Influence of different types of sugar on overfeeding performance—part of meat quality

Zhaoyun Luo,[*,†] Rongxue Wei,[*,†] Yongqiang Teng,[*,†] Rong Ning,[*,†] Lili Bai,[*,†] Cangcang Lu,[*,†] Donghang Deng,[*,†] Mariama Abdulai,[*,†] Liang Li,[*,†] Hehe Liu,[*,†] Shengqiang Hu,[*,†] Shouhai Wei,[*,†] Bo Kang,[*,†] Hengyong Xu,[*,†] and Chunchun Han [*,†,1]

[*]*Key Laboratory of Livestock and Poultry Multi-omics, Ministry of Agriculture and Rural Affairs, College of Animal Science and Technology, Sichuan Agricultural University, PR China; and* [†]*Farm Animal Genetic Resources Exploration and Innovation Key Laboratory of Sichuan Province, Sichuan Agricultural University, PR China*

ABSTRACT Previous research in our lab showed that 10% glucose, 10% fructose, and 10% sucrose can induce lipid deposition in goose fatty liver formation process more efficiently. However, whether the overfeeding diet supplement with sugar can affect the meat quality is unclear. The aim of this research was to estimate the meat quality of geese overfed with overfeeding diet adding with different types of sugar. The results indicated there were no significant differences in the diameter of muscle fiber, the muscle fiber density, pH0, pH24, the meat color, the cooking loss, the drip loss, the shear force and the dry matter in breast muscle and thigh muscle between corn flour groups and three sugars groups ($P > 0.05$). The crude fat content of breast muscle in fructose group was significantly higher than that in sucrose group ($P < 0.05$); the inosinic acid content of leg muscle in fructose group was significantly higher than that in the sucrose group ($P < 0.05$); the ratios of essential amino acids to total amino acids (**EAA/TAA**) in the breast muscle of maize flour group, fructose group, sucrose group and glucose group were 42%, 35%, 32% or 34%;57%, 64%, 64%, and 62%, respectively; the ratios of essential amino acids to total amino acids in leg muscle of maize flour group, fructose group, sucrose group and glucose group were 31%, 33%, 35%, and 34%, respectively. The contents of C16:1 and C18:1 n-9c in breast muscle in fructose group were significantly higher than that in sucrose group ($P < 0.05$). Compared with maize flour group, the contents of C18:0 and C20:0 were lower in leg muscle of sugar group ($P < 0.05$). Compared with the maize flour group, the activities of hydrogen peroxide (**H2O2**) and glutathione peroxidase (**GSH-PX**) in breast muscle were higher than those of sucrose group ($P < 0.05$), the total antioxidant capacity (**T-AOC**) levels in breast muscle was higher than that of fructose group and sucrose group ($P < 0.05$). Cluster analysis and principal component analysis (**PCA**) showed that there was no difference in meat quality between maize flour and sugar group. In conclusion, the overfeeding with maize flour supplement with 10% sugar had no evident influence on the meat quality.

Key words: goose, overfeeding, meat quality, glucose, fructose, sucrose

2022 Poultry Science 101:102149
https://doi.org/10.1016/j.psj.2022.102149

INTRODUCTION

Previous research found that glucose, fructose and sucrose all induced more lipid deposition in goose liver (Supplement materials-1 S-Figure 1) (Wei et al., 2022). *Margret* and *foie gras* are the main products of overfeeding production. However, whether the overfeeding diet supplement with sugar can affect the meat quality is unclear. The meat quality evaluation indexes include the meat color, pH, water holding capacity, tenderness, intramuscular fat, tasting evaluation, and flavor. Flavor comes from muscle inosinic acid and certain amino acids. The greater the density of the muscle fibers, the finer the diameter, the tenderer the meat, the better its flavor. Lipid content in meat influences the meat quality, taste, flavor, nutritional, and sensorial quality. The breast or leg muscle of overfed waterfowl is quite different from that of waterfowl fed ad libitum, because it had higher total lipids content (Baeza et al., 2013). The reason may be that overfeeding induced fat accumulation in breast muscle, which accompanied with lipid deposition in liver. As shown in previous study, glucose, fructose, and sucrose all can promote fat accumulation in liver tissue (Wei et al., 2022). Whether these 3 types of sugar induce lipid deposition in muscle tissue and then influence the meat quality need further research.

Received June 3, 2022.
Accepted August 19, 2022.

[1]Corresponding author: chunchunhai_510@163.com

Anaerobic glycolysis is the main way of generating energy after slaughtering livestock and poultry meat. Since there is no blood circulation, wastes such as lactic acid and H^+ accumulate in large quantities, resulting in a decrease in the pH value of meat. The pH value of meat will affect meat quality, such as PSE meat (Gonzalez-Rivas et al., 2020). Our previous study showed that overfeeding dietary supplementation with fructose and sucrose increased the serum lactic acid content in overfed geese (Lu et al., 2021). Whether the change of serum lactic acid can affect the meat quality is unclear. Fatty acids not only constructed TG, but also influence the meat relish. When unsaturated fat acids are oxidized, meat flavor may be negatively affected (Aaslyng and Meinert, 2017). In addition, fatty acid composition in livestock and poultry meat has a significant impact on human health. The meat fatty acids composition is important, as it can generate energy to promote the absorption of fat-soluble vitamins and provide essential fatty acids (Jaturasitha et al., 2016). Our previous study showed that overfeeding dietary supplementation with glucose, fructose and sucrose changed the fatty acids composition in goose liver (Wei et al., 2022). Whether overfeeding dietary supplementation with glucose, fructose, and sucrose can affect the fatty acids composition of muscle is also unclear.

In order to comprehensively compare overfeeding influence of different types of sugar on meat quality of overfed goose, more physical and chemical indexes were introduced to comprehensively estimate meat quality. Physical and chemical indexes contained texture parameters, color, drip loss, cooking loss, pH; content of dry matters (**DM**), crude protein (**CP**), crude fat (**CF**), antioxidant capacity, inosinic acid, amino acid, and long-chain fatty acid were detected. Combined with these indexes, different comparison analysis, correlation analysis, principal component analysis (**PCA**) and cluster analysis were performed to estimate the meat quality of breast muscle and leg muscle in overfed geese. Not only will this study reveal the relationship between the overfeeding and meat quality, it is also conducive to comprehensive evaluation for feeding influence of different types of sugar in livestock production.

METHODS AND MATERIALS

Birds and Experiment Design and Sampling

The overfeeding procedure and sampling were performed as our previously study (Wei et al., 2022) (Supplement materials-1 S-Table 1). In brief, one hundred and twenty 13-wk-old male Tianfu Meat Geese came from Experimental Farm for Waterfowl Breeding at Sichuan Agricultural University (Ya'an, China), and the ganders were randomly separated into 4 groups (maize flour overfeeding group, 10% glucose overfeeding group, 10% fructose overfeeding group, 10% sucrose overfeeding group); each overfeeding group was consisted of 30 ganders (considered the mortality and guaranteed to have more than 20 geese after overfeeding). All the experimental geese were reared in cages with a density of 3 birds /m^2, the temperature was controlled at about 25°, and light was provided at night (dim light). During overfeeding, the daily feed intake reached 1,600 g dry matters (4 meals a day; dry matter: water = 1:0.75), which lasted 3 wk. After slaughter, the overfed geese breast muscle and leg muscle was collected and weighted immediately. All procedures in the present study were subject to approval by the Institutional Animal Care and Use Committee (**IACUC**) of Sichuan Agricultural University (Permit No. DKY-B20141401), and carried out in accordance with the approved guidelines. All efforts were made to minimize the suffering of the animals.

The breast muscle and leg muscle sample were separated into 3 parts, respectively. The first part of the muscle tissue was frozen at −20°C for detection of antioxidant capacity, inosinic acid, amino acids and long-chain fatty acids determination. The second part of muscle sample was washed in ice-cold saline (0.9% NaCl; 4° C) and fixed in 4% formaldehyde-phosphate buffer for histomorphology determination. The third part of muscle sample was kept at 4°C for other indexes detection (texture parameters, meat color, drip loss, cooking loss, pH, DM, CP, and CF).

Texture Parameters Detection

Texture parameters were measured by TA.XTC-18 texture analyzer (Shanghai Baosheng Industrial Development Co., Ltd, Shanghai, China). Apparatus detection parameter as below: Probe: cylindrical instrument probe (TA/36); Type of trial: total texture determination; Type of test: down-stroke; Target model: displacement; Goal value: 5 mm; Time: 2.00 sec; Pretest speed: 2.00 mm/s; Test speed: 1.00 mm/s; Post-test speed: 1.00 mm/s; Trigger point type: force; Trigger point value: 5.00 gf.

