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**Primary Audience:** Nutritionists, Flock Supervisors

## SUMMARY

Feeding has high economic and environmental costs in poultry production. The feeding of waterfowl for fatty liver production is largely based on the use of maize as an energy source. The aim of this trial was to study the effect of the form of presentation (whole grain or flour) and the amount (40.5, 56, or 100%, depending on the form) of sorghum in the overfeeding diet on the performance of geese. During overfeeding, a diet mainly composed of sorghum reduced the FCR of the geese and increased the weight of fatty liver, but reduced their commercial grading. The use of sorghum during geese overfeeding offers interesting prospects for a more sustainable fatty liver production system. Indeed, it could reduce the environmental effect of goose feeding while improving the flexibility of production systems, making it possible to use a cereal other than maize for overfeeding.

**Key words:** goose, sorghum, fatty liver, overfeeding

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## DESCRIPTION OF PROBLEM

France is the main producer (73%) of foie gras (fatty liver) of ducks or geese in the world [1]. French foie gras is a traditional product, a coveted dish with a high added value. The feeding of waterfowl for fatty liver production is largely based on the use of maize as an energy source. This cereal is used during the rearing period but is mainly used during the overfeeding period, when maize represents more than 95% of the raw material in the diet [2]. Maize represents the largest part of the economic [3] and environmental costs of poultry production [4–6], and the use of a single energy source reduces the flexibility of systems, imposing the use of a material whose price fluctuates greatly. Arroyo et al. [7, 8] reported that sorghum [*Sorghum bicolor* (L.) Moench] could be used in goose diets during the growing-finishing period. Sorghum could also be valuable to induce the steatosis of the liver; however, the use of this cereal during

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the overfeeding period remains to be studied. It was previously shown that geese must be overfed with a high-energy diet to induce steatosis [9]. Researchers have reported that high-protein (soybean [10]), starchless carbohydrate (fig [11]), or fatty ingredients (nut meal [12]) are less efficient in inducing steatosis than starchy ingredients. Sorghum, such as maize, is rich in starch (64% [13]), but is more drought-resistant and, thus, needs less water for crop irrigation [14] and does not require drying before storage. Therefore, using sorghum can reduce the environmental effect of foie gras production, mainly through water and energy use.

During the overfeeding period, for practical reasons, the diet is generally given as a mixture of 40.5% whole grain and 56% flour [15]. Therefore, the aim of this trial was to study the effect of the form of presentation (whole grain or flour) and the amount (40.5, 56, or 100%, depending on the form) of sorghum in the overfeeding diet on the performance of geese.

## MATERIALS AND METHODS

### *Birds and Management Conditions*

The animals were cared for in accordance with the guidelines for animal research of the French Ministry of Agriculture. In total, 264 ganders [16] were reared from d 1 to 98 as described by Arroyo et al. [17]. At 99 d of age, the birds were assigned to 3 treatments of 88 birds differing in the percentage and form of presentation of the sorghum in the diet offered to birds between 99 and 115 d of age. Treatment 1 consisted of 405 g of whole grain yellow maize/kg and 560 g of sorghum flour/kg (**F** treatment); treatment 2 consisted of 405 g of whole grain sorghum/kg and 560 g of yellow maize flour/kg (**W** treatment); or, treatment 3, which consisted of 405 g of whole grain sorghum/kg and 560 g of sorghum flour/kg (**FW** treatment). All the diets contained 3.5% of a vitamin/mineral premix (Table 1). Birds were allocated to the 3 treatments so as to have similar mean live weight and weight variability at 99 d in each treatment, as described by Arroyo et al. [7].

Before overfeeding, to homogenize the mixture and facilitate its distribution with the automatic feed dispenser, Gaveuse Mg 300 [18], 754 g of water/kg was added to the diets. The planned overfeeding program was previously described by Dubois et al. [15] and is shown in Figure 1. At 99 d, geese were overfed once a day, from d 100 to 102, the diet was given twice a day, and from d 103 to 114 the diet was given 5 times a day.

### *Housing and Management Conditions*

The 264 geese were housed in twenty-four 3- × 1-m pens, each with 11 geese. Each pen was equipped with drinkers. The room was maintained at a maximum temperature of 20°C and a maximum relative humidity of 90%.

