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Effects of fibre-rich ingredient levels on goose growth performance, blood profile, foie gras quality and its fatty acid profile: a meta-analysis

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ABSTRACT. A meta-analysis was performed to investigate the effect of different sources and levels of dietary fibre-rich ingredients on the growth performance, foie gras quality, and its fatty acid profile in geese. Peer-reviewed articles were strictly evaluated, and selected according to the protocols of the Systematic Review for Laboratory Animal Experimentation (SYRCLE'). The final dataset consisted of 21 *in vivo* studies covering 83 treatment units. Meta-analysis was performed using a non-linear mixed model (NLME) library. The quadratic patterns (P < 0.001) of the gain:feed ratios were calculated based on the result of meta-analyses of goose data. The linear patterns (P < 0.001) of foie gras quality were also presented. It was concluded from the meta-analysis based on *in vivo* studies that fibre-rich ingredients effectively improved foie gras quality.

Introduction

Geese are herbivorous grazing waterfowl, whose bills and mouths are specially adapted for grasping and tearing apart vegetation. The diet of geese consists of sedges, grasses, grains, seeds, and aquatic plants, and they are more adapted to eating high-fibre diets than other poultry species (Amano et al., 2004; Tian et al., 2017). Experimental work in geese has increased rapidly in many countries in an attempt to provide sustainable food for rapidly expanding human population (Lou and Zhang, 2008). Geese can thrive on a variety fibre sources in aquatic areas and marshlands (Lou and Zhang, 2008). Several breeds of geese have been introduced and farmed in various regions, including European countries, China, and

Southeast Asia, and have shown promising growth potential (Lou and Zhang, 2008). According to Liu et al. (2019), digestive features and physiological structure allow geese to effectively digest the cell wall of plants. Their active foraging characteristics make them useful as beak , and their meat is leaner than chicken meat (Liu et al., 2019). Moreover, they can be used to produce a well-known product called foie gras (Liu et al., 2019). It has a smoother texture and more buttery taste than regular goose or duck pate (Arroyo et al., 2012a). European countries, particularly France, have used force-feeding (cramming) to produce foie gras for many years (Arroyo et al., 2012b). Despite several articles reporting positive effects of increasing dietary fibre content, little information can be found in the literature regarding the correlation between fibre-rich ingredient levels and foie gras quality in experimental studies. A previous study showed that less than 3% fibre in goose diets had a negative effect on the performance and meat quality of these animals (Li et al., 2017a). If the fibre provided does not meet the nutritional requirements of geese, it may negatively affect intestinal nutrient utilisation. In light of the findings of these previous studies, the authors wish to critically evaluate the importance of dietary fibre for geese using the quantitative method known as meta-analysis. Therefore, the aim of this study was to determine the effect of different sources and levels of dietary fibre-rich ingredients on growth performance of geese, foie gras quality, and its fatty acid profile through a meta-analysis.

Material and methods

Eligibility criteria

The articles selected needed to fulfil the following inclusion requirements: (1) articles published in peer-reviewed journals; (2) articles and studies reporting the use of fibre source in other animals were not included; (3) research directly concerned geese as experimental animals; (4) fibre source thoroughly described in methods; (5) experiments conducted under controlled trial environments; (6) written in English, available as full texts, and reporting on the use of any fibre source in any breed of geese at any age; (7) reporting animal growth performance and foie gras quality parameters. Any additional parameters such as blood serum data and nutrient digestibility was considered to be included in the database; (8) listing in the article information such as year of publication, doses administered, source, country where the experiment was conducted, experimental period, and the strain of geese used.

Dataset development

Raw data from articles were strictly extracted if articles reported the use of a source of fibre-rich ingredients in goose diets. Peer-reviewed articles were thoroughly evaluated, and selected according to the protocols of the Systematic Review for Laboratory Animal Experimentation (SYRCLE'). An algorithm was chosen to search for peer-reviewed published articles on the following websites: ScienceDirect (https://www.sciencedirect.com/overview); Medline (https://www.nlm.nih.gov/medline/index.html); PubMed (https://pubmed.ncbi.nlm.nih.gov/advanced//). The time period set for the relevant published articles was from 1995 to 2022, and the following keywords were used: 'fibre', 'foie gras', 'geese', and 'performance'. In each selected article, we also evaluated reference lists to search for potentially relevant articles that might have been missed during the initial search.

