Influence of the incorporation mode of sugar beet pulp in the finishing diet on the digestive tract and performances of geese reared for foie gras production

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Influence of the incorporation mode of sugar beet pulp in the finishing diet on the digestive tract and performances of geese reared for *foie gras* production

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ABSTRACT The aim of this work was to study the effects of incorporating sugar beet pulp (SBP) into the diet of geese in two feeding systems (complete pelleted feed or loose-mix feeding system) on crop development and performance. A total of 480 1-d-old male geese were divided into three groups whose diet differed from d 56 to 90: a complete pelleted diet containing 50% corn (control diet: AME_n 11.5 MJ/kg; CP 161 g/kg), and no SBP; a complete pelleted diet containing 50% corn and 10% SBP (SBP_{cp} diet: AME_n: 11.5 MJ/kg; CP: 161 g/kg); and a mix in the same feeder (SBP_{lm} diet) of 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}: AME_n: 9.0 MJ/kg; CP: 250 g/kg) and 500 g/kg of whole corn (WC: AME_n: 14.0 MJ/kg; CP: 72 g/kg). Body traits, including crop volume, were measured at d 91. From d 91 to 106, 88 birds/group were overfed with a mixture containing mainly corn and water before slaughter to measure fatty liver performance. Feed intake from d 56 to 90 was higher (+10%; $P = 0.004$) in the SBP_{cp} group than the other two, but at d 90, the body weight (BW) of the birds was higher (+7%; $P = 0.002$) in the SBP_{lm} group than the other two. At d 91, the volume of the crop was greater in the SBP_{cp} group (80.4 mL/kg of BW, $P < 0.001$) than in the control group (60.3 mL/kg of BW), the SBP_{lm} group being intermediate (64.1 mL/kg of BW). Feed intake (13,321 g), weight gain (2,733 g), and feed-to-gain ratio (4.9) during the overfeeding period, as well as fatty liver weight (963 g) and commercial grading, were similar ($P > 0.05$) between the three groups. In conclusion, the use of sugar beet pulp in the diet of finishing geese helps the adaptation of the digestive tract to the overfeeding period, even in a loose-mix feeding system based on whole corn.

Key words: goose, sugar pulp beet, crop, loose-mix feeding, overfeeding

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INTRODUCTION

Goose foie gras (fatty liver) is considered to be a delicacy with a high added value. However, the production of goose foie gras has gradually been replaced by that of mule duck (Comité Interpofessionnel du Foie Gras = Inter-branch organization of fattyu liver production (CIFOG), 2015), essentially because mule duck is a hardier animal that adapts more quickly to changes in environmental conditions (Guy et al., 1995). Consequently, scientific research has been done in the field of genetic selection, nutrition, and breeding practices in the duck species to improve the efficiency of the production system (Huang et al., 2012; Drouilhet et al., 2014). The combination of production and transfer knowledge make it possible to produce foie gras with reduced rearing (d 70 vs. 98) and overfeeding (d 10 vs. 14) time in mule ducks compared to geese (Guémené and Guy, 2004).

Foie gras is mainly produced in Europe. France is the most important producer country in the world with 19,310 t/yr which represents 73% of total world production (CIFOG, 2015), followed by Bulgaria which produced 2,600 t/yr and Hungary 2,590 t/yr (CIFOG, 2015). The production of duck foie gras dominates the world market with about 90% of the world tonnage. The French production of goose foie gras is 462 t/yr. The foie gras production system includes two steps: 1) the rearing period from hatching to 10 (duck) or 15 (geese) wk depending on species during which the animals are generally fed with complete pelleted feed followed by 2) the fattening period which lasts between 9 and 20 d depending on the species and system (European charter on breeding of waterfowl for foie gras, 2008) during which the birds were fed a mixture composed mainly of corn and water.

In the goose, unlike the duck, the crop is not an anatomically differentiated organ (Sturkie, 1986). Thus, the animals need to be carefully prepared for the overfeeding period, which induces hepatic steatosis by enlarging their crop volume. This goal is achieved through restricted access to feed during the finishing period (Guémené and Guy, 2004). The goose foie gras

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production system, like other livestock production systems today, is faced with societal demands for more natural feeding systems and/or a reduced environmental impact. On the one hand, genetic selection for feed efficiency (Drouilhet et al., 2014, 2016) or the modification of feed content (Arroyo et al., 2013a, e) are possible ways to reduce the environmental impact of fatty liver production systems. On the other hand, the use of whole, locally produced cereal (Arroyo et al., 2012a, 2013b) is a way to meet consumer demands concerning more natural feeding systems. However, the use of whole cereals in geese during the finishing period could prevent the enlargement of the crop and/or could increase the mortality rate during the overfeeding period (Arroyo et al., 2012a). These results are partly explained by the lower hydration capacity of whole grains compared to pellets (Brachet et al., 2015). Indeed, the swelling of feed in the digestive tract, which results from the ingestion of water after a meal, contributes to crop development.