### *Measurements*

The chemical composition of the experimental diets was analyzed by InVivo Labs [19] and is shown in Table 1. Briefly, the $AME_n$ was 4,440, 4,338, and 4,445 kcal/kg and the CP content was 7.3, 7.2, and 7.8% in the diets offered to the F, W, and FW treatments, respectively. Particle size of the diets was measured using successive sieves with decreasing mesh on the dry material. Birds were weighed individually at 99 d after 18 h of fasting, and at 115 d after 10 h of fasting. During the overfeeding period, the quantity of food given to the birds was measured individually at each meal. Mortality was recorded daily. At 115 d, the birds were slaughtered according to European council regulations [20].

After carcass evisceration, the liver was removed and weighed. Color was measured on the cold fatty liver (after 6 h at 7°C) along the ventral face of the large lobe [21]. The mean of 3 measurements at different sites (top, middle, and bottom of the large lobe) was computed for each liver. A commercial grading was carried out by an industry professional [22] trained to classify the raw fatty livers according to their potential commercial use. The livers were graded on a 3-point scale: class 1 corresponded to the best commercial class for livers with no defects, appropriate texture, usually processed as entire-canned livers, class 2 corresponded to livers with no external defects but too heavy (>900 g) to be processed as entire-canned livers, and class 3 livers had several defects in appearance or texture.

**Table 1.** Ingredients, chemical composition, and physical characteristics of the 3 experimental diets

| | Treatment[1] | | |
|---|---|---|---|
| Item | F | W | FW |
| Ingredient (g/kg) | | | |
| Sorghum | | | |
| Whole grain | — | 405 | 405 |
| Flour | 560 | — | 560 |
| Maize | | | |
| Whole grain | 405 | — | — |
| Flour | — | 560 | — |
| Vitamin and mineral premix[2] | 35 | 35 | 35 |
| Nutrient levels (% of gross matter, unless otherwise noted) | | | |
| DM | 86.9 | 87.0 | 86.7 |
| Ash | 1.4 | 1.4 | 1.2 |
| Organic matter | 85.5 | 85.6 | 85.5 |
| CP | 7.3 | 7.2 | 7.8 |
| Cellulose | 3.2 | 3.2 | 3.4 |
| Fat | 3.6 | 3.6 | 3.4 |
| Starch | 58.1 | 58.5 | 57.3 |
| Sugar | 1.3 | 1.4 | 1.1 |
| Met + Cys[3] | 0.4 | 0.4 | 0.3 |
| Lys[3] | 0.2 | 0.2 | 0.2 |
| Thr[3] | 0.3 | 0.3 | 0.3 |
| $AME_n$[4] (kcal/kg) | 4,440 | 4,338 | 4,445 |
| Physical characteristic (%) | | | |
| >4.0 mm | 42 | 0 | 0 |
| 2.0 mm | 0 | 41 | 41 |
| 1.0 mm | 13 | 21 | 14 |
| 0.5 mm | 26 | 21 | 26 |
| 0.3 mm | 8 | 9 | 8 |
| <0.3 mm | 11 | 8 | 11 |

[1]F = 405 g of whole maize and 560 g of sorghum flour/kg; W = 405 g of whole sorghum and 560 g of maize flour/kg; FW = 405 g of whole sorghum and 560 g of sorghum flour/kg.

[2]Vitamin and mineral premix contained 32 IU/kg of vitamin E; 4.00 mg/kg of vitamin $B_1$; 2.86 mg/kg of vitamin $K_3$; 55.40 mg/kg of $FeSO_4$; 15.00 mg/kg of $CuSO_4$; 40.00 mg/kg of $ZnSO_4$; 74.00 mg/kg of $MnSO_4$; 2.13 g/kg of Ca; 1.44 g/kg of Na; and 0.23 g/kg of P.

[3]Calculated from Sauvant et al. [13].

[4]$AME_n$, calculated from Fisher and McNab [33].

### *Statistical Analysis*

Data were analyzed using the GLM procedure [23]. Performance of geese was analyzed using the 3 experimental treatments as the only factor in the model (3 levels: F, W, and FW treatments) [24]. When significant, means between treatments were compared using Duncan's test. The fatty liver commercial grading and bird mortality during overfeeding periods were analyzed using a $\chi^2$ test. Differences were treated as significant when $P \leq 0.05$.

## RESULTS AND DISCUSSION

The proportions of particle sizes were different in the 3 diets (Table 1). The proportion of large particles (>4.0 mm) was higher in the F treatment than in the other 2 treatments (42 vs. 0 and 0% in F, W, and FW treatments, respectively), whereas the proportion of medium-sized particles (2.0–4.0 mm) was lower in the F treatment than in the others (0 vs. 41 and 41%, in F, W, and FW treatments, respectively). The proportion of small particles (<1.0 mm) was similar in all 3 treatments.