In addition, shear force measurements by TA. XTplus. The muscle was packed in a plastic bag and heated in hot water to a central temperature of about 75 to 80°C (about 45 min), and then cooled it to room temperature naturally. The cut meat spline was placed on the force platform of the texture instrument to make the muscle fiber direction and the knife edge vertical. By starting the vector force of the machine, the tenderness data can be read on the induction element. Each sample was determined for 3 times. The result took the mean value.

Color and pH detection

After slaughter for 45 min, meat color was measured by CR-400 automatic colorimeter (Minolta, Japan). The value of brightness (L*), redness (a*), and yellowness (b*) represented muscle color. Meat pH value was determined using a pH meter (Model PC 510; Cyberscan, Singapore) at 45 min (pH0) and 24 h (pH24). Each sample was determined for 3 times. The result takes the mean value.

Water Holding Capacity Determination

Water holding capacity determination of *foie gras* can refer to the determination of muscle dripping loss and cooking loss. In brief, muscle tissue was into 5 cm*3 cm*1 cm block. And then, weighted this block (mL), threaded the muscle block with iron wire and kept vertical downward, placed it in the sealing plastic bag, made it does not contact the sealing plastic bag, and sealed plastic bag. After hanging the muscle block in 4°C refrigerators 24 h, wiped off the surface of muscle sample with clean filter paper and weighted the liver block (m2). Dripping loss (%) = [(m1−m2)/mL] *100%.

The muscle sample measured by drip loss was placed in a plastic bag, the air in the bag was removed and the mouth of the bag was sealed so that the surface of the muscle sample was tightly attached to the plastic bag. The sealed muscle sample bag was placed in 75°C water bath for about 30 min to make the internal temperature of the muscle sample reach 70°C. After water bath cooking, removed it and cooled it to room temperature, and then wiped off the surface of muscle sample with clean filter paper and weighted the muscle block (m3). Cooking loss (%) = [(m1−m3)/m1]*100%. All assays were performed three times.

Histomorphology Examinations

The cross-sections from the middle of muscle sample were preserved in 4% formaldehyde-phosphate buffer were prepared using standard paraffin embedding techniques, sectioned (5 μm) and stained with hematoxylin and eosin (**HE**), and sealed by neutral resin size thereafter, and then examined by microscope photography system (Olympus, Tokyo, Japan), each slice was observed and 5 visual fields were randomly selected at 40 × magnifications. The selected visual fields were measured via imaging software (Image Pro Plus 6.0, Media Cybernetics, Bethesda, MD). The density and diameter of breast and leg muscle fiber were measured 10 times and taken an average.

Determination of Dry Matter, Crude Fat and Crude Protein

The water content of muscle was determined by freeze-drying method. In brief, wrapped about 0.5g grinding muscle tissue (m) with filter paper (marked with pencil), and weighted the total mL; and then put it in in vacuum freeze dryer (Thermo Fisher Scientific, Shanghai, China). After 72 h (until the error between 2 weighing less than 0.002 g), weighted its total m2. m3 = m1−m2, water content (%) = m3/m*100%, DM (%) = 100%−water content (%).

After freeze-drying, about 0.5 g grinding dry mater sample of muscle (m) wrapped with filter paper, weighted the total mL, was put in Soxhlet extractor, the crude fat content was determined by Soxhlet leaching method (50°C heating in water bath, diethyl ether extraction 24 h). After extraction, weighted the total m2. Crude fat content (%) = (m1−m2/m) *100%. Each sample was performed in triplicate.

Crude protein detection used Kjeldahl method. First-phase preparations: about 0.5 g grinding dry mater sample of muscle was used to mix with 0.4 g copper sulfate pentahydrate, 6 g anhydrous sodium sulfate in a 100 mL conical flask, two zeolites, and then 10 mL concentrated sulfuric acid (98%) were added. After finishing first-phase preparations, conical flask was covered with curved neck funnel, and then heated with electric furnace until the liquid color became blue (digestion process completed). Whole process was performed in the fume hood. When the conical flask cooled it to room temperature, added 50 mL water dissolved the blue crystal, the solution was digestive solution. Digestive solutions were analyzed by automatic Kjeldahl nitrogen determination instrument (Foss, Sweden). Digestive solution mixed with 40 mL 40% sodium hydroxide aqueous solution. After distillation, the emitted ammonia is absorbed by 40 mL Boric acid absorption solution (1% boric acid aqueous solution 1000 mL + 0.1% methyl red ethyl alcohol solution 7 mL + 0.1% bromocresol green ethyl alcohol solution 10 mL + 4% sodium hydroxide aqueous solution 0.5 mL). Its content is determined by 0.01 mol/L standard hydrochloric acid solution titration (HCL solution was calibrated by sodium carbonate). Result output mode was "Pro (%)" which represented the crude protein content. Standard hydrochloric acid solution consumption of sucrose which substituted muscle sample was set as blank value (less than 0.2 mL). Nitrogen content of ammonium sulfate (21.19 ± 0.2 %) was used to evaluate the accuracy of detection process.

Inosinic Acid, Amino acids, and Long-chain Fatty Acids Detection

About 0.5 g grinding muscle sample was mixed with 1.5 mL 5% perchloric acid homogenized. After homogenization, homogenate was removed to a 15 mL centrifugal tube, and centrifuged at 8,000 × g for 10 min. The upper solution removed into another 15 mL centrifugal tube. Settling matter was mixed with 2 mL 5% perchloric acid and shook for 2 min, and then centrifuged at 8,000 × g for 10 min, and removed supernatant. This process was repeated in triplicate. Supernatant was collected and adjusted pH to 6.5 with 5 mol/L sodium hydroxide solution, and diluted with water to 10 mL, and mixed, which was sample solution. Transferred 1 mL sample solution and filtered it through a 0.22 μm filter membrane to the sample bottle for determination by reversed phase high performance liquid chromatography (**HPLC**). Chromatograph parameter value as below: Chromatograph Column: 4.6 × 2500 mm, 5 μm Hypersil GOLD (25005-254630) (Thermo Fisher Scientific) and Guard cartridge: 4 × 10 mm, 5 μm Hypersil GOLD (25005-014001) (Thermo Fisher Scientific). Injection volume: 10 μm. Flow rate: 1 mL/min; Column temperature: 40°C. Mobile phases A: Ammonium formate aqueous solution (0.05M; pH = 6.5); mobile phases

B: methyl alcohol; ratio of mobile phase A to mobile phase B = 90%:10%. Inosinic acid standard (Sigma-Aldrich, Shanghai, China) was set different concentration gradients (diluted with 5% methyl alcohol). According to the corresponding relationship between concentration and peak area, the linear equation is constructed for result analysis of sample inosinic acid content (Supplement materials-2, Inosinic acid detection part).

Reversed phase HPLC by using ortho-phthalaldehyde (**OPA**) and 9-Fluorenylmethyl Chloroformate (**FMOC**) as online derivatization reagent was performed for amino acid determination. The method was described in detail in Supplement materials-2, amino acid detection part. Long-chain fatty acid determination was refer to the Chinese standard (GB5009.168-2016); pretreatment method of muscle sample was performed as described in previous study (Wei et al., 2022); the method was described in detail in Supplement materials-2, long-chain fatty acid detection part.

Determination of Antioxidant Activities

A total of 0.50 g muscle was mixed with 4.50 mL saline, homogenized in an ice water bath, and centrifuged at 4°C with 3,000 r/min for 10 min. The supernatant (10% stock solution of the muscle) was stored at −20°C for further analysis. The kits that detected total antioxidant capacity (**T-AOC**), maleic dialdehyde (**MDA**), H_2O_2, catalase (**CAT**), glutathione peroxidase (**GSH-PX**), and superoxide dismutase (**SOD**) were provided by Nanjing Jiancheng Bioengineering Institute (Nanjing, China), respectively. Protein concentration of samples was employed to calculate the antioxidation activities using a Coomassie brilliant blue kit. The results were calculated on the basis of the protein content in muscle homogenates.

The antioxidant status of meat was analyzed by DPPH 1,1-diphenyl-2-picrylhydrazyl assay (**DPPH**). The DPPH was purchased from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan). A DPPH free radical elimination ability was determined according to the method described as below. Briefly, the reaction mixture was prepared adding 50 μL of each muscle homogenates sample to 950 μL of an ethanolic solution of 0.1 mmol/L DPPH radical. The absorbance of the supernatant at 517 nm was determined centrifuged at 3500 r/min for 10 min after 30 min of reaction in the darkness. The percentage of DPPH radical inhibition was calculated according to the Equation: AAR% = (1-$A_{sample}/A_{control}$) * 100%. Take the concentration of the sample with the clearance rate of DPPH in the range of 45%−55% for determination. The results were expressed as μmol of Trolox equivalent (**TE**) per gram of protein in muscle homogenates (μmol TE/g protein).