Sugar beet pulp (**SBP**) is a co-product of both the sugar and the biofuel industries, and is commonly used in animal feed. SBP has a high hydration capacity (Giger-Reverdin, 2000) since its water-holding capacity is around 10 times greater than that of maize (0.6 vs. 9.6 g H_2O/g DM) (Brachet et al., 2015), and its swelling capacity is more than 30 times higher (10.4 vs. 0.3 mL H_2O/g DM). Incorporation of SBP (10%) into a poultry diet based on corn, sunflower meal, barley, and wheat increases its water-holding capacity (+30%) and its swelling capacity (+15%) (Brachet et al., 2015). Its use in goose diets has no detrimental effects on geese reared for meat production (Arslan, 2003, 2005) and could help mitigate the environmental consequences of both the animal production system (Mackenzie et al., 2016) and the biofuel industry (Popp et al., 2016). Additionally, Arroyo et al. (2015) showed that SBP incorporation (10%) in a complete pelleted diet for geese reared for foie gras production tended to increase the crop volume of the birds (+8%). Therefore, SBP could counteract the negative effect of the use of whole cereal during the finishing period on crop development and performance during the overfeeding period.

The aim of this work was to study the influence of the incorporation mode of sugar beet pulp in a finishing diet, i.e., in a complete pelleted diet or in a whole corn loose-mix feeding system, on the digestive tract and performance of geese reared for *foie gras* production.

MATERIALS AND METHODS

The animals were cared for in accordance with the guidelines for animal research of the French Ministry of Agriculture. This trial was carried out at the Goose and Duck Breeding Station (Coulaures, Dordogne, France), which has experimental approval A24-137-1, a technical staff and scientists with individual authorizations to conduct animal experiments in accordance with the good animal practices established by the DDCSPP (Departmental Directorate of Social Cohesion and the Protection of Populations), and uses the in vivo method for measuring crop development authorized by the French Ministry of National Education, Higher Education and Research (n° APAFIS#2261-2015100215034522v3). In this experiment, all the birds were slaughtered according to the European Council regulations (EC, 2009).

Birds and Feeding Programs

A total of 480 1-d-old ganders (Maxipalm ganders; *Anser anser*), were divided into three groups (four pens with 40 birds per group) whose diet during the finishing period (56 to 90 d of age) differed in both composition and presentation. All diets used during the rearing period met National Research Council (**NRC**) requirements (NRC, 1994) and were manufactured by Sanders Centre Auvergne (Aigueperse, France).

The feeding program was previously described by Arroyo et al. (2015). Briefly, birds were fed a pre-starter diet (nitrogen-corrected apparent metabolizable energy, AME_n: 11.72 MJ/kg; CP: 220 g/kg) from d 1 to 10, a starter diet (AME_n: 11.72 MJ/kg; CP: 200 g/kg) from d 11 to 28, and a grower diet (AME_n: 12.14 MJ/kg; CP: 180 g/kg) from 29 to 55 d of age. Between 56 and 90 d of age, three diets were used (Table 1): (i) control diet: complete pelleted diet containing 50% corn (AME_n: 11.5 MJ/kg; CP: 161 g/kg) and no SBP; (ii) SBP_{cp} diet: complete pelleted diet containing 50% corn and 10% SBP (AME_n: 11.5 MJ/kg; CP: 161 g/kg); and (iii) SBP_{lm} diet: in the same feeder, a loose-mix diet containing 500 g/kg of protein-rich pellets with 20% SBP (SBP_{prp}; AME_n: 9.0 MJ/kg; CP: 250 g/kg) and 500 g/kg of whole corn (**WC**; AME_n: 14.0 MJ/kg; CP: 72 g/kg). Birds had free access to feed from 0 to 55 d of age, and then had a controlled access time to feed: 3 h/d (2 h in the morning and 1 h in the afternoon) from d 56 to 63, followed by 2 h/d from d 64 to 90.

From d 91 to 106, eighty-eight birds/group were overfed with a mixture of 340 g of corn flour, 240 g of whole corn, 400 g of water, and 20 g of vitamins (E: 32.00 UI/kg; B1: 4.00 mg/kg; K3: 2.86 mg/kg) and minerals ($FeSO_4$: 55.40 mg; $CuSO_4$: 15.00 mg; $ZnSO_4$: 40.00 mg; $MnSO_4$: 74.00 mg; Ca: 2.13 g; Na: 1.44 g; P: 0.23 g/kg) per kg, according to standardized practices (Arroyo et al., 2012c). The planned overfeeding program (Figure 1) was adapted from Arroyo et al. (2013d). The diet was distributed daily with an automatic feed dispenser (Gaveuse Mg 300, Dussau, Distribution Sas, Pecorade, Landes, France). The birds used for overfeeding were chosen according to their BW at d 90 to be representative of the BW mean and variability within groups.

Housing and Management Conditions

During the rearing period, the birds were housed in 19-m^2 pens containing 40 birds. The pens were

Table 1. Ingredients and chemical composition of the experimental diets fed to geese during the finishing period (d 56 to 90).