Mortality during the overfeeding period was similar in the 3 treatments (16/264 = 6.1%; $P = 0.405$). The BW of birds was similar in the 3 treatments at 99 (5,584 g; $P = 0.629$; Table 2) and at 115 d of age (8,308 g; $P = 0.754$). Actual amount of food distributed during the overfeeding period approximated the target amounts

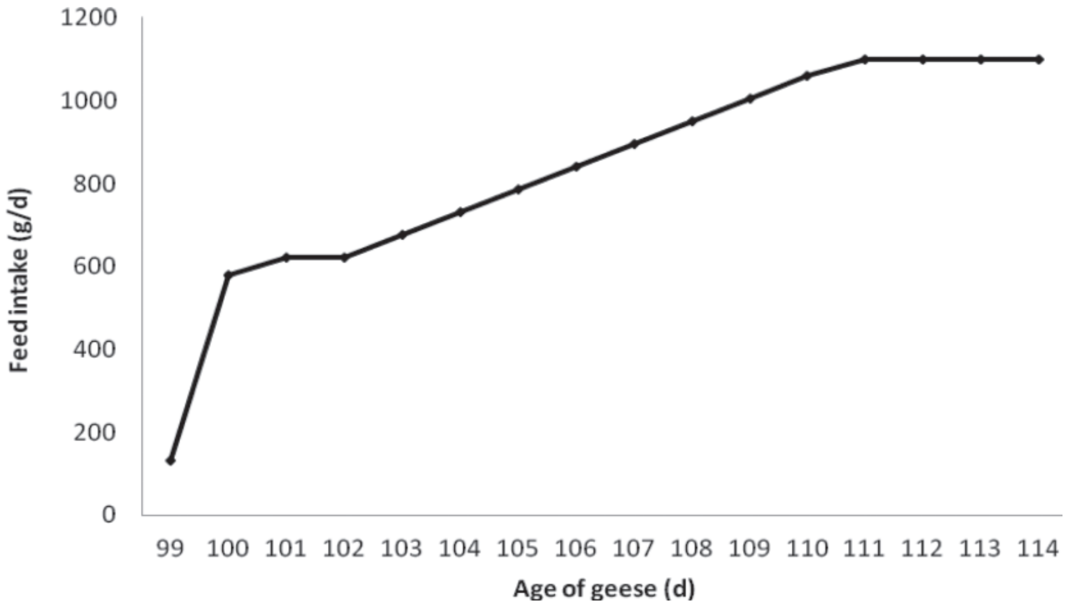


**Figure 1.** Planned feed intake of birds during the experimental period.

(Figure 1). In spite of a similar total amount of food distributed (13,220 g; $P = 0.234$; Table 2), the FW birds had an FCR lower than the F birds (−4%; $P = 0.029$; Table 2). Overfeeding the geese with sorghum was effective in inducing liver steatosis, as the average weight of fatty liver observed here (1,028 g) is very satisfactory compared with previous work in which birds were overfed with maize only (906 g [25]; 858 g [7]). The FW birds had a heavier fatty liver than the F birds (8%; $P = 0.017$; Table 3); this resulted in a lower grading of the liver in this treatment ($P < 0.001$; Table 3). The better performance of birds receiving 100% sorghum, rather than a mixture of sorghum and maize (especially the lower FCR and fatty liver weight with the same total quantity of feed), can be explained by the characteristics of maize and sorghum. First, the protein content was higher in sorghum than in maize [13] and, thus, higher in the FW diet than in the other diets (8%). In previous studies with geese, a higher fatty liver weight resulted when the dietary protein content was increased [10, 12, 26] in the diet offered to birds during overfeeding. Second, the different size of food particles between diets can also partly explain the better performance of FW birds. Indeed, the particle size influences the size of the gizzard

**Table 2.** Effect of the form of presentation and of the amount of sorghum in the overfeeding diet on the performance of geese during the experimental period (99–115 d)

| | Treatment[1] | | | | |
|---|---|---|---|---|---|
| Item | F | W | FW | SEM | $P$-value |
| Number of birds | 88 | 88 | 88 | | |
| BW at 99 d (g) | 5,606 | 5,598 | 5,549 | 27 | 0.629 |
| BW at 115 d (g) | 8,278 | 8,334 | 8,312 | 31 | 0.754 |
| Feed intake (g) | 13,259 | 13,210 | 13,192 | 16 | 0.234 |
| Average gain (g) | 2,672 | 2,736 | 2,764 | 16 | 0.051 |
| FCR | 5.00$^{a}$ | 4.87$^{ab}$ | 4.81$^{b}$ | 0.03 | 0.029 |

[a,b]Within a row, means with no common superscript differ significantly ($P < 0.05$).