Data Analysis

The comparisons of multiple groups were performed by SPSS statistics 21. One-way ANOVA was used to compare the data (LSD method). All results were expressed as means ± SD and P-value below 0.05 was considered statistically significant. Cluster analysis and PCA were performed by R language (Supplement materials-2, data analysis part). In cluster analysis and PCA, the variables contained muscle weight, texture parameters, color, drip loss, cooking loos, pH; DM, CP, CF, inosinic acid, 17 amino acids and 8 long-chain fatty acids.

RESULTS

Influence of Supplementation with Different Types of Sugar on Physical Parameters

Compared with the maize flour group, the leg weight was higher in glucose group ($P < 0.05$). Compared with the glucose group, the body weight, slaughter weight, half evisceration weight, and full evisceration weight were significantly higher in the sucrose group ($P < 0.05$). There was no significant difference on breast muscle weight, leg muscle weight, the ratio of breast muscle weight to full evisceration weight and the ratio of leg muscle to full evisceration weight between different types of sugar groups ($P > 0.05$) (Table 1). The histological characteristics of the muscle are shown in Figure 1, there was no significant difference between maize flour

Table 1. Influence of supplementation with different types of sugar on slaughter performance of meat.

Itermm	MF	G	F	S	P value
Body weight (g)	6310 ± 559^{a}	6123 ± 658^{c}	6641 ± 737^{ab}	6839 ± 626^{a}	0.0461
Carcass weight (g)	5668 ± 412^{a}	5401 ± 562^{b}	6016 ± 760^{a}	6005 ± 575^{a}	0.0257
Eviscerated yield (g)	4720 ± 412^{ab}	4875 ± 427^{c}	5564 ± 597^{ab}	5587 ± 403^{a}	0.0190
Semi- eviscerated yield (g)	4529 ± 371^{ab}	4167 ± 362^{b}	4695 ± 555^{a}	4668 ± 356^{a}	0.0156
Breast muscle weight (g)	418 ± 56.0^{b}	400 ± 58.0^{a}	465 ± 68.0^{a}	443 ± 71.0^{a}	0.0300
Leg muscle weight (g)	337 ± 85.0^{b}	370 ± 67.0^{b}	383 ± 86.0^{a}	372 ± 92.0^{b}	0.0453
Carcass percentage (%)	90.9 ± 3.30^{a}	87.8 ± 3.60^{c}	90.4 ± 2.50^{ab}	88.1 ± 2.80^{bc}	0.0189
Semi-eviscerated percentage (%)	85.6 ± 3.10^{a}	82.0 ± 3.50^{c}	85.1 ± 2.80^{ab}	82.7 ± 3.00^{bc}	0.0365
Eviscerated percentage (%)	72.7 ± 3.00^{a}	70.2 ± 3.60^{a}	71.8 ± 2.80^{a}	69.4 ± 3.90^{b}	0.0330
Breast muscle percentage (%)	9.30 ± 1.30	9.70 ± 1.40	10.0 ± 1.50	9.40 ± 1.30	0.357
Leg muscle percentage (%)	7.40 ± 1.60	8.90 ± 1.60	8.40 ± 1.90	7.90 ± 1.80	0.423

Note: Values are means ± SD (n = 20). In the same column, values within the same row with different superscripts mean significant difference ($P < 0.05$).

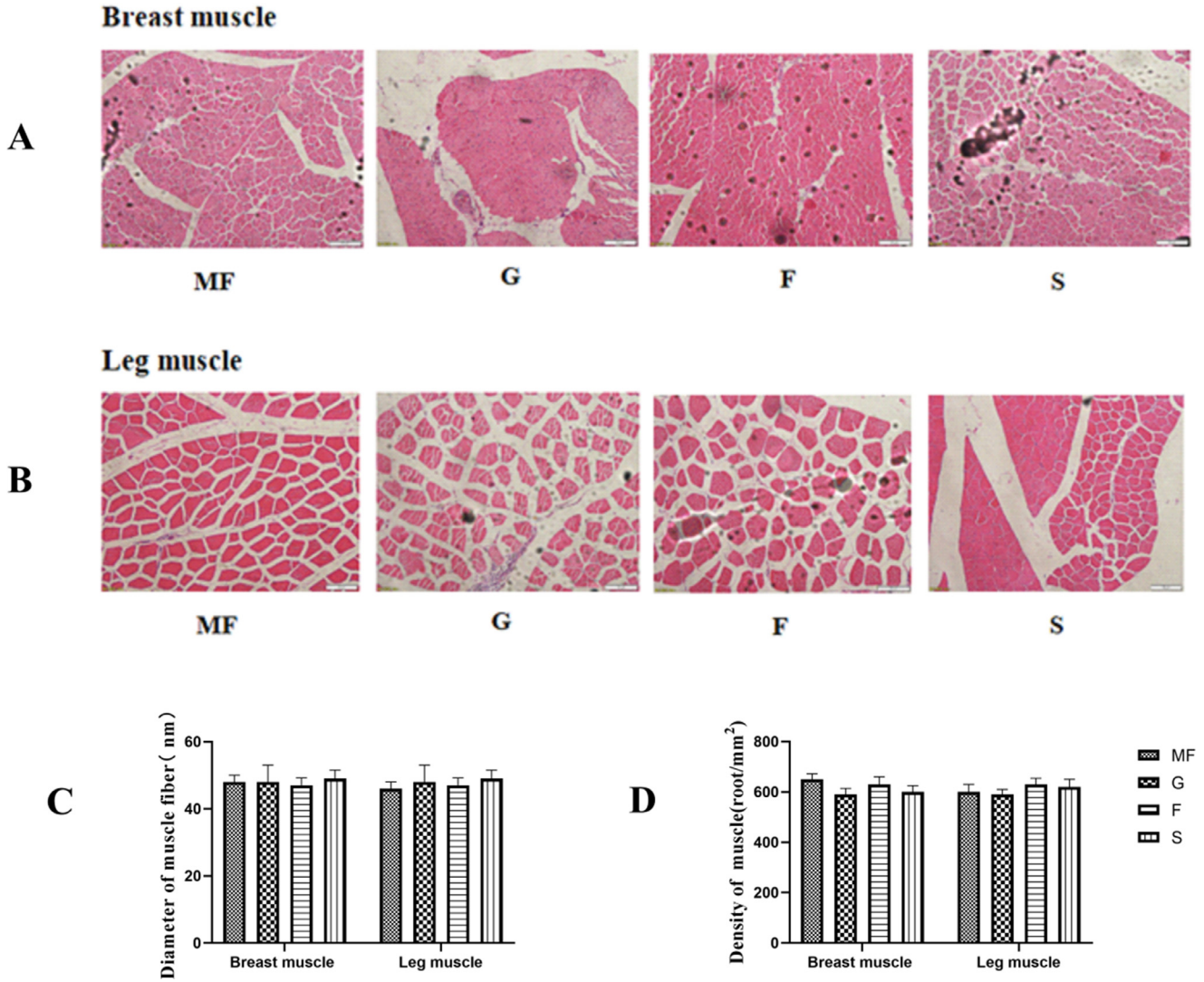

Figure 1. Influence of supplementation with different types of sugar on muscle morphology (n = 3). A, Histology observation of breast muscle; B, Histology observation of leg muscle; C, Comparison of muscle fiber diameter (μm); D, Comparison of muscle fiber density (root/mm^2). Values are means ± SD (n = 3). Abbreviations: F, fructose group; G, glucose group; MF, maize flour group; S, sucrose group.

group and three sugar groups on the muscle fiber diameter and density of the breast muscle and leg muscle ($P > 0.05$). There was no significant difference between maize flour group and three sugar groups on the pH0, pH24, L*, a*, b*, cooking loss rate, drip loss rate and shear force in breast muscle and leg muscles ($P > 0.05$). The hardness, brittleness and resilience of leg muscles in the sucrose group were significantly higher than those in the glucose group, and the viscosity of the leg muscles in the glucose group was significantly higher than that in the sucrose group ($P < 0.05$) (Table 2).

Influence of Supplementation with Different Types of Sugar on Chemical Parameters

After overfeeding with the diet supplementation with sucrose, the DM and CP of the breast muscle significantly increased ($P < 0.05$); the CP of the breast muscle of the sucrose group was significantly higher than that of fructose group and glucose group ($P < 0.05$); there was no significant difference between maize flour group and sugar group in IMP content of breast muscle ($P > 0.05$). Compared with sucrose group, the water content of leg muscle was lower in maize flour group, fructose group and glucose group ($P < 0.05$); the leg muscle CP of sucrose group was significantly higher than that of maize flour group ($P < 0.05$); leg muscle inosinic acid content of fructose group was significantly higher than that of sucrose group ($P < 0.05$) (Table 3).