Items	Diets[1]			
			SBP_{lm}	
	Control diet	SBP_{cp}	SPB_{prp}	WC
Ingredients (% as fed)				
Corn	8.3	50.0	–	100
Sugar pulp beet	–	10.0	20.0	–
Wheat	38.0	9.8	19.6	–
Triticale	10.0	–	–	–
Barley	10.0	–	–	–
Wheat bran	7.6	–	–	–
Wheat distillers	3.0	3.0	6.0	–
Corn distillers	3.0	3.0	6.0	–
Soybean meal	8.8	18.4	32.8	–
Defatted rapeseed meal	4.4	–	5.1	–
Sunflower cake	2.4	–	–	–
Colza oil	–	1.5	2.0	–
Calcium carbonate	2.7	2.0	3.8	–
Dicalcium phosphate	0.7	1.4	2.7	–
Salt	0.2	0.1	0.3	–
L-Lysine-HCl	0.2	0.1	0.2	–
Vitamin and mineral premix[2]	0.7	0.7	1.5	–
Chemical composition (% raw material except AMEn)				
AMEn (MJ/kg)	11.5	11.5	9.0	14.0
CP	16.1	16.1	25.0	7.2
Fat	2.6	4.1	5.0	3.2
DM	89.1	88.0	89.8	86.2
Ash	6.5	6.9	12.5	1.3
Starch	41.7	40.0	16.1	63.9
Cellulose	4.9	4.6	6.7	2.5
Phosphorus total	0.6	0.6	0.9	0.3
Calcium	1.4	1.4	2.8	0.0
Lysine	0.8	0.8	1.5	0.1
Methionine	0.5	0.5	0.8	0.2
Methionine + Cystine	0.8	0.8	1.2	0.4
Threonine	0.5	0.6	0.9	0.3

SBP: sugar beet pulp

[1]Control diet: complete pelleted diet containing 50% corn and no SBP; SBP_{cp} diet: complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} diet: mix of 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).

[2]Vitamins, A: 9,990 UI/kg; D3: 1,998 UI/kg; E: 10.0 UI/kg; B1: 2.0 mg/kg; K3: 1.0 mg/kg; B2: 2.5 mg/kg; B5: 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.

equipped with two drinkers, three feeders, and an outdoor access (91.5 m^2/pen). Geese had outdoor access between 0700 h and 1800 h from 30 to 90 d of age, but from d 56 to 90, the time of outdoor access was reduced because it was denied during the time when birds received experimental diets. The room temperature was maintained at 28°C from the first week after hatching and was subsequently gradually reduced to 20°C at 30 d of age, after which no heat was provided. From 0 to 6 days of age, the light was kept on all day (60 to 80 lux). From 7 to 26 d, artificial light was provided only during feed access, and a night light was kept on overnight. Once geese had outdoor access, only natural light was used.

During the overfeeding period, the 264 geese were housed in 24 3 × 1 m pens containing 11 geese each. Each pen was equipped with drinkers. The room was maintained at a maximum temperature of 20°C and a maximum relative humidity of 90%. Artificial light was provided only during feed distribution.

Measurements

Diets. The chemical composition of the experimental diets is shown in Table 1. The physical characteristics of the experimental diets are shown in Table 2. The length and diameter of the pellets were measured on 50 samples. The pellet hardness was measured using a "Kahl" type tester (Hardness tester, Amandus Kahl GmbH & Co., Hamburg, Germany), according to Thomas and van der Poel (1996). The hydration capacity was evaluated by measuring both the water-holding capacity (**WHC**: g of H_2O/g of dry matter) and the swelling capacity (**SC**: mL of H_2O/g of dry matter), as described by Brachet et al. (2015). Briefly, to measure WHC, 2 g of feedstuff 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) and the supernatant was removed before weighing the hydrated pellets. To measure SC, 25 mL of distilled water at room temperature were added to 2 g of feedstuff.