Data extraction

After importing from scientific databases, four authors were responsible for screening titles and abstract lists to evaluate the published articles. Since the number of articles that reported dietary fibre sources in geese and met the established criteria was low, the final dataset consisted of 21 *in vivo* studies with 83 treatments units. The initial assessment included 112 scientific articles that discussed the use of dietary fibre sources in geese. Twenty-three articles were excluded due to non-relevant parameters, while 6 works were excluded because they referred to non-relevant sources of fibre-rich ingredients. Furthermore, 59 articles concerned animals other than geese. Subsequently, after a careful full text evaluation, 4 further articles were excluded as they lacked statistical information. After this process, 21 studies remained eligible for meta-analysis.

A total of 4 238 geese were used in the 21 selected articles, and all studies were conducted as modern, controlled, environmental trials. The dietary fibre levels provided ranged from 0 to 100%. The feeds administered were based on maize and soybean. Two articles that met the inclusion requirements for this study were conducted before 2000, and the remaining 19 were conducted in or after 2000. Details of the selection of studies included in this meta-analysis are provided in Figure 1 and the summary of the final dataset is presented in Table 1.

Table 1. Studies included in the meta-analysis

No.	References	Fibre-rich ingredients level, %	Crude fibre, %	Source of fibre	Countries of study	Period, d	Strain of geese	Basal diet used
1.	Jin et al., 2020	4–10	4.68–10.13	*Pennisetum hydridum*	China	22–70	White Roman	Maize – Soya bean
2.	Clauss et al., 2020	0–10	5	Alfalfa (*Medicago sativa*)	Switzerland	0–21	Domestic geese (hybrid)	Maize – Soya bean
3.	Liu et al., 2019	0–10	4.9	Alfalfa (*Medicago sativa*)	China	42–70	Sichuan White	Maize – Soya bean
4.	Li et al., 2020	0–10	3.04–6.93	Wheat bran (*Triticum aestivum* L.)	China	28–42	Hainan	Maize – Soya bean
5.	Guo et al., 2020	0–3	5.22–5.30	Ryegrass (*Lolium perenne* ssp.)	China	29–70	Yangzhou	Maize – Soya bean
6.	Li et al., 2017a	0–10	3.04–6.93	Cassava foliage (*Manihot esculenta*)	China	28–42	Hainan indigenous	Maize – Soya bean
7.	Li et al., 2017b	0–10	2.52–5.01	Cassava foliage (*Manihot esculenta*)	China	28–70	Hainan	Maize – Soya bean
8.	Liu et al., 2020	0–10	4.9	Alfalfa (*Medicago sativa*)	China	28–70	Sichuan White	Maize – Soya bean
9.	Li et al., 2019	2.5–4.3	4.32–5.58	Commercial fibre-rich ingredients	China	28–70	Yangzhou	Maize – Soya bean
10.	Yin and Huang, 2016	0–20	6.11–6.18	Alfalfa (*Medicago sativa*)	China	0–35	Gushi	Maize – Soya bean
11.	Wang et al., 2017	0–16	5.1	Mulberry leaf (*Morus alba*)	China	0–12	Not reported	Maize – Soya bean
12.	Chen et al., 2016	0–0.45	5.58	Alfalfa (*Medicago sativa*)	China	28–70	Yangzhou	Maize – Soya bean
13.	Yang et al., 2013	2.83–23.86	6.92–6.96	Alfalfa (*Medicago sativa*)	China	21–70	Yangzhou	Maize – Soya bean
14.	He et al., 2015	30	12.33–14.88	Corn straw (*Zea Mays*)	China	28–112	Greylag Landaise	Maize – Soya bean
15.	Arroyo et al., 2012a	0–0.05	4.1–5	Wheat middling (*Triticum aestivum* L.)	Frances	44–105	Greylag Landaise	Maize – Soya bean
16.	Arroyo et al., 2013	0–0.09	4.1	Fibrous straw	Frances	42–98	Maxipalm	Maize – Soya bean
17.	Jiang et al., 2012	0–9	0–8.8	Alfalfa (*Medicago sativa*)	China	14–49	Muscovy	Maize – Soya bean
18.	Yu et al., 1998	2.7–6.22	2.5–9.4	Alfalfa (*Medicago sativa*)	China	0–42	White Roman	Maize – Soya bean
19.	Arslan, 2005	2.95–10.4	6.39–6.43	Barley (*Hordeum vulgare*)	Turkey	0–64	Native geese	Maize – Soya bean
20.	Hsu et al., 2000	0.01–0.02	4.09–4.91	Rice straw (*Oryza sativa* L.)	Taiwan	0–28	White Roman	Maize – Soya bean
21.	Hsu et al., 1996	0.005–0.025	4.08–5.01	Alfalfa (*Medicago sativa*), Barley (*Hordeum vulgare*), Rice straw (*Oryza sativa* L.)	Taiwan	0–14	White Roman	Maize – Soya bean