In Table 4, the comparison analysis of amino acids content was shown. Compared with maize flour group, the contents of serine and cystine were higher in the breast muscle of sugar group ($P < 0.05$). The contents of aspartic acid, glutamic acid, arginine methionine and phenylalanine of sucrose and glucose group were higher than those of maize flour group in breast muscle ($P < 0.05$). Alanine, tyrosine and leucine content of glucose group were higher than those of maize flour group in breast muscle ($P < 0.05$). The content of isoleucine was higher than that of maize flour group in breast muscle ($P < 0.05$). After overfeeding with the maize flour

Table 2. Influence of supplementation with different types of sugar on physical parameters of meat.

Iterm		MF	G	F	S	*P* value
Breast muscle	Hardness (g)	984 ± 665	780 ± 493	946 ± 703	936 ± 538	0.814
	Brittleness (g)	984 ± 665	813 ± 548	941 ± 684	985 ± 603	0.377
	Viscous (g)	760 ± 261	1405 ± 1117	1083 ± 533	1050 ± 628	0.993
	Elasticity (g)	0.580 ± 0.230	0.520 ± 0.130	0.520 ± 0.120	0.520 ± 0.120	0.510
	Chewability (g)	268 ± 158	229 ± 142	263 ± 157	286 ± 167	0.185
	Adhesive (g)	716 ± 548	5200 ± 442	660 ± 596	668 ± 512	0.773
	Cohesion (g)	0.470 ± 0.150	0.480 ± 0.130	0.480 ± 0.150	0.470 ± 0.120	0.555
	Resilience (g)	0.230 ± 0.170	0.210 ± 0.0601	0.220 ± 0.140	0.221 ± 0.0901	0.591
	Shear force (g)	4562 ± 1493	3911 ± 1184	3848 ± 1834	5669 ± 2148	0.406
	pH0	5.08 ± 0.340	5.22 ± 0.280	5.10 ± 0.510	5.17 ± 0.340	0.343
	pH24	5.37 ± 0.380	5.42 ± 0.210	5.41 ± 0.350	5.38 ± 0.390	0.666
	L*	52.0 ± 11.6	55.4 ± 6.50	55.2 ± 5.70	50.3 ± 8.00	0.186
	a*	23.1 ± 8.30	22.6 ± 4.10	22.3 ± 5.10	21.6 ± 3.50	0.199
	b*	9.50 ± 3.11	10.0 ± 4.07	10.5 ± 4.18	10.3 ± 2.83	0.221
	Cooking loss (%)	34.2 ± 2.40	37.8 ± 3.02	34.9 ± 7.04	37.5 ± 10.0	0.347
	Drip loss (%)	3.20 ± 1.00	9.20 ± 2.60	6.41 ± 2.00	7.52 ± 3.00	0.563
Leg muscle	Hardness (g)	451 ± 250	369 ± 144	489 ± 212	541 ± 258	0.913
	Brittleness (g)	503 ± 284	365 ± 142	531 ± 257	704 ± 413	0.441
	Viscous (g)	414 ± 261	953 ± 559	669 ± 469	731 ± 462	0.785
	Elasticity (g)	0.550 ± 0.120	0.49 ± 0.111	0.590 ± 0.130	0.531 ± 0.120	0.907
	Chewability (g)	373 ± 250	286 ± 179	272 ± 199	406 ± 234	0.766
	Adhesive (g)	211 ± 93.7	262 ± 140	299 ± 146	332 ± 152	0.870
	Cohesion (g)	0.443 ± 0.141	0.430 ± 0.120	0.500 ± 0.120	0.460 ± 0.120	0.243
	Resilience (g)	0.191 ± 0.0601	0.181 ± 0.0400	0.214 ± 0.0601	0.201 ± 0.0500	0.385
	Shear force (g)	3891 ± 1695	4118 ± 870	3888 ± 789	4014 ± 1191	0.0591
	pH0	5.30 ± 0.450	5.34 ± 0.280	5.26 ± 0.520	5.40 ± 0.420	0.693
	pH24	5.63 ± 0.381	5.43 ± 0.401	5.25 ± 0.481	5.47 ± 0.380	0.735
	L*	54.1 ± 15.9	58.0 ± 15.1	59.0 ± 9.79	54.9 ± 7.18	0.776
	a*	23.7 ± 4.20	23.9 ± 4.87	23.9 ± 4.38	25.0 ± 4.48	0.654
	b*	12.6 ± 2.94	11.6 ± 3.24	15.4 ± 5.00	12.1 ± 3.76	0.0823
	Cooking loss (%)	31.9 ± 9.94	49.1 ± 29.4	35.9 ± 1.73	43.6 ± 11.3	0.749
	Drip loss (%)	7.40 ± 3.40	4.30 ± 1.20	4.50 ± 1.00	3.90 ± 1.40	0.778

Note: Values are means ± SD (n = 20).
Abbreviations: F, fructose group; G, glucose group; MF, maize flour group; S, sucrose group.

supplementation with different types of sugar, the content of aspartate, glutamate, serine, threonine, phenylalanine, and isoleucine increased in leg muscles ($P < 0.05$), and the leucine content significantly decreased in fructose or sucrose group ($P < 0.05$), and the proline content significantly decreased in glucose group ($P < 0.05$), the content of tyrosine, cysteine and valine significantly decreased in sucrose group; in addition, the histidine content significantly increased in sucrose and glucose group ($P < 0.05$). In breast muscles, the ratio of essential amino acids to total amino acids (**EAA/TAA**) of maize flour group, fructose group, sucrose group and glucose group were 42%, 35%, 32%, and 34%, respectively, and the ratio in leg muscles was 31%, 33%, 35% and 34%, respectively (Figure 2).

The comparison analysis of fatty acids content was shown in the Table 5. There was no significantly difference in fatty acids content of breast muscle between different sugar groups ($P > 0.05$); compared with the sucrose group, the contents of C16:1 and C18:1n9c were significantly higher in fructose group ($P < 0.05$). Compared with maize flour group, the content of C16:0 was lower in sucrose group ($P < 0.05$). As to the fatty acids in leg muscle, compared with the maize flour group, the content of C18:0 was lower in all sugar groups ($P < 0.05$), the content of C18:1n9c was lower in glucose group ($P < 0.05$), and the content of C20:0 was lower in sucrose group ($P < 0.05$). There was no significantly difference in fatty acids content of leg muscle between 3 sugar groups ($P > 0.05$).

Table 3. Influence of supplementation with different types of sugar on chemical parameters of meat−moisture, crude protein, crude fat, and inosinic acid.

Iterm		MF	G	F	S	*P* value
Breast muscle	Moisture (%)	68.6 ± 2.38	69.5 ± 4.35	69.6 ± 2.55	71.1 ± 4.21	0.156
	Crude protein (%)	75.33 ± 3.21	75.8 ± 2.47	75.4 ± 3.97	78.5 ± 2.46	0.163
	Crude fat (%)	17.1 ± 1.70	17.6 ± 2.90	18.8 ± 3.50	16.2 ± 2.60	0.153
	inosinic acid (mg/g)	0.630 ± 0.110	0.640 ± 0.290	0.650 ± 0.130	0.590 ± 0.280	0.115
Leg muscle	Moisture (%)	71.4 ± 1.25	71.51 ± 1.79	69.7 ± 1.89	73.1 ± 2.00	0.130
	Crude protein (%)	76.1 ± 2.51	77.2 ± 3.77	76.9 ± 3.23	78.5 ± 2.95	0.218
	Crude fat (%)	17.25 ± 3.1	13.95 ± 1.69	18.2 ± 3.67	16.9 ± 3.92	0.164
	Inosinic acid (mg/g)	0.640 ± 0.240	0.630 ± 0.170	0.750 ± 0.220	0.460 ± 0.140	0.178

Note: Values are means ± SD (n = 20).
Abbreviations: F, fructose group; G, glucose group; MF, maize flour group; S, sucrose group.

Table 4. Influence of supplementation with different types of sugar on chemical parameters of meat−amino acids (μmol/g).