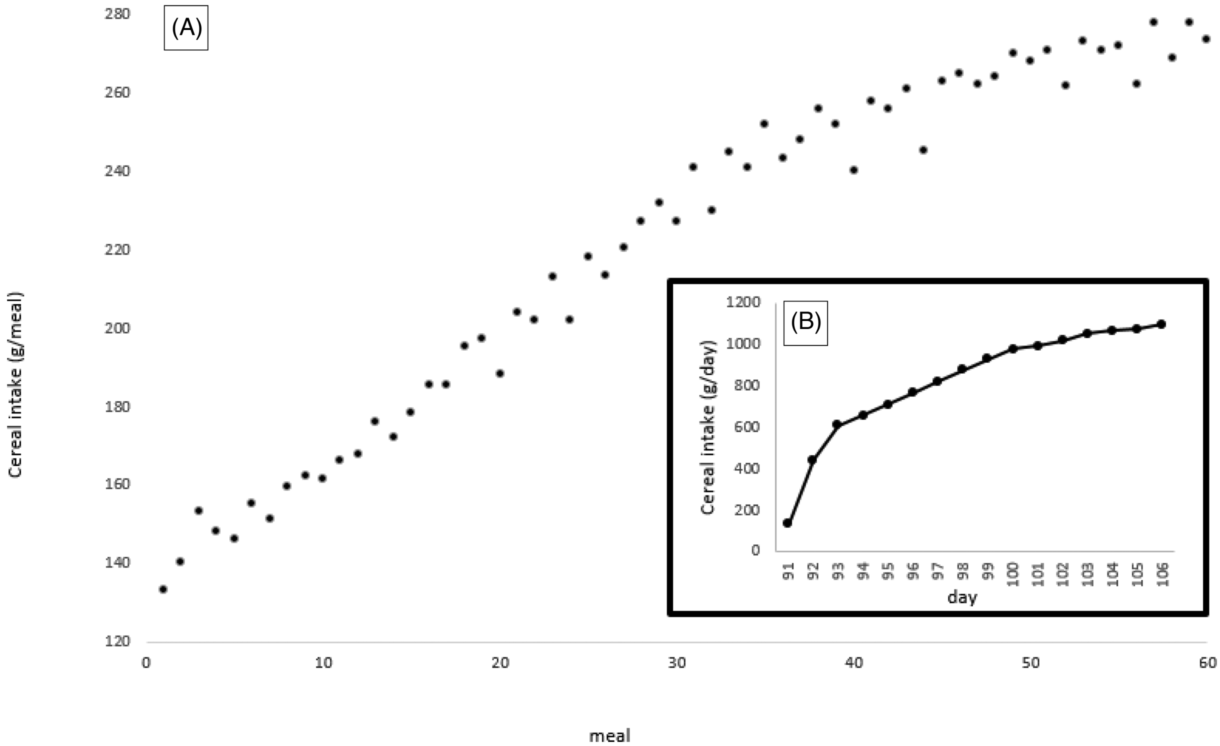

Figure 1. Planned cereal intake (without water) of birds (or g/meal [A] or g/d [B]) during the overfeeding period (d 91 to 106).

The volume of the hydrated pellets was measured at 5, 10, 20, 40, and 60 min after adding water. Particle size was measured using successive sieves of decreasing mesh size on the wet material for the experimental pelleted diets (Lebas and Lamboley, 1999), or on the dry material for WC (Melcion, 2000).

Animals. Birds were weighed individually at 56, 70, and 90 d of age after 18 h of fasting. At the end of overfeeding (106 d of age), BW was measured after 8 h of fasting because more than 8 h of fasting leads to a reduced *foie gras* weight (Leprettre et al., 1998). Mortality was recorded daily throughout the experiment. Feed intake was measured weekly from d 56 to 90 (one measurement per pen) and daily from d 91 to 106 (individual measurements). At d 91, the crop volume (40 geese per group selected on the basis of their BW at 90 d) was measured in vivo, as described by Arroyo et al. (2015). Briefly, an inflatable balloon was gently introduced into the esophagus and inflated to a constant pressure (70 mm Hg). The volume of air introduced was measured by displacement of a water column. Twelve geese per group (three per pen) were slaughtered at 91 d of age to study carcass traits according to the method of the World's Poultry Science Association (Fris Jensen, 1984). The gut (small intestine, duodenum, jejunum, ileum, and cecum), gizzard, liver, carcass (eviscerated carcass with skin but without neck), and abdominal fat were weighed, as were the breast and thigh (without skin and subcutaneous fat).

Foie Gras. At 106 d of age, all geese (88 per group at the beginning of the overfeeding period) were slaughtered after 8 h of fasting to measure the weight of fatty liver. The commercial grading of the fatty livers was carried out by an industry professional (Coopérative Sarlat Périgord, Sarlat-la-Canéda, Dordogne, France) trained to classify raw fatty livers according to their potential commercial use, as described by Arroyo et al. (2013c). The livers were graded using a three-point scale: Class 1 corresponded to the best commercial class for livers with no defects, appropriate texture, usually processed as whole canned livers; Class 2 corresponded to livers with no external defects but that were too heavy (>900 g) to be processed as whole canned livers; and Class 3 livers had several defects in appearance or texture.

Statistical Analysis

Data were analyzed using PASW Statistics18 for Windows (version 18.0.2, SPSS Inc., Chicago, IL). For bird data, the pen during the rearing period (four/group) was the statistical unit according to Gill (1989). Goose performance (except mortality rate and fatty liver commercial grading) was first analyzed using the GLM procedure, using the following equation: $Y_i = \mu + G_i + \varepsilon_i$, where Y is the dependent variable, μ the overall mean, G_i the group effect, and ε_i the error. In order to normalize the values of relative weight expressed as percentage (such as crop, which is expressed as % LW), data were transformed as log(x) or arcsin$\sqrt{(x)}$ when ranging between 0 and 10% prior to analysis.

Physical characteristics of the diets (length, diameter, WHC, SC, hardness) were analyzed using the

Table 2. Physical characteristics of the experimental diets fed to geese during the finishing period (d 56 to 90).

	Diets[1]					
	Pellets					
Items	Control	SBP_{cp}	SBP_{prp}	WC	SEM	*P*-value
Length (mm)	8.83^b	10.15^a	8.48^b	–	0.23	0.005
Diameter (mm)	3.00	3.00	3.00	–	0.00	–
Hardness (kg)	5.79^b	7.93^a	5.85^b	–	0.25	<0.001
Particle mesh size[2] (mm)						
4	–	–	–	99.81	–	–
2.8	–	–	–	0.15	–	–
2	–	–	–	0.01	–	–
1	10.07	17.70	13.91	0.01	–	–
0.5	20.55	17.69	13.43	0.01	–	–
0.315	11.01	8.53	8.73	–	–	–
0.1	13.41	11.96	16.46	–	–	–
Others[3]	44.97	44.11	47.47	0.01	–	–
Feedstuff hydration						
WHC[4] (g of H_2O/ g of DM)	2.51^c	4.31^a	3.04^b	0.67^d	0.34	<0.001
SC[5] (mL of H_2O/ g of DM)						
after 5 min	1.13^a	0.28^b	1.13^a	0.00^c	0.13	<0.001
after 10 min	1.70^a	0.55^b	1.69^a	0.00^c	0.19	<0.001
after 20 min	2.08^a	1.11^b	1.98^a	0.00^c	0.22	<0.001
after 40 min	2.27^a	1.75^b	1.98^b	0.29^c	0.20	<0.001
after 60 min	2.27^a	1.75^b	1.98^b	0.29^c	0.20	<0.001

SBP: sugar beet pulp.