[1]F = 405 g of whole maize and 560 g of sorghum flour/kg; W = 405 g of whole sorghum and 560 g of maize flour/kg; FW = 405 g of whole sorghum and 560 g of sorghum flour/kg.

**Table 3.** Effect of the form of presentation and of the amount of sorghum in the overfeeding diet on quality of fatty liver

| | Treatment[1] | | | | |
|---|---|---|---|---|---|
| Item | F | W | FW | SEM | *P*-value |
| Number of fatty livers | 82 | 82 | 84 | | |
| Weight of fatty liver (g) | $982^{b}$ | $1{,}033^{ab}$ | $1{,}069^{a}$ | 12 | 0.017 |
| Commercial grading[2] (%) | | | | | |
| Class 1 | 64 | 50 | 32 | | <0.001 |
| Class 2 | 24 | 41 | 42 | | |
| Class 3 | 12 | 9 | 26 | | |

$^{a,b}$Within a row, means with no common superscript differ significantly ($P < 0.05$).

[1]F = 405 g of whole maize and 560 g of sorghum flour/kg; W = 405 g of whole sorghum and 560 g of maize flour/kg; FW = 405 g of whole sorghum and 560 g of sorghum flour/kg.

[2]Class 1 = livers with no defects and <900 g; class 2 = heavy livers (>900 g) with no external defects; class 3 = livers with several defects in appearance or texture.

[27], and the gizzard is an essential contributor to gastrointestinal motility [28, 29] and digestive efficiency. Previously, however, the size of ingested particles influenced the weight of gut but this effect was smaller with sorghum than with whole maize [30, 31].

The livers from the F birds were lighter in color than those from the other 2 treatments (3%; $P < 0.001$; Table 4). Thus, the intensity of yellow color was higher in fatty liver from birds fed with yellow maize whole grain than with sorghum whole grain (4 and 22% in the F treatment compared with the W and FW treatments, respectively; $P < 0.001$; Table 4). The intensity of the red color of fatty liver was not affected by the diet. The difference in the color of the fatty liver from birds of the 3 treatments can be explained by the lower content of carotenoids and vitamin A (0.1 vs. $0.83 \times 10^3$ UI/kg) in sorghum than in maize [13]. Indeed, Fernandez et al. [25] reported a higher intensity of lightness and yellow color (68.5 and 28.4 for L* and b*, respectively) in fatty liver from birds fed maize than in the present study. A similar phenomenon was observed in the loss of yellow pigmentation in broiler skin or a reduction in the yolk color in the eggs [32] when birds were fed sorghum rather than maize.

## CONCLUSIONS AND APPLICATIONS

1. In this study, we observed a significant influence of the amount and form of sorghum in the overfeeding diet on the performance of geese.
2. Geese overfed with a diet containing only sorghum had better FE and higher liver weights.
3. This feeding strategy is promising but needs further study to avoid downgrading of the fatty liver. The economic and environmental effects of a pure sorghum diet also need to be evaluated.

**Table 4.** Effect of the form of presentation and of the amount of sorghum in the overfeeding diet on fatty liver color

| | Treatment[1] | | | | |
|---|---|---|---|---|---|
| Item | F | W | FW | SEM | *P*-value |
| Number of fatty livers | 82 | 82 | 84 | | |
| Fatty liver color[2] | | | | | |
| L* | $66.5^{a}$ | $64.5^{b}$ | $64.8^{b}$ | 0.2 | <0.001 |
| a* | 15.7 | 15.1 | 15.7 | 0.1 | 0.072 |
| b* | $24.2^{a}$ | $23.4^{b}$ | $19.7^{c}$ | 0.1 | <0.001 |

$^{a–c}$Within a row, means with no common superscript differ significantly ($P < 0.05$).

[1]F = 405 g of whole maize and 560 g of sorghum flour/kg; W = 405 g of whole sorghum and 560 g of maize flour/kg; FW = 405 g of whole sorghum and 560 g of sorghum flour/kg.

[2]Trichromatic Commission Internationale de l'Eclairage Lab coordinate system (L*, a*, b*).

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