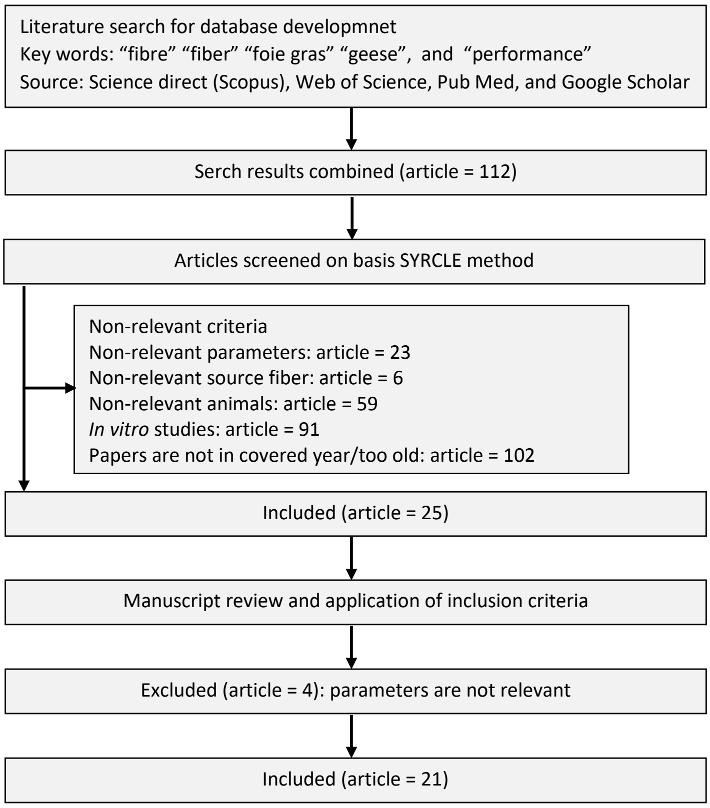

Figure 1. Details of the selection of studies included in meta-analysis.

Data analysis and coding

Prior to statistical meta-analysis, the data were transformed into similar units of measure to enable direct analysis within a particular observation. Data analysis and coding was performed using R statistical software version 4.1.3, computing with algorithm (readx1); (xlsx); (reshape2); (data.table); (tidyverse), and non-linear mixed effect model (NLME). The dataset was analysed using NLME where the experiments were considered a random effect, and fibre level as a fixed effect, according to the following mathematical model (Sjofjan et al., 2021a; b):

$$Y_{ij} = \beta_0 + \beta_1 \text{Level}_{ij} + \text{Experiment}_i + \text{Experiment}_i \text{Level}_{ij} + e_{ij} \quad (1)$$

$$Y_{ij} = \beta_0 + \beta_1 \text{Level}_{ij} + \beta_2 \text{Level}_{2ij} + \text{Experiment}_i + \text{Experiment}_i \text{Level}_{ij} + e_{ij} \quad (2),$$

where: Y_{ij} – dependent variable, β_0 – Y-axis intercept for combinations of level and random effects, β_1 – level of order 1 (linear regression), β_2 – coefficient level of order 2 (quadratic regression), Level_{ij} – level of fibre-rich ingredient addition (fixed effects), Experiment_i – number of experiments-i (random effects), e_{ij} – model error. Data were weighted by the number of replicates in each study. Additionally, an effect was considered significant at the probability level of $P < 0.05$, whereas the trends were declared at $P \geq 0.05 < 0.10$. Regression equations were also presented with *P*-value, root mean square error (RMSE), and akaike information criterion (AIC).

Results

Our meta-analysis showed that nutrient digestibility was not significantly represented, indicating that it was not affected by dietary fibre source. There was no statistical association in this dataset between fibre-rich ingredient sources and nutrient digestibility (Table 2). The meta-analysis demonstrated that there was no significant effect of dietary fibre supplementation on average daily gain (ADG) and average daily feed intake (ADFI) of geese; however, the gain:feed ratio was significantly ($P < 0.01$) affected (Table 2). Accordingly, fibre-rich components showed no significant effect on the blood profile ($P > 0.05$).

Surprisingly, the changes in carcass yield, breast meat, leg muscle meat, gizzard weight, foie gras yellowness, and remaining fatty acids were insignificant (Table 2).