[1]Control diet: complete pelleted diet containing 50% corn and no SBP; SBP_{cp} diet: complete pelleted diet containing 50% and 10% SBP; SBP_{lm} diet: mix of 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).

[2]Particle size was measured using successive sieves of decreasing mesh on the wet material for the pelleted diets (Lebas and Lamboley, 1999), or on the dry material for the whole corn (Melcion, 2000), with three samples per diet.

[3]Corresponds to particles <0.100 mm (pellet) or <0.50 mm (WC).

[4]WHC = water-holding capacity.

[5]SC = swelling capacity.

[a–d]Within a row, means with no common superscript differed at $P < 0.05$.

following equation: $Y_i = \mu + D_i + \varepsilon_i$, where Y_i is the dependent variable, μ the overall mean, D_i the effect of diet, and ε_i the error.

When significant, differences between treatments were compared using Bonferroni's test. The fatty liver commercial grading and mortality during the rearing and overfeeding periods were analyzed using a χ^2-test. Differences were treated as significant when $P \leqslant 0.05$.

RESULTS

Physical Characteristics of Experimental Diets

The diameter of the pellets (control, SBP_{cp}, SBP_{prp}) was similar (3.00 mm; Table 2) in the three experimental diets, but pellets were longer and harder for the SBP_{cp} diet than for the control and SBP_{prp} diets (+17%, $P < 0.005$ and +36%, $P < 0.001$, respectively; Table 2).

The proportion of large particles (>1.0 mm) was higher in the mixed diet (57.04% in SBP_{lm}) than in the pelleted diets (10.07% and 17.70% in the control and SBP_{cp} diets, respectively; Table 2), mainly due to the proportion of very large particles (>4.0 mm) in WC (99.8%). Conversely, for the same reason, the proportion of small particles (<0.5 mm) was higher in the pelleted diets (69.4% and 64.6% in the control and SBP_{cp} diets, respectively) than in the mixed diet (36.3%; Table 2).

WHC differed in the four experimental diets. It was the lowest in WC (0.67 g of H_2O/g of DM), and the highest in the SBP_{cp} diet (4.31 g of H_2O/g of DM, $P < 0.05$; Table 2).

SC at 60 min differed between experimental diets. It was the lowest in WC (0.29 mL of H_2O/g of DM), the highest in the control diet (2.27 mL of H_2O/g of DM 2), the pellets containing SPB (SBP_{cp} and SBP_{prp}) being intermediate (1.87 mL of H_2O/g of DM; Table 2).

Feed Intake during the Finishing Period

Total feed intake (control, SBP_{cp} or SBP_{lm}) was similar in the three groups from d 56 to 63, (218 g/d; $P = 0.159$) and from d 70 to 76 (201 g/d; $P = 0.099$; Table 3). On the opposite, the total feed intake was 24% higher in the SBP_{cp} group than in the control group between d 64 and 69 ($P = 0.002$), and intermediate in the SBP_{lm} group (Table 3). Between d 77 and 83, feed intake in the control group was lower than in the SBP_{lm} group (226 vs. 271 g/d; $P < 0.05$), SBP_{cp} being intermediate (257 g/d). Between d 84 and 90, feed intake was higher in the SBP_{cp} group (320 g/d) than in the

Table 3. Influence of the incorporation mode of sugar beet pulp in the finishing diet on average daily (g/d) and cumulative (g/bird) feed intake[1] of geese during the finishing period (d 56 to 90).

Period	Groups[2]			SEM	*P*-value
	Control	SBP_{cp}	SBP_{lm}		
No.[3]	160	160	160		
d 56 to 63 *(g/d/goose)*	213	211	230	4	0.159
d 64 to 69 *(g/d/goose)*	165[b]	204[a]	182[a,b]	6	0.002
d 70 to 76 *(g/d/goose)*	191	210	201	4	0.099
d 77 to 83 *(g/d/goose)*	226[b]	257[a,b]	271[a]	8	0.028
d 84 to 90 *(g/d/goose)*	256[b]	320[a]	236[b]	11	<0.001
Finishing period, d 56 to 90 *(g/goose)*	7,398[b]	8,428[a]	7,876[b]	141	0.004

[a,b]Within a row, means with no common superscript differed at $P < 0.05$.
[1]The individual feed intake was calculated from the intake per pen (n = 4 pens/group) and the number of birds in the pen during the period (40 birds per pen at the beginning of the experimental period).
SBP: sugar beet pulp.
[2]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix with 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).
[3]Number of birds at the beginning of the experimental period.