Iterm		MF	G	F	S	*P* value
Breast muscle	Aspartic acid	36.4 ± 28.1^{ab}	44.9 ± 17.0^{a}	23.3 ± 20.0^{b}	43.2 ± 17.0^{a}	0.0331
	Glutamic acid	132.3 ± 14.8^{b}	152 ± 13.1^{a}	130 ± 9.46^{b}	155 ± 8.83^{a}	0.0123
	Serine	24.0 ± 5.58^{c}	44.1 ± 8.43^{b}	25.6 ± 5.96^{b}	45.2 ± 4.92^{b}	0.0221
	Histidine	39.0 ± 2.21	39.1 ± 3.95	38.1 ± 3.14	38.5 ± 3.79	0.197
	Glycine	123.8 ± 19.9^{b}	142 ± 19.9^{a}	135 ± 28.3^{ab}	136 ± 21.6^{ab}	0.0255
	Threonine	66.8 ± 4.85	68.8 ± 3.54	65.6 ± 2.06	69.2 ± 5.23	0.684
	Arginine	100 ± 6.11^{b}	106 ± 8.14^{a}	97.6 ± 4.86^{b}	118 ± 5.83^{b}	0.0166
	Alanine	77.6 ± 7.79^{b}	84.0 ± 11.1^{a}	82.8 ± 4.57^{ab}	70.8 ± 4.11^{c}	0.00233
	Tyrosine	23.3 ± 3.28^{b}	26.2 ± 2.55^{a}	23.9 ± 1.95^{ab}	24.7 ± 3.74^{ab}	0.0400
	Lysine	192 ± 13.5	193 ± 16.5	188.17 ± 5.75	186.7 ± 17.1	0.0977
	Cystine	147 ± 89.5^{c}	428 ± 269^{ab}	379 ± 100^{b}	520 ± 52.6^{a}	<0.001
	Valine	60.5 ± 4.26^{b}	74.8 ± 5.56^{a}	61.1 ± 2.87^{b}	74.9 ± 4.05^{a}	0.0
	Methionine	38.9 ± 6.53^{b}	49.6 ± 7.71^{a}	43.4 ± 5.35^{b}	48.8 ± 8.62^{a}	0.0488
	Phenylalanine	27.6 ± 2.65^{c}	31.0 ± 2.24^{b}	28.8 ± 1.95^{c}	34.9 ± 2.27^{a}	<0.001
	Isoleucine	52.2 ± 5.63	53.9 ± 3.91	54.9 ± 2.67	55.8 ± 3.41	0.198
	Leucine	98.5 ± 9.86^{b}	107 ± 8.06^{a}	99.8 ± 5.06^{b}	103 ± 8.49^{ab}	0.018
	Proline	69.4 ± 7.99	71.6 ± 9.18	66.5 ± 6.95	70.5 ± 7.87	0.102
Leg muscle	Aspartic acid	192 ± 6.81^{a}	94.5 ± 23.9^{b}	60.5 ± 20.8^{c}	44.2 ± 22.5^{c}	0.0356
	Glutamic acid	228 ± 56.7^{a}	167.3 ± 11.8^{b}	162.9 ± 13.9^{b}	155 ± 7.59^{b}	0.0287
	Serine	77.17 ± 19.33^{a}	54.88 ± 24.61^{b}	52.83 ± 23.86^{b}	42.57 ± 13.70^{b}	0.0444
	Histidine	32.5 ± 7.92^{b}	37.9 ± 7.82^{a}	35.03 ± 6.00^{a}	38.7 ± 5.57^{a}	0.0113
	Glycine	121 ± 29.85	111 ± 27.2	128 ± 29.7	116 ± 38.2	0.0800
	Threonine	86.2 ± 6.46^{a}	75.5 ± 6.64^{b}	74.8 ± 9.42^{b}	68.7 ± 3.38^{c}	<0.001
	Arginine	122 ± 9.85	117 ± 8.07	114 ± 9.73	112 ± 7.17	0.217
	Alanine	126 ± 43.8^{a}	100 ± 39.7^{b}	103 ± 41.1^{b}	70.0 ± 6.88^{c}	<0.001
	Tyrosine	33.4 ± 9.30^{a}	29.5 ± 8.83^{a}	29.8 ± 8.67^{a}	23.6 ± 3.45^{b}	0.0155
	Lysine	146 ± 38.2	157 ± 40.5	156 ± 33.2	184.6 ± 23.7	0.161
	Cystine	338 ± 68.6^{a}	303 ± 117^{a}	394 ± 100^{a}	318 ± 151^{b}	0.0450
	Valine	77.5 ± 20.4^{a}	67.9 ± 19.7^{a}	73.1 ± 23.4^{a}	56.7 ± 13.7^{b}	0.0239
	Methionine	44.3 ± 3.69	44.9 ± 7.96	43.2 ± 7.39	43.2 ± 12.1	0.104
	Phenylalanine	44.2 ± 10.7^{a}	37.3 ± 8.67^{b}	37.4 ± 10.4^{b}	33.2 ± 5.59^{b}	0.0145
	Isoleucine	73.8 ± 12.1^{a}	65.3 ± 12.4^{b}	65.0 ± 15.5^{b}	56.1 ± 3.44^{b}	0.0371
	Leucine	130 ± 24.1^{a}	116 ± 21.0^{ab}	114 ± 26.8^{b}	98.3 ± 6.35^{c}	0.0339
	Proline	74.4 ± 14.2^{a}	76.3 ± 12.6^{b}	72.4 ± 20.3^{ab}	74.4 ± 17.4^{a}	0.0441

Note: Values are means ± SD (n = 15). In the same column, values within the same row with different superscripts mean significant difference ($P < 0.05$).

Influence of Supplementation with Different Types of Sugar on Anti-oxidative Activity

The influence of supplementation with different types of sugar on anti-oxidative activity of meat was shown in **Table 6**. Compared with the maize flour group, the H2O2 content of breast muscle in fructose group was higher ($P < 0.05$); the content of GSH-PX was higher in sucrose group ($P < 0.05$); the content of T-AOC was higher in both fructose and sucrose group ($P < 0.05$); the content of SOD was lower in both fructose and sucrose group ($P < 0.05$). Compared with the maize flour group, the content of H2O2 of leg muscle was lower in both fructose and sucrose group in leg muscle ($P < 0.05$), the content of T-AOC was higher in glucose group, the content of SOD was lower in glucose group ($P < 0.05$).

The correlation analysis between antioxidant capacity and meat quality parameters was shown in Supplement materials-1 S-Figure 2 and S-Figure 3. In breast muscle of the maize flour group, there was a significantly positive correlation between SOD and L* and shear force ($P < 0.05$). In sugar group, most meat quality indexes of breast muscle were significantly correlated with antioxidant capacity ($P < 0.05$). In leg muscle, SOD was significantly positively correlated with L* and shear force in maize flour group ($P < 0.05$); GSH-PX was significantly positively correlated with drip loss in fructose, sucrose and glucose groups ($P < 0.05$). In maize flour group, T-AOC was significantly positively correlated with L*, GSH-PX was significantly positively correlated with b*, H2O2 was significantly positively correlated with pH24 ($P < 0.05$).

Comprehensive Estimation of Meat Quality via Principal Component Analysis (PCA) and Cluster Analysis

In order to comprehensive compare the meat quality difference between these overfeeding groups, the PCA and cluster analysis which combined the detected physical and chemical parameters were performed. There was a huge overlap between these overfeeding groups in breast muscle and leg muscle, and the sample distribution of each group was indistinguishable, which indicated that there was no significant difference between maize flour, glucose, fructose, and sucrose group in meat quality of breast muscle and leg muscle. Base on the number of overfeeding groups, the number of clusters was 4, the cluster method was complete, and the cluster analysis results were shown in Figure 3. In breast muscle, more samples cluster in the second and the fourth category. In leg muscle, more samples cluster in the