Table 2. Regression model of the effect of fibre-rich ingredients on slaughtered weight, carcass yield, internal organs and foie gras quality of geese

Response variable	Unit	Model	N	Intercept	Mean	SE intercept	Slope	SE slope	*P*-value	Sig.	RMSE	AIC	X (optimum)	Y (optimum)
Gain:feed ratio	–	Q	43	4.87	4.81	−0.0001	0.008	0.58	0.001	**	1.80	165.67	32.61	5.01
ADG	g	L	42	50.54	52.67	4.36	0.021	0.013	0.115	NS	1.33	280.58	41.22	49.34
ADFI	g	L	49	106.22	214.36	16.00	0.005	0.001	0.129	NS	1.70	464.66	101.2	107.32
Cholesterol	mg/dl	L	12	0.80	3.53	0.08	−0.03	0.03	0.45	NS	0.15	25.92	–	–
Triglyceride	mg/dl	L	12	0.22	1.02	0.22	−0.005	0.01	0.31	NS	0.08	10.04	–	–
Albumin	mg/dl	L	9	4.54	12.09	4.54	−0.02	0.08	0.23	NS	0.33	34.83	–	–
SW	g	Q	15	3579.91	3522.97	−0.09	−1.30	683.00	0.005	**	0.96	187.24	−7.02	3584.4
Carcass yield	%	L	17	78.50	79.74	5.32	0.17	14.73	0.20	NS	1.00	83.00	–	–
Breast meat	%	L	41	10.70	11.02	1.02	0.02	10.40	0.47	NS	0.52	116.90	–	–
LMM	%	L	38	12.00	12.08	0.70	−0.004	17.30	0.02	NS	0.22	70.10	–	–
Gizzard	g/kg	L	20	15.06	24.04	8.81	0.34	0.16	0.17	NS	1.16	100.82	–	–
Heart	g/kg	L	11	6.13	8.54	5.38	0.02	1.14	0.14	NS	0.07	31.16	–	–
FGW	g/kg	Q	14	671.30	605.57	0.04	−3.40	27.04	0.0001	**	0.91	129.23	35.41	585.73
pH	–	L	11	5.52	5.71	0.10	0.11	0.006	0.33	NS	0.10	7.61	–	–
Sher force	N	L	11	25.21	24.79	1.17	−0.06	21.44	0.06	NS	0.51	43.69	–	–
Lightness (L)	–	Q	13	57.38	58.32	0.49	−0.17	27.04	0.0001	**	0.64	57.76	−6.31	57.93
Redness (a)	–	Q	13	14.86	15.35	0.0003	0.10	−3.10	0.01	**	0.14	37.82	10.84	13.12
Yellowness (b)	–	L	20	72.46	8.33	−0.006	0.66	4.51	0.18	NS	0.94	34.86	–	–
Hardness	N	L	21	4.36	4.50	0.012	0.11	35.41	0.77	NS	0.15	14.93	–	–
Springiness	mm	L	15	0.51	0.52	0.031	0.001	0.0001	0.34	NS	0.01	−25.82	–	–
Gumminess	N	L	16	1.35	1.38	0.040	0.03	33.19	0.02	NS	0.07	−2.65	–	–
Chewiness	mJ	L	16	0.80	0.81	0.02	0.001	0.32	0.15	NS	0.05	−11.00	–	–
Adhesiveness	n-mm	L	14	0.05	0.05	0.005	0.0014	8.66	0.23	NS	0.002	−62.56	–	–
DM	%	L	11	30.63	29.71	1.86	−0.22	0.10	0.11	NS	0.20	18.36	–	–
CP	%	L	15	25.40	22.89	1.63	−0.17	0.06	0.15	NS	0.20	24.70	–	–
EE	%	L	15	4.58	5.20	1.544	0.03	0.30	0.07	NS	0.31	28.37	–	–
C14:0	%	Q	11	0.90	0.90	−0.08	−0.07	0.04	0.05	**	0.66	0.004	−0.0003	0.55
C17:0	%	L	11	0.13	0.18	2.41	−0.002	2.15	0.06	NS	0.13	30.21	–	–

AIC – akaike information criterion, ADG – average daily gain, ADFI – average daily feed intake, DM – dry matter, CP – crude protein, EE – ether extract, SW – slaughtered weight, TP – total protein, LMM – leg muscle yield, FGW – foie gras weight, N – number of data, SE – standard error, Sig. – significant, RMSE – root mean square errors, X – the value optimum at (x), Y – the value optimum at (y); ** – means within a row with different superscripts are significantly different at $P < 0.05$; NS – non-significant, Q – quadratic; in case where the above quadratic model was not significant, it was changed to the corresponding linear model, where: L – linear, Q – quadratic