Table 4. Effect of sugar beet pulp offered in a loose-mix feeding system on the relative amount[1] of SBP_{prp} and WC intake[1] during the finishing period (d 56 to 90, n = 160).

Period	SBP_{lm} group[2]		SEM	*P*-value
	SBP_{prp}	WC		
d 56 to 63 *(g/d/goose)*	131	99	11	0.177
d 64 to 69 *(g/d/goose)*	110	72	8	0.003
d 70 to 76 *(g/d/goose)*	125	76	9	<0.001
d 77 to 83 *(g/d/goose)*	172	99	15	0.002
d 84 to 90 *(g/d/goose)*	157	79	15	<0.001
Finishing period, d 56 to 90 *(g/goose)*	4,876	3,000	366	<0.001

SBP: sugar beet pulp.
[1]The individual feed intake was calculated from the intake per pen (n = 4 pens/group) and the number of birds in the pen during the period (40 birds per pen at the beginning of the experimental period).
[2]SBP_{lm} group: in the same feeder, birds received a mix of 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).

other two (246 g/d; $P = 0.004$; Table 3). Over the entire finishing period, from d 56 to 90, the feed intake was +10% higher in the SBP_{cp} group than in the other two ($P = 0.004$; Table 3).

In the SBP_{lm} group, the intake of WC was lower than that of SPB_{prp} (P < 0.01) for each periods except between d 56 and 63 when the intake of WC and SBP_{prp} were similar (115 g/d; $P = 0.177$; Table 4). Over the entire finishing period, from d 56 to 90, the total intake of the SBP_{prp} diet was higher than the WC (+63%; $P < 0.00$).

The energy intake was similar in the three groups (Table 5) except between d 64 and 69 and d 84 and 90 when it was higher in the SBP_{cp} group than in the other two ($P < 0.01$). Protein intake was similar in the three groups between d 56 and 63 (37 g/d). However, from d 64 to 90, it was higher in the SBP_{lm} group than in the control group but similar in the SBP_{cp} and SBP_{lm} groups ($P < 0.05$, Table 5). Over the entire finishing period, from d 56 to 90, the total energy intake was higher in the SBP_{cp} group than in the two other groups (96.92 vs. 85.5 MJ/goose; $P = 0.003$), while the total protein intake was lower in the control group than in the other two (−15%; $P = 0.001$; Table 5).

Mortality and Bird Growth during the Finishing Period

The mortality rate was similar in the three groups throughout the rearing period (6/480 = 1.25% from 1 to 90 d; $P = 0.219$). At 56 and 70 d of age, the BW of geese was similar in the three groups (4,825 g; $P = 0.839$ and 4,959 g; $P = 0.211$; Table 6). However, at the end of the rearing period (90 d), the BW of the geese was higher (P < 0.001) in the SBP_{lm} group than in the other two (+7%; Table 6). Between d 56 and 70, the ADG in the SBP_{lm} group was higher than in the SBP_{cp} (13.7 vs. 4.8 g/d; $P < 0.05$) and control (10.2 g/d; Table 6) groups. Between d 71 and 90, the ADG was higher ($P < 0.001$) in the SBP_{lm} group than in the control and SBP_{cp} groups (+33% and +328%, respectively; Table 6). Over the entire finishing period, from d 56 to 90, the ADG was higher ($P < 0.001$) in the SBP_{lm} group than in the control

Table 5. Influence of the incorporation mode of sugar beet pulp in the finishing diet on energy (MJ/goose) and protein intake (g/goose) during the finishing period (d 56 to 90).

	Groups[1]				
Period	Control	SBP_{cp}	SBP_{lm}	SEM	*P*-value
No.[2]	160	160	160		
d 56 to 63					
Energy intake (MJ/goose/d)	2.45	2.43	2.56	0.07	0.784
Protein intake (g/goose/d)	34.3	34.0	39.7	1.8	0.375
d 64 to 69					
Energy intake (MJ/goose/d)	1.89^{b}	2.35^{a}	1.99^{b}	0.07	0.002
Protein intake (g/goose/d)	26.5^{b}	32.8^{a}	32.6^{a}	1.0	0.002
d 70 to 76					
Energy intake (MJ/goose/d)	2.20	2.41	2.19	0.05	0.061
Protein intake (g/goose/d)	30.7^{b}	33.8^{a,b}	36.7^{a}	0.8	0.002
d 77 to 83					
Energy intake (MJ/goose/d)	2.59	2.96	2.94	0.08	0.139
Protein intake (g/goose/d)	36.3^{b}	41.4^{a,b}	50.2^{a}	1.8	<0.001
d 84 to 90					
Energy intake (MJ/goose/d)	2.94^{b}	3.68^{a}	2.52^{c}	0.15	<0.001
Protein intake (g/goose/d)	41.2^{c}	51.6^{a}	44.9^{b}	1.4	<0.001
Finishing period, d 56 to 90					
Energy intake (MJ/goose)	85.07^{b}	96.92^{a}	85.89^{b}	1.92	0.003
Protein intake (g/goose)	1,191.0^{b}	1,356.9^{a}	1,435.1^{a}	34.3	0.001

[1]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix with 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC). Energy and protein intake were calculated per pen (n = 4 pens/group) as a function of the number of birds in the pen during the period (40 birds per pen at the beginning of the experimental period).
[2]Number of birds at the beginning of the experimental period.
[a–c]Within a row, means with no common superscript differed at $P < 0.05$.