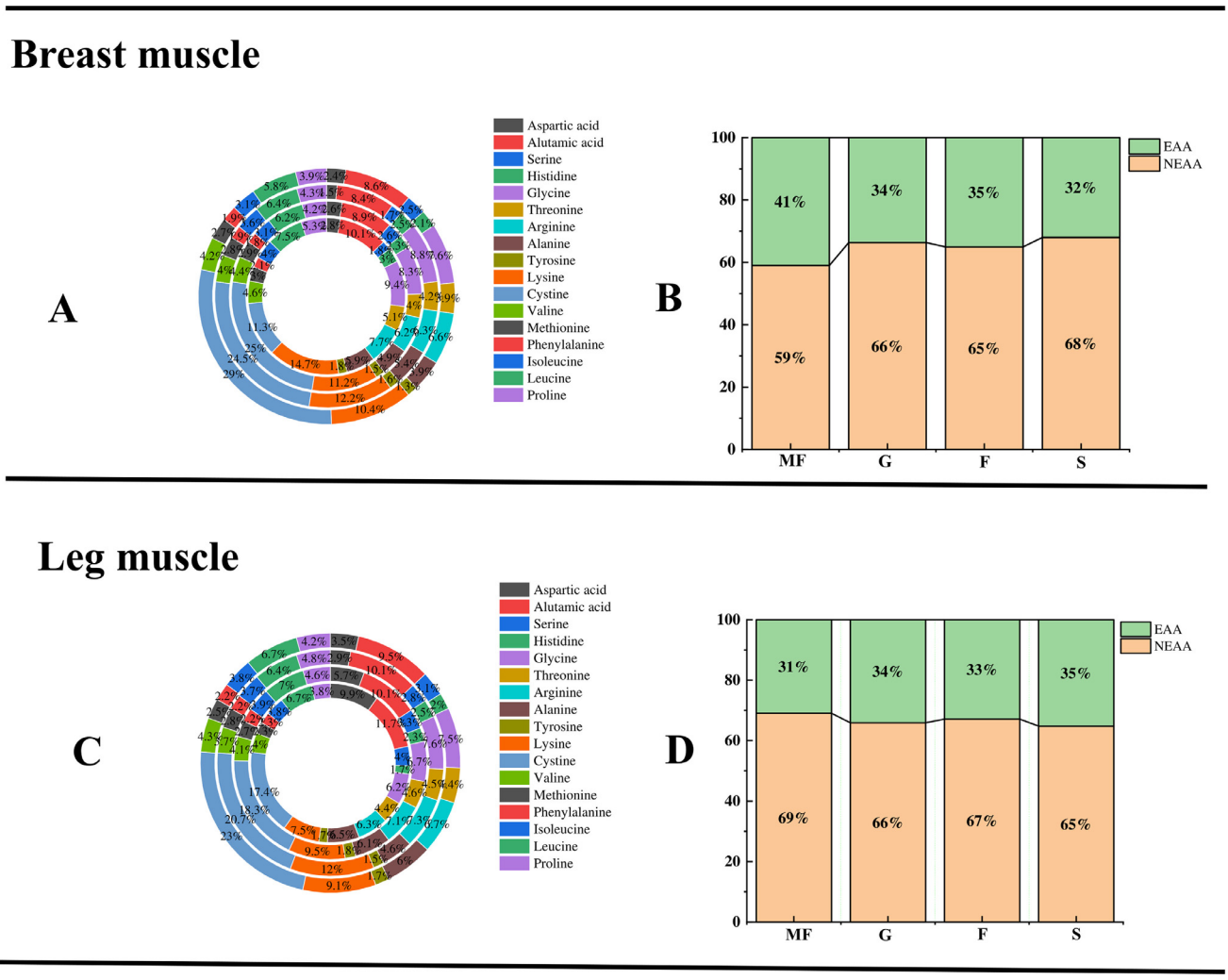

Figure 2. Influence of supplementation with different types of sugar on amino acids composition (n = 15). A, amino acid percentage stacking chart of breast muscle; B, ratio of EAA and NEAA of breast muscle; C, amino acid percentage stacking chart of thigh muscle; D, ratio of EAA and NEAA of leg muscle. MF = maize flour group, G = glucose group, F = fructose group, S = sucrose group. The essential amino acids: Histidine, Threonine, Tyrosine, Lysine, Cystine, Valine, Methionine, Phenylalanine, Isoleucine, Leucine. The circles from the center outward denote: MF, G, F, S. Abbreviations: EAA, essential amino acids; NEAA, nonessential amino acids.

Table 5. Influence of supplementation with different types of sugar on chemical parameters−fatty acids (g/100 g).

Fatty acids		MF	G	F	S	*P* value
Breast muscle	C14:0	0.321 ± 0.220^{a}	0.0231 ± 0.110^{ab}	0.217 ± 0.0900^{ab}	0.147 ± 0.0700^{b}	0.0443
	C16:1	0.226 ± 0.160^{ab}	0.206 ± 0.140^{ab}	0.447 ± 0.510^{a}	0.195 ± 0.140^{b}	0.0231
	C16:0	7.94 ± 3.72^{a}	6.40 ± 2.92^{a}	7.31 ± 2.22^{a}	4.90 ± 1.73^{b}	0.0159
	C18:2n6c	4.11 ± 1.69	3.16 ± 1.14	3.36 ± 0.770	3.89 ± 0.861	0.445
	C18:1n9c	7.77 ± 3.69^{a}	6.44 ± 3.69^{a}	8.18 ± 2.96^{a}	4.99 ± 2.26^{b}	0.0234
	C18:0	4.22 ± 1.60	3.37 ± 1.39	3.83 ± 1.05	2.96 ± 1.09	0.768
	C20:4n6	2.45 ± 1.27	1.91 ± 1.04	1.84 ± 0.841	2.21 ± 0.963	0.0550
	C20:0	0.140 ± 0.0500	0.0751 ± 0.0300	0.0890 ± 0.0100	0.141 ± 0.0601	0.115
	C22:6n3	0.154 ± 0.100	0.172 ± 0.0901	0.229 ± 0.151	0.221 ± 0.0300	0.197
Leg muscle	C14:0	0.226 ± 0.130	0.154 ± 0.0704	0.148 ± 0.0601	0.177 ± 0.123	0.453
	C16:1	1.39 ± 0.672	1.351 ± 0.534	0.950 ± 0.651	1.54 ± 0.864	0.176
	C16:0	5.52 ± 1.08	4.31 ± 1.26	4.57 ± 1.38	4.86 ± 1.92	0.212
	C18:2n6c	2.78 ± 1.08	2.48 ± 0.518	2.369 ± 0.38	2.47 ± 0.211	0.105
	C18:1n9c	7.19 ± 3.66^{a}	4.65 ± 1.66^{b}	5.21 ± 1.97^{ab}	5.39 ± 2.28^{ab}	0.0291
	C18:0	3.87 ± 1.15^{a}	2.58 ± 0.64^{b}	2.85 ± 1.77^{b}	2.79 ± 0.53^{b}	0.0324
	C20:4n6	2.51 ± 0.701	2.00 ± 0.344	2.06 ± 0.522	2.01 ± 0.261	0.317
	C20:0	0.124 ± 0.0345^{a}	0.0881 ± 0.0335^{ab}	0.084 ± 0.0204^{ab}	0.0710 ± 0.0202^{b}	0.0145
	C22:6n3	0.118 ± 0.0201^{d}	0.145 ± 0.0803^{c}	0.146 ± 0.0311^{b}	0.148 ± 0.0815^{a}	0.0227

Note: Values are means ± SD (n = 15). In the same column, values within the same row with different superscripts mean significant difference ($P < 0.05$). Abbreviations: MF = maize flour group, G = glucose group, F = fructose group, S = sucrose group.

Table 6. Influence of supplementation with different types of sugar on antioxidant capacity of meat.

Item		MF	G	F	S	*P* value
Breast muscle	MDA	3.75 ± 1.63	3.07 ± 1.34	2.53 ± 0.874	2.91 ± 1.40	0.313
	H2O2	90.9 ± 35.6^{b}	88.1 ± 6.60^{b}	173 ± 63.6^{a}	64.3 ± 28.5^{b}	0.0233
	DPPH•EA	0.450 ± 0.180^{ab}	0.320 ± 0.0900^{b}	0.300 ± 0.280^{b}	0.730 ± 0.340^{a}	0.0155
	T-AOC	55.1 ± 19.5^{b}	111 ± 24.5^{ab}	111 ± 49.2^{a}	121 ± 27.7^{a}	0.0117
	CAT	31.45 ± 9.21	17.9 ± 10.5	26.80 ± 22.17	26.33 ± 16.15	0.276
	GSH-PX	2116 ± 839^{b}	2325 ± 469^{b}	2531 ± 859^{b}	4055 ± 1364^{a}	0.0310
	SOD	10.8 ± 1.70^{a}	8.75 ± 1.28^{ab}	7.21 ± 0.190^{b}	7.34 ± 1.04^{b}	0.0105
Leg muscle	MDA	5.35 ± 2.71	4.46 ± 1.80	5.21 ± 1.89	5.29 ± 0.30	0.759
	H2O2	107 ± 62.0^{a}	116 ± 44.4^{b}	112 ± 19.6^{b}	95.2 ± 70.4^{ab}	0.029
	DPPH•EA	1.12 ± 0.360	0.560 ± 0.310	0.309 ± 0.0600	0.67 ± 0.200	0.072
	T-AOC	3.15 ± 0.843^{b}	7.52 ± 2.61^{a}	2.98 ± 0.760^{b}	4.93 ± 3.18^{ab}	0.032
	CAT	23.4 ± 10.4	32.8 ± 26.9	22.2 ± 2.23	40.3 ± 22.9	0.146
	GSH-PX	2108 ± 1037	2495 ± 1390	2195 ± 860	1378 ± 256	0.055
	SOD	10.1 ± 2.05^{a}	4.63 ± 1.90^{b}	8.02 ± 3.58^{b}	5.24 ± 2.35^{b}	0.016

Note: MAD = Malonyldialdehyde (nmmol/mgprot); H_2O_2 = Hydrogen Peroxide (mmol/mgprot); DPPH•EA = 1-diphenyl-2-picrylhydrazyl free radical elimination ability (μmol Trolox equivalent (TE)/g protein); T-AOC = Total antioxidant capacity (ml/mgprot); CAT = Catalase (U/gprot); GSH-PX = Glutathione Peroxidase (U/gprot); SOD = superoxide dismutase (U/mgprot). Values are means ± SD (n = 5). In the same column, values within the same row with different superscripts mean significant difference ($P < 0.05$). Abbreviations: MF = maize flour group, G = glucose group, F = fructose group, S = sucrose group.

second category. In Figure 4, PCA for meat quality of breast muscle and leg muscle among the maize flour, glucose, fructose, and sucrose group was shown. In breast muscle, the PCA1 was 40.29, the PCA2 was 16.57; in leg muscle, the PCA1 was 51.67, the PCA2 was 19.07. In addition, the sample distribution was intercross, which also indicated that there was no significant difference between maize flour, glucose, fructose and sucrose group in meat quality of breast muscle and leg muscle, as the clustering analysis.

