Supplementation With Purple Corn Anthocyanin Improves Growth Performance, Meat Quality, Muscle Antioxidant Status and Unsaturated Fatty Acid Profiles in Growing Goat

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Research

Keywords: Anthocyanin, Antioxidant status, Fatty acid profile, Lipid oxidation, Meat quality

Posted Date: March 31st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-359148/v1

Abstract

Background: There are abundant anthocyanin compounds in purple corn, which has a wide range of biological activity in terms of antioxidation, scavenging free radicals, and preventing lipid peroxidation. However, the impact of anthocyanins on the meat quality, muscle antioxidant activity and fatty acid profiles in growing goats has not been studied. This experiment was conducted to observe the effects of anthocyanin from purple corn pigment (PCP) on growth performance, nutrient digestibility, meat quality, muscle antioxidant activity and fatty acid profiles of goats during the growing period. It aimed to provide the important rationale for anthocyanin preventing lipid peroxidation in goats.

Results: A total of eighteen Qianbei Ma wether kids (body weight, 21.38 ± 1.61 kg; mean ± standard deviation) were randomly allotted into three groups using a completely randomized design with six duplicates per group. The dietary treatments were: 1) the control group was provided with basal diet; 2) treatment 1 (LA) was provided basal diet with 0.5 g/d PCP; and 3) treatment 2 (HA) was provided basal diet with 1 g/d PCP. The results showed that supplementation of PCP anthocyanin could increase ($P < 0.05$) CP and GE digestibilities compared to the control. The addition of PCP tended to drop ($P < 0.05$) shear force during the growing goat phase. Goat receiving PCP showed higher ($P < 0.05$) levels of reduced glutathione, DPPH scavenging activity, and peroxidase in *Longissimus dorsi* muscle (LD) relative to the control. Compared with the control, LA and HA displayed lower ($P < 0.05$) concentrations C10:0, C12:0, C14:0, C15:0, C16:0, C17:0 and saturated fatty acid (SFA), but increased ($P < 0.05$) various individual unsaturated FA of C14:1, C16:1, C17:1, C18:1n9, C18:1n12, C18:2n6, C18:3n3, C20:4n6, C22:1n9, C22:4, C22:5n6, C22:6n3, C24:1, PUFA, n-6 PUFA, MUFA/SFA and PUFA/SFA. Specifically, some stronger ($P < 0.05$) positive correlations were detected between antioxidant status and UFA profiles (GSH-Px, GSH, catalase, DPPH scavenging activity with C14:1, C15:1, C16:1, C18:1n9, C20:4n6, C22:1n9, C22:4, C22:5n6, C24:1, MUFA) in LD of goats.

Conclusion: Results indicated that anthocyanin could be used as a source of natural functional additive because anthocyanin-rich PCP had the potential to improve growth performance, meat quality, and enhance muscle antioxidant status and unsaturated FA profiles in the growing goats.

Background

It was generally known that essential fatty acid (EFA) was polyunsaturated fatty acid (PUFA), substances essential for increasing the body immune, improving the health of consumers [1]. However, high PUFA concentration was often responsible for the reduction of oxidative stability, thereby reducing the shelf life of products [2]. Moreover, ruminant meat had high saturated fatty acid (SFA) content because the rumen biohydrogenation, and thus might have negative effect on the human health [3]. Various study did show that supplementation of natural antioxidant extract in ruminant diet would seem to be an effective of improving antioxidant potential and alleviating lipid oxidation, and even more and more popular with numerous consumers [4, 5].

Anthocyanin is a large type of polyphenols compound, which is a strong natural antioxidant and widely exists in nature plant and food fields [6]. Indeed, anthocyanin as a suitable source of natural active substances for ruminant with health care functions, which it can scavenge free radical (FR) and improve the body's antioxidant capacity [7, 8]. Purple corn contained a lot of anthocyanins, which was possessed of a variety of physiological functions, just as preventing tumors, cancer, cardiovascular disease, etc. [9]. Supplementation of anthocyanin in ruminant feed could