Table 6. Influence of the incorporation mode of sugar beet pulp in the finishing diet on live weight (BW), average daily gain (ADG), and feed-to-gain ratio (F:G)[1] of geese during the finishing period (d 56 to 90).

	Groups[2]				
Items	Control	SBP_{cp}	SBP_{lm}	SEM	*P*-value
No.[3]	160	160	160		
BW (g)					
d 56	4,842	4,797	4,834	195	0.839
d 70	4,986	4,864	5,027	220	0.211
d 90	5,287^{a}	4,986^{b}	5,426^{a}	263	0.002
ADG (g/d)					
d 56 to 70	10.2^{b}	4.8^{c}	13.7^{a}	6.1	0.035
d 71 to 90	14.3^{b}	5.8^{c}	19.0^{a}	6.2	<0.001
d 56 to 90	12.7^{b}	5.4^{c}	16.9^{a}	1.5	<0.001
F:G					
d 56 to 70	19.11^{b}	53.47^{a}	17.58^{b}	6.56	0.020
d 71 to 90	15.95^{b}	46.43^{a}	12.63^{b}	4.76	<0.001
d 56 to 90	16.75^{b}	45.75^{a}	13.62^{b}	0.08	<0.001

SBP: sugar beet pulp.
[a–c]Within a row, means with no common superscript differed at $P < 0.05$.
[1]The BW, ADG and F:G were calculated per pen (n = 4 pens/group) as a function of the number of birds in the pen during the period (40 birds per pen at the beginning of the experimental period).
[2]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix with 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).
[3]Number of birds at the beginning of the experimental period.

and SBP_{cp} groups (+33% and +313%, respectively; Table 6). Regardless of the period, the F:G was higher in the SBP_{cp} group than in the other two (Table 6).

Body Traits at the End of the Finishing Period

At the end of the finishing period (91 d), the weight of the carcass (2,734 g vs. 3,004 g; $P < 0.001$), of abdominal fat (0.89 vs. 2.16% of BW; $P = 0.001$), and of thigh with bones (11.90 vs. 11.23% of carcass; $P = 0.018$) were lower in the SBP_{cp} group than in the other two (Table 7). The relative volume of the crop was greater in the SBP_{cp} group (80.4 mL/kg of BW, $P < 0.001$) than in the control (60.3 mL/kg of BW) and SBP_{lm} group being intermediate (64.1 mL/kg of BW). The other body traits were similar ($P > 0.05$) in the three groups (Table 7).

Bird Performance during and after Overfeeding

The mortality rate was similar in the three groups throughout the overfeeding period (14/288 = 5.3% from 91 to 106 d; $P = 0.239$). At the beginning of the overfeeding period (91 d), the BW of the geese was higher ($P < 0.001$) in the SBP_{lm} group than in the other two (+ 7%; Table 8). The diet used during the rearing period had no effect on feed intake (13,321 g; $P = 0.468$), weight gain (2,733 g; $P = 0.926$), and feed-to-gain ratio (4.91; $P = 0.955$; Table 8) during the overfeeding period. At the end of the overfeeding period (106 d), the BW was higher in the SBP_{lm} than SBP_{cp} groups (8,155 vs. 7,713g; $P < 0.001$), the control group being

Table 7. Influence of the incorporation mode of sugar beet pulp in the finishing diet on goose carcass composition at 91 d of age.

Items	Groups[1]			SEM	*P*-value
	Control	SBP_{cp}	SBP_{lm}		
d 91 (n = 12/group)[2]					
BW (g)	5,279[a]	4,966[b]	5,388[a]	56	<0.001
Carcass (g)	2,979[a]	2,734[b]	3,028[a]	41	<0.001
Liver (% of BW)	2.83	3.36	3.04	0.13	0.274
Gizzard (% of BW)	3.77	4.19	4.01	0.09	0.119
Gut (% of BW)	5.01	5.47	5.21	0.10	0.180
Abdominal fat (% of BW)	2.14[a]	0.89[b]	2.17[a]	0.20	0.001
Pectoral muscle (% of carcass)	7.95	8.18	7.58	0.11	0.079
Thigh with bones[3] (% of carcass)	11.24[a]	11.90[b]	11.22[a]	0.12	0.018
Volume of crop (mL/kg of BW)[4]	60.3[b]	80.4[a]	64.1[a,b]	3.6	<0.001

[a,b]Within a row, means with no common superscript differed at $P < 0.05$.
[1]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix with 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).
[2]n = 3/pen except for crop volume (n = 40).
[3]Without skin and subcutaneous fat.
[4]n = 40 per group (10/pen).

Table 8. Influence of the incorporation mode of sugar beet pulp in the finishing diet on performance traits of geese before, during and after overfeeding.