Discussion

Nutrient digestibility. The current meta-analysis has confirmed that source of fibre does not significantly affect the digestibility variables of all nutrients, meaning that supplementation with dietary fibre does not impair nutrient utilisation in geese. In a previous study, Jha and Mishra (2021) have argued that dietary fibre is considered an anti-nutritional factor due to its adverse effect on nutrient digestibility. Mateos et al. (2012) mentioned that dietary fibre were affected by several factors such as digestive viscosity, fermentation capability, and bulking effect in the gastro-intestinal tract of geese. Mateos et al. (2012) reported that the microorganism population was more abundant in the ileum when geese were fed a fibre-rich plant-based diet compared to grain-based fibre. Conversely, the microorganisms in the caecum were reported to be present in higher numbers when geese were fed grain than grass (64.7% for grain-based fibre and 47.3% for grass, respectively).

Additionally, Sjofjan et al. (2021b) have suggested that there must be enzymes stimulating crude protein (CP) substances to donate methyl groups in the biogenesis pathways in eukaryotes. Methyl donation of the substrate can reduce phytase content and improve nutrient digestibility (Sjofjan et al., 2021b). Recently, non-degraded fibre has been correlated with "wet" droppings which contribute to sanitation problems. Beta-glucans, which are soluble in water, formed a gel in the digestive tract of geese causing "wet" droppings. The amount of "wet" droppings was correlated with the apparent total digestibility coefficient of the poultry, and ranges from 0 to 0.4 (Kroismayr, 2015).

Growth performance. The results of our meta-analysis confirmed that fibre-rich ingredients had a positive effect on the production performance of geese, as evidenced by the positive curvilinear relationship of fibre levels on the gain to feed ratio, regardless of fibre source. It has been reported the high energy value might increase growth performance (Kroismayr, 2015). This finding strengthens the general consensus that the inclusion of dietary fibre could optimize geese performance. At this point, fibre-rich ingredients play an essential role in optimising the development of the goose digestive tract, which is the most important factor stimulating higher productivity. Consistently, there is a number of empirical studies supporting this statement. For instance, higher production performance was reported in geese fed fibre-rich dietary sources obtained from king grass (Jin et al., 2020), rice hull or rice husk (Wang et al., 2017), alfalfa meal (Chen et al., 2016), and cassava leaves (Li et al., 2019). These studies reported that raising levels of dietary fibre from those sources increased gizzard volume and small intestine length. It is plausible that a high-fibre diet has longer passage rates, which may stimulate physical contraction of the gizzard wall, leading to enlarged diameter of digestive tract and volume capacity.

As mentioned earlier, different sources of fibre-rich ingredients, including fibre from grains, exerted similar effects on goose performance. For instance, barley products containing less than 10% beta-glucan had no adverse effect on performance. Arslan (2005) observed that even though grasses used as dietary fibre-rich sources reduced the energy of diets, they did not negatively affect the gain of goose body weight. Furthermore, the author claimed that the use of grass or other dietary fibre in the amount of 10–20% of the feed was recommended to satisfy the herbivorous behaviour of geese. Arroyo et al. (2013) also suggested that growth efficiency is increased when sorghum was supplemented as dietary fibre source. Despite similar feed intake, nutritional content is the main factor in this finding. To this end, Li et al. (2017b) found that fibre-rich ingredients were important nutrients that should be included in goose feed, as well as energy and protein sources. They reported that geese receiving low levels of fibre-rich nutrients failed to achieve optimum growth performance and organ development, and the digestion of nutrients was directly affected by growth and development of internal organs (Arroyo et al., 2013). Bones and tissues reflect the efficiency of nutrients absorption, here in the form of fibre (Li et al., 2017a).

Moreover, Jin et al. (2020) suggested that the ideal level of dietary fibre was 4%, especially for Sichuan White geese. Another study indicated that dietary fibre could provide excellent results at a level of 5.5% (Liu et al., 2019), although other work reported no significant improvement at this proposed level (Dobos et al., 2019). In contrast, the findings of Jha and Mishra (2021) showed that high fibre content was associated with low energy that could reduce feed intake, and low feed consumption was correlated with the low gain:feed ratio and body weight gain (BWG). This may be true when high-fibre diet neglects minimum nutrient requirements. Individual peer-reviewed, published articles presented in this study may contain discrepancies in soluble fibre content, especially for pectin (Jha and Mishra, 2021).

