
<td>11.0</td>
<td>10.5</td>
</tr>
<tr>
<td>96 d of age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (g)</td>
<td>5,641</td>
<td>5,824</td>
<td>5,976</td>
</tr>
<tr>
<td>Carcass (g)</td>
<td>3,209</td>
<td>3,317</td>
<td>3,352</td>
</tr>
<tr>
<td>Carcass (% of BW)</td>
<td>56.9</td>
<td>57.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Gut (% of BW)</td>
<td>5.94</td>
<td>5.53</td>
<td>6.28</td>
</tr>
<tr>
<td>Gizzard (% of BW)</td>
<td>3.87</td>
<td>3.90</td>
<td>3.74</td>
</tr>
<tr>
<td>Liver (% of BW)</td>
<td>2.04</td>
<td>1.94</td>
<td>2.06</td>
</tr>
<tr>
<td>Abdominal fat (% of BW)</td>
<td>3.86</td>
<td>3.30</td>
<td>3.65</td>
</tr>
<tr>
<td>Breast (% of carcass)</td>
<td>8.1</td>
<td>7.8</td>
<td>7.7</td>
</tr>
<tr>
<td>Thigh with bones (% of carcass)</td>
<td>10.2</td>
<td>10.8</td>
<td>10.5</td>
</tr>
</tbody>
</table>

1CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash and 50% of protein-rich pellets; MS: mixture diet containing 50% of sorghum whole seeds and 50% of protein-rich pellets.

2C: cereal; P: presentation of the diet; S: sex.

3Without skin and subcutaneous fat.
FCR during rearing compared with a complete pelleted diet. But it also reduced the volume of the crop, which could reduce the success of the force feeding.

Sorghum has not been used in poultry feeding for many years because in old varieties (NK 123 or Sultian), the seeds contained condensed tannins, mainly flavonoids (Bate-Smith, 1969; Watterson and Butler, 1983), which reduce the diet’s digestibility and the growth of the birds (Elkin et al., 1996; Nyachoti et al., 1997). Genetic selection programs were devoted to develop tannin-free varieties (0.06% vs. > 1.5% in old varieties; Conan et al., 1992) and now sorghum is commonly used in poultry feeding (Gualtieri and Rapaccini, 1990; Selle et al., 2010). The present results show that sorghum could be used in goose feeding, in complete pellets, or as whole seeds, as previously demonstrated (Arroyo et al., 2012). Indeed, in the present study, the cereal used in the diet had very little effect on animal performance.

Sorghum and corn have very similar chemical and nutritional composition. Sorghum has a slightly higher energy content (+100 kcal AMEn/kg; +3%) but a lower content of carotenoids and vitamin A (0.1 vs. 0.83 $10^3$ UI/kg) than corn (Sauvant et al., 2004), but this would not affect the dietary balance for birds. Another difference between the 2 grains could concern the type of starch, amylopectin or amylose, which differ greatly between cereals but also among varieties and due to seasonal effects within cereals (Jenkins and Donald, 1995). In birds, digestibility is higher for amylopectin than for amylose (Skiba et al., 2005; Zhou et al., 2010), and generally, the amylopectin level is higher in corn than in sorghum. Hence, a difference in the nature of the starch could explain the lower weights of carcass and abdominal fat observed at 69 d in birds fed sorghum instead of corn, despite similar feed intake and nutritional composition of experimental diets. Indeed, the digestive tract needs time to adapt to a change in nutrient supply (Bedford, 1996), in this case at 52 d. Similar body traits at 96 d with both cereals support this latter hypothesis and suggest that 6 wk after the diet switch, the animals were adapted and had compensated for the differences. At that age, the breast development was less in animals fed sorghum rather than corn. This difference could be due to kafirins, proteins of sorghum, which disrupt the protein digestion (Selle et al., 2010).

In addition to its value for bird feeding, sorghum also has several advantages in regard to the environment. It is more drought-resistant than corn (Farré and Faci, 2006) and can be more easily grown without irrigation. Sorghum seeds do not need to be dried before storage, which reduces energy use. Finally, the use of local whole sorghum seeds could reduce the feed costs due to transport, handling, and processing (Dozier et al., 2006). Therefore, sorghum offers an interesting alternative to corn to progress toward more sustainable goose feeding system.