Items	Groups[1]			SEM	*P*-value
	Control	SBP_{cp}	SBP_{lm}		
Number of birds at d 91	88	88	88		0.239[3]
Number of birds at d 106	86	81	83		
BW at d 91 (g)	5275[a]	4964[b]	5393[a]	29	< 0.001
Feed intake[2] from d 91–106 (g)	13,311	13,329	13,322	6	0.468
Weight gain d 91–106 (g)	2,728	2,731	2,739	15	0.926
Feed-to-gain ratio d 91–106	4.92	4.91	4.90	0.03	0.955
BW at d 106 (g)	8,006[a,b]	7,713[b]	8,155[a]	31	< 0.001

SBP: sugar beet pulp.
[1]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix with 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn (WC).
[2]without water
[3]Effect of experimental treatment on mortality rate during the overfeeding period (χ^2-test on initial and final number of birds).
[a,b]Within a row, means with no common superscript differed at $P < 0.05$.

intermediate (8,006g; Table 8). The weight (963 g; $P = 0.926$) and commercial grading of the fatty liver (91% in Class 1; $P = 0.172$) were similar in the three groups (Table 9).

DISCUSSION

The aim of this work was to study the influence of the incorporation mode of sugar beet pulp in finishing diets on the digestive tract and performance of geese reared for *foie gras* production. The underlying hypothesis concerned the ability of SBP to naturally adapt the digestive tract of birds to high feed intake during the overfeeding period due to its high hydration capacity, even in a loose-mix feeding system based on whole cereal known to be detrimental in this case.

Our results confirmed that WC had a much lower hydration capacity than a complete pelleted diet (more than 5 times lower), as previously shown (Arroyo et al., 2012a; Brachet et al., 2015). Moreover, our results showed that diet composition had a strong influence on its hydration capacity, as previously demonstrated by Brachet et al. (2015). As expected, the incorporation of SBP into the diet increased its WHC capacity compared to the control diet. Additionally, SC was similar for diets containing 20% of SBP than 10%. However, the relationship between WHC and SC for our three experimental pelleted diets was low. This is in agreement with the results of Brachet et al. (2015), which revealed a weak correlation ($R^2 = 0.52$) between WHC and SC, especially for high values, like in the present study. This discrepancy can be explained by the chemical composition and/or the particle size of the feedstuffs included in the diets, as well as the length/diameter ratio of the press die used in our experiment (Brachet et al., 2015).

Present results showed an increase in feed intake (+14%) and a decrease in the BW (−6%) at the end

Table 9. Influence of the incorporation mode of sugar beet pulp in the finishing diet on raw fatty liver quality

Item	Groups [1]			SEM	P-value
	Control	SBP_{cp}	SBP_{lm}		
Number	86	81	83		
Fatty liver weight (g)	958	962	968	11	0.926
Commercial grading[2] (%)					
Class 1	91	95	87		
Class 2	8	5	8		0.172
Class 3	1	0	5		

[1]Control group: birds received a complete pelleted diet containing 50% corn and no SBP; SBP_{cp} group: birds received a complete pelleted diet containing 50% corn and 10% SBP; SBP_{lm} group: in the same feeder, birds received a mix of 500 g/kg of protein-rich pellets containing 20% SBP (SBP_{prp}) and 500 g/kg of whole corn/kg (WC).

[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.

of the rearing period in geese fed a complete pelleted diet containing 10% SBP. This is not consistent with the results of Arroyo et al. (2015) who showed a decreased feed intake (−7%) and no effect on the BW using the same SBP incorporation level. On the other hand, geese submitted to the loose-mix feeding system were not significantly heavier than geese fed a complete pelleted diet at the end of the rearing period, as previously shown by Arroyo et al. (2012a,b and 2013b). In the SBP_{lm} group, the geese preferred SBP_{prp} over WC, which led to a higher ingestion of protein in the SBP_{lm} group during the entire finishing period than in the other groups. This result is surprising since the geese generally decreased their intake of protein-rich pellets in a previous experiment to adapt to the reduction in their protein needs (Arroyo et al., 2012a).

In the present study, we observed a strong relationship between WHC of the pelleted diet intake and the crop volume at the end of the growing period, as previously shown (Arroyo et al., 2012a; Arroyo et al., 2015). However, we observed no link between crop volume and mortality rate during the overfeeding period. It should be noted that the mortality rate in our experiment was lower than the one previously observed (5.3% in our study vs. 9.8% in Arroyo et al., 2012a), whereas the crop volume was higher (68 vs. 45 mL/kg of BW). These results suggest the existence of a threshold effect. It is possible that below a minimum crop volume, goose viability increases with crop volume during the overfeeding period, whereas above this minimum threshold, crop volume no longer has a positive effect on goose viability. In a further experiment, it would be interesting to explore the individual relationship between the crop volume at the beginning of the overfeeding period and subsequent mortality in order to validate this hypothesis.

In the present study, the use of a protein-rich pelleted feed containing SBP in a loose-mix feeding system led to geese with a crop volume similar to those fed a control pelleted diet. Thus, the use of SBP is an interesting way to prepare the birds for overfeeding in a feeding system based on whole cereals and that combines a natural feeding system while maintaining performance. The consequences on the environmental impact of fatty liver production remain to be evaluated.

In conclusion, the incorporation of SBP is an interesting alternative for feeding geese during the finishing period because it can help the digestive tract adapt to the overfeeding period without reducing animal performance during this period, even in a loose-mix feeding system based on whole corn.

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