Blood profiles. This meta-analysis presented non-significant results across the dataset, indicating that fibre-rich ingredients had little effect on blood serum parameters. Wang et al. (2017) listed several nutritional factors that correlated with the resultant changes in blood metabolites in geese. Meanwhile, fibre-rich ingredients can protect blood circulation from metabolic disorders. Raised glucose has been shown to correlate with energy nutrition and not with high dietary fibre components. Triglycerides, total cholesterol, and total protein can be lowered by fibre-based diets. Similarly, Ran et al. (2021) reported that the use of up to 20% grass meal as a fibrous diet can reduce total serum protein and albumin during the growth period of geese. Surprisingly, Regar et al., (2019) conducted a single experiment and reported that the content of fibre-rich ingredients below 10% resulted in higher cholesterol levels. When bile acid level is low, serum cholesterol concentration is reduced. Hasanuddin and Rusdi (2017) reported that fibre could bind to bile acid, thereby increasing its faecal excretion. Additionally, Arroyo et al. (2012b) classified fibre associated with plant substances as polysaccharides, oligosaccharides and lignin, and suggested that fibre promoted beneficial physiological parameters, including lowering cholesterol and glucose levels. There are several processes that may occur in the blood stream. First, fibre binds gall acid by increasing the number of villi in the small intestine during growth and development. Second, fibre reduces the rate of carbohydrate absorption, which in turn lowers insulin levels. This reduces the stimulation of cholesterol and lipoprotein cycles. Third, fibre circulates from the coeliac artery for the normal maintenance of the liver as an organ. Fourth, fibre is transferred into the small intestine via the hepatic circulation system after passing to the liver. Both the third and fourth pathway enter from two veins, and then merge inside the organ. Finally, fibre inhibits the synthesis of cholesterol from SCFA generated by lactic acid bacteria in the colon.

Carcass yield and internal organs. The meta-analysis confirmed that there was positive relationship between fibre-rich ingredients and foie gras weight. Arroyo et al. (2012a) mentioned that there were several factors involved in the production of foie gras of good quality. First, the digestive capacity of geese to adapt to the sensory environment in terms of feed characteristics. Second, feed quality, such as colour, texture, particle size, water retention, strain, nutrient compositions, and source of fibre. High quality foie gras was reported to be produced from goose strains such as Landes, Toulouse, White Roman, Greylag Landaise, Hainan, or Yangzhou geese (Rochlitz and Broom, 2017; Massimino et al., 2019; Delpont et al., 2018). Accordingly, Li et al. (2017b) argued that the greater ability of geese to digest roughage compared to other waterfowl reflected their larger and stronger gastrointestinal tracts. Thus, the powerful gizzards of geese can generate the forces required to effectively utilise high-fibre feed such as forage, straw and even rice by-products (Dawson et al., 2000). In addition, Arroyo et al. (2013) reported a significant increase in foie gras quality, both before and after cooking. Additionally, in this study, sorghum was shown to be a better feed component than maize in terms of the starch ratio. Moreover, colour intensity was increased, while the yellow colour of foie gras was reduced since carotenoid and vitamin A levels in sorghum were lower compared to maize.

Foie gras quality. The biological mechanism behind the effect of fibre-rich ingredients on liver quality is attributed to several important factors, particularly adipose tissue deposition and steatosis metabolism. First, geese are used for foie gras production because they are predisposed to high adipose tissue deposition, and have a lower digestive capacity and a liver prone to steatosis. The metabolism of steatosis is based on hepatic lipid channelling and secretion into the plasma and peripheral adipose storage (Guémené and Guy, 2004).

Moreover, foie gras is obtained through force-feeding methods used to increase liver size. Liver size is enlarged due to the hypertrophy of hepatocytes – a process that does not occur in other cells. Hepatic steatosis is a reversible cycle caused by an increase in lipid synthesis. These lipids are produced thanks to the feed that contain rich sources of fibre (Rodriguez et al., 2003).

Conclusions

To a certain extent, fibre-rich ingredients are recommended in the diet as geese are herbivorous waterfowl by nature, and therefore adapted to the digestion of roughage. Fibre-rich dietary sources contain cellulosic and non-cellulosic polysaccharides, non-carbohydrate components and lignin, which can be digested or absorbed into the blood stream, and thus play an important role in goose diets if applied properly. The quality of foie gras depends on the diet and specific fibre source.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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