DISCUSSION

The percentage of slaughter weight was above 80% and the percentage of eviscerated yield was above 60%, which is considered to have good slaughter and meat performance (Xu et al., 2018). In this study, the percentage of slaughter weight was above 80% and the percentage of eviscerated yield was above 60% in all overfeeding group, which was consistent with previous studies that overfeeding improved the slaughter performance in fatty liver production. The body weight, slaughter weight, semi-eviscerated weight and full eviscerated weight of sucrose group and the CP content was higher than those of other overfeeding group, which indicated that overfeeding dietary supplementation with sucrose promoted the protein synthesis. The texture parameter is related to muscle fibers, for example, the shear force value is an indicator of tenderness, which is associated with muscle fibers (Hughes et al., 2014; Tijare et al., 2016). In this study, there was no significant difference in muscle fiber diameter and fiber density of breast and leg muscle between maize flour group and three sugar groups. In breast muscle and leg muscle there was no significant difference in shear force, hardness, brittleness, viscosity, elasticity, chewiness, cohesion, resilience between maize flour group and sugar groups. The L* value reflects the brightness and paleness of meat. The L* value is closely related to muscle water retention as well (Huang et al., 2014). However, in this study, there was no significant difference in meat color and cooking loss of breast and leg muscle between maize flour group and three sugar groups.

The destruction of the cell membrane integrity induced-by lipid peroxidation is associated with the incremental drip loss (Zhang et al., 2019). Oxidative stress has been shown to reduce the collagen solubility, possibly affecting the toughness of meat (Chen et al., 2016). In this study the lipid oxidation status was assessed by estimation of MDA value, and the antioxidant ability of geese meat was analyzed by DPPH assay. After slaughtered, the muscle tissue lacks the antioxidant enzymes from the liver when the blood circulation is stopped, the residual levels of antioxidant enzymes in muscle tissue is closely related to the storage time (Zheng et al., 2020). In addition, the increase of meat color may also be related to antioxidant properties. The a* may be due to the antioxidative property, which delays the metmyoglobin formation (Yan et al., 2020). The experimental data also showed that muscle antioxidant capacity was significantly correlated with meat quality, and increased muscle antioxidant capacity delayed methemoglobin oxidation, which may be the reason for the increase in meat color a* (Yan et al., 2020). However, there was no significant difference between these overfeeding groups in this current study, the relationship between meat color and antioxidant capacity needs further research. To sum up, the results of this experiment showed overfeeding dietary supplementation with glucose, fructose and sucrose could increase the antioxidant capacity of the muscle, which may be beneficial to the subsequent slaughtering and processing of the muscle, and then improve meat quality of overfed geese.

Inosinic acid is an effective flavor enhancer, the flavor enhancer effect is about 50 times that of monosodium glutamate, is an important indicator of meat flavor (Tian et al., 2021; Tu et al., 2021). The inosinic acid content of leg muscle in fructose group was significantly

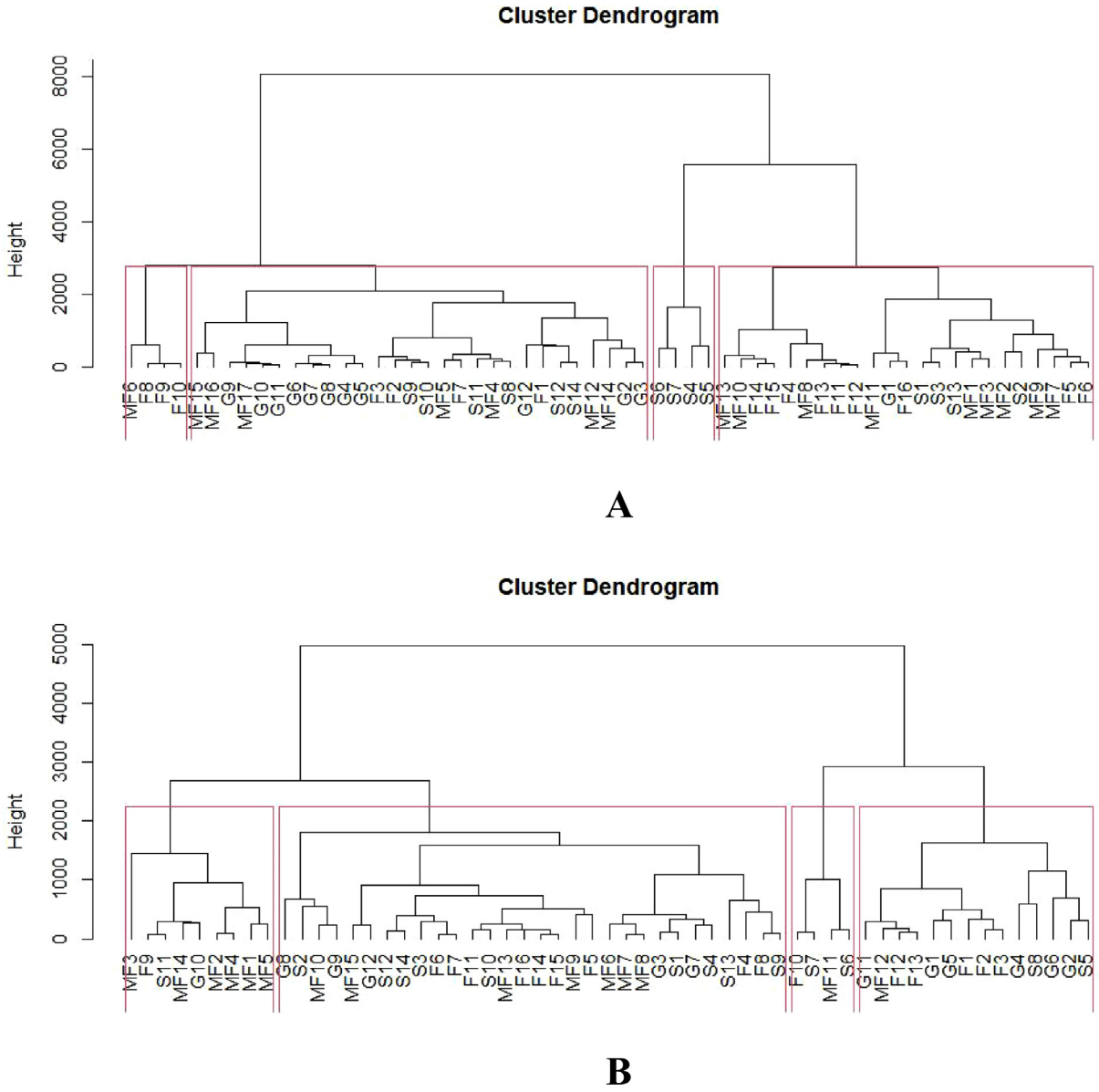

Figure 3. Cluster analysis for meat quality among the maize flour, glucose, fructose and sucrose group. A, Cluster analysis for meat quality of breast muscle; B, Cluster analysis for meat quality of leg muscle. Abbreviations: F, fructose group; G, glucose group; MF, maize flour group; S, sucrose group.