Contrary to cereal effects which were weak, the presentation of the diet greatly affected the geese’s performance, that is, feed intake, growth, and body traits. The results showed that during the first 2 wk of the trial, the diet presentation did not affect the feed intake. However, the birds were given a complete pelleted diet before the trial, from 1 to 52 d of age. Therefore, here, the geese adapted quickly to a new feed presentation. On the other hand, Arroyo et al. (2012) showed that a change in the feed presentation could alter the feed intake for one week after the switch, when the diet was offered in the form of flour or a loose mixture. Such a difference could be explained by the age of the birds at the moment of the diet change, which was later in the present study (52 d vs. 42 d). At the end of the trial, the intake was higher when the diet was offered in the form of a mixture compared with a complete pelleted diet, in agreement with Arroyo et al. (2012). This result confirmed that separating the sources of energy (in the form of cereal grains) and proteins (in form of protein-rich pellets) did not prevent the birds from having a balanced diet (Hughes, 1984).

The results showed that the presentation of the diet affected the body traits, mainly digestive tract but also

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**Table 7. Performance of geese before, during, and after force-feeding**

<table>
<thead>
<tr>
<th>Item</th>
<th>Group1</th>
<th>SEM</th>
<th>Significance2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>CS</td>
<td>MC</td>
</tr>
<tr>
<td>At 102 d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (g)</td>
<td>5,673</td>
<td>5,734</td>
<td>5,913</td>
</tr>
<tr>
<td>Volume of crop/BW (mL/g)</td>
<td>47.0</td>
<td>45.5</td>
<td>42.2</td>
</tr>
<tr>
<td>102–117 d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed intake (g)</td>
<td>13,324</td>
<td>13,238</td>
<td>13,223</td>
</tr>
<tr>
<td>Average gain (g)</td>
<td>2,276</td>
<td>2,382</td>
<td>2,310</td>
</tr>
<tr>
<td>FCR</td>
<td>5.9</td>
<td>5.6</td>
<td>5.8</td>
</tr>
<tr>
<td>At 117 d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (g)</td>
<td>7,968</td>
<td>8,122</td>
<td>8,256</td>
</tr>
<tr>
<td>Fatty liver (g)</td>
<td>858</td>
<td>880</td>
<td>889</td>
</tr>
<tr>
<td>Breast3 (g)</td>
<td>384</td>
<td>389</td>
<td>403</td>
</tr>
<tr>
<td>Gizzard (g)</td>
<td>151</td>
<td>151</td>
<td>160</td>
</tr>
</tbody>
</table>

1CC: complete pelleted diet containing 50% of corn; CS: complete pelleted diet containing 50% of sorghum; MC: mixture diet containing 50% of corn mash and 50% of protein-rich pellets; MS: mixture diet containing 50% of sorghum whole seeds and 50% of protein-rich pellets.

2C: cereal; P: presentation of the diet; S: sex.

3Muscles with skin and subcutaneous fat.
carcass composition. Whole grains increased the animal gut development, as previously described (Lu et al., 2011), but tended to reduce the gizzard development, contrary to previous results (Gabriel et al., 2008; Lu et al., 2011). The crop volume was smaller in birds fed the mixture of protein-rich pellets and cereal than with the complete pelleted diet. These results could be explained by the lower hydration capacity of whole grains compared with pellets. First, previous results suggested a relation between feedstuff hydration capacity and structure of the gut (Shelton et al., 2005; Scott, 2007). Second, a lower SC of simplified feed probably expanded the crop less than the pellets.

Hydration capacity of a feedstuff is correlated with cell wall content (Robertson and Eastwood, 1981; Buffo et al., 1998), especially NDF and ADF levels (Giger-Reverdin, 2000), and the form of starch (Pinnavaia and Pizzanrani, 1998). The fiber and the starch contents of the experimental diets were similar whichever way they were presented. However, crushing and pelleting reduces the particle size, increasing the contact surface of feed particles with water, and could increase the hydration capacity of the diet. Additionally, pelleting partially gelatinizes starch, which should increase its WHC (Pinnavaia and Pizzanrani, 1998). On the other hand, Selle et al. (2009) showed in chickens a positive relationship between WHC and feed intake whereas in the present study, the diet with the highest hydration capacity was eaten the least.

The rearing of geese for fatty liver production should prepare the birds for force feeding. However, the diet should have a high hydration capacity to allow sufficient development of the crop and prepare the birds for force feeding.}

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