higher than that in sucrose group, indicating that the muscle in fructose group may be fresher. In addition, amino acids can also affect meat flavor. Glutamic acid is the main meat flavor compound. Glutamine is the main amino acid in aromatic amino acids that determines the meat relish, and the glycine is also closely related to the meat relish (Kong et al., 2021). Aspartic acid, arginine, alanine, and glycine are also important precursors of volatile flavor compounds in meat (Ganguly et al., 2018; Sabikun et al., 2021). Free glutamine and free aromatic amino acids such as phenylalanine and tyrosine also play an important role in enhancing the saltiness or umami taste of livestock and poultry muscle (Petrujkic et al., 2018). After overfeeding with dietary supplementation with glucose, fructose, and sucrose, the content of aspartic acid and glutamic acid increased in breast muscle of sucrose group and glucose group, and the content of alanine increased in breast muscle of glucose group. These results that flavor amino acids increased, indicating that breast muscle may be fresher after overfeeding dietary supplementation with sugar. However, compared with common maize flour overfeeding, the content of aspartic acid and glutamic acid significantly decreased in leg muscle in all sugar groups, which suggested that goose leg muscles umami taste may be impaired after overfeeding dietary supplementation with sugar. Compared with common maize flour overfeeding, the content of cystine increased in sugar, sucrose and glucose group, the content of methionine and phenylalanine increased significantly in the breast muscle of sucrose and glucose group, leucine content increased in the breast muscle of sucrose group, tyrosine and leucine content significantly increased in the breast muscle of glucose group. Cystine, methionine, phenylalanine, isoleucine, leucine, and tyrosine are all essential amino acids (He et al., 2021). These results

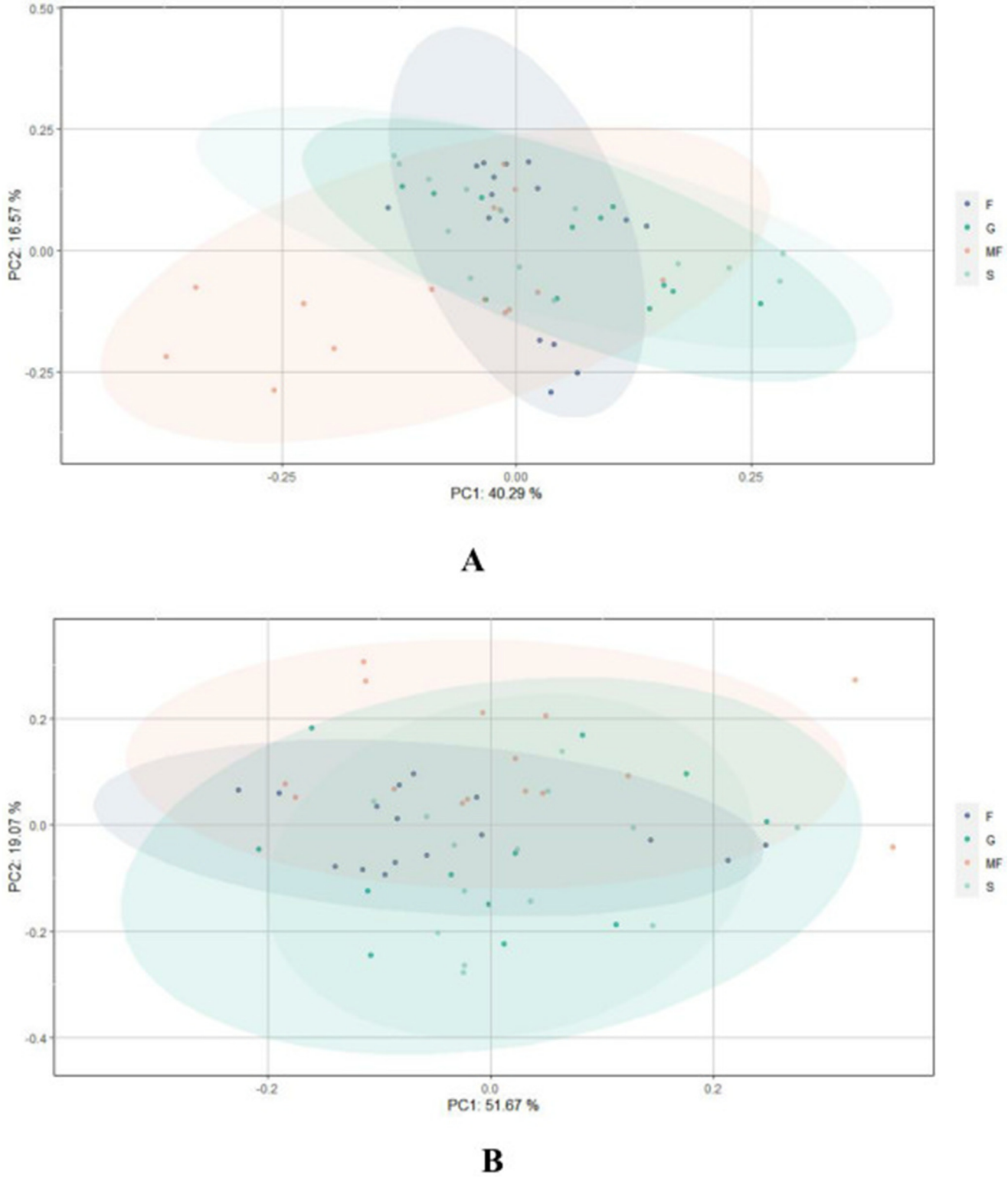

Figure 4. Principal component analysis for meat quality among the maize flour, glucose, fructose and sucrose group. A, Principal component analysis for meat quality of breast muscle; B, Principal component analysis for meat quality of leg muscle. Abbreviations: F, fructose group; G, glucose group; MF, maize flour group; S, sucrose group.

showed that overfeeding dietary supplementation with sugar can increase the essential amino acid content, which will improve the geese meat nutrition.

The fatty acid composition in livestock and poultry meat not only affects the nutritional composition of muscles, but also affects the flavor of the meat and the later storage and processing. Linoleic acid and α-linolenic acid are two essential fatty acids required by the body. Unsaturated fats acids (**UFAs**) have been proven to help prevent cardiovascular diseases in humans (Meex and Blaak, 2021). While UFAs have health benefits, they are more likely to self-oxidize than saturated fats acids (**SFAs**), and meat flavor may be negatively affected (Barros et al., 2021). Compared with

common maize flour overfeeding, the C18:0 content of leg muscles significantly decreased after overfeeding dietary supplementation with sugar; and the arachidic acid (C20:0) content of leg muscles significantly decreased in sucrose group. Among the saturated fatty acids, C14:0, C18:0, and C16:0 is particularly important because of their high cholesterol properties associated with coronary heart disease (Praagman et al., 2015). Thereby, it will be beneficial to human health that reducing the content of saturated fatty acid C18:0 and C20:0 in the leg muscle resulted from overfeeding dietary supplementation with sugar. Stearoyl-CoA desaturase (**SCD**) is the rate-limiting enzyme that catalyzes the synthesis of monounsaturated fatty acids from saturated fatty acids including palmitoyl-CoA (C16:0) and stearoyl-CoA (C18:0). The contents of palmitoleic acid (C16:1) and C18:1n-9c in the breast muscle of the fructose group were significantly higher than those of the sucrose group. The reason may be that fructose promotes the expression of SCD1 gene in breast muscle (Wood et al., 2008). Studies have shown that long-term fructose intake increases hepatic SCD1 activity in mice (Liu et al., 2016). Nevertheless, it is necessary to further research that SCD regulated fatty acid metabolism in overfed geese muscle. Meat with high concentrations of UFAs is prone to oxidation, which can lead to rancidity, poor flavor, and color. The 2-thiobarbituric acid (MDA) reflects the concentration of lipid oxidation products, which may contribute to meat flavor (Tomovic et al., 2021). In this current study, the lipid oxidation state was assessed by measuring the MDA value of the muscle. There was no significant difference in MDA level of leg muscle between maize flour, glucose, fructose and sucrose group, which indicated that lipid oxidation in the leg muscle was stable and the overfeeding with diet supplementation with sugar had no adverse effect on the muscle.

In conclusion, overfeeding maize flour supplementation with 10% glucose, fructose, and sucrose increased some amino acids, fatty acids and the antioxidant capacity in breast and leg muscle. However, meat quality is a comprehensive indicator involved in multiple aspects of the parameter estimation. By the comprehensive analysis combined with multiple aspects of the parameter (cluster analysis and PCA), the results showed that overfeeding with diet supplementation with 10% glucose, fructose, and sucrose had no effect on the meat quality. *Foie gras* and *magret* are the main products of overfeeding production. Combined with previous result that 10% fructose and 10% sucrose promoted more lipid deposition in liver, therefore, overfeeding dietary supplementation with 10% fructose and 10% sucrose will gain better economy effectiveness in *foie gras* production.

ACKNOWLEDGMENTS

The work was supported by the National Natural Science Funds of China (No. 31672413), and the Natural Science Funds of Sichuan Province (No. 2022NSFSC0059).

DISCLOSURES

We declare that all authors have no conflict of interest about this manuscript.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.psj.2022.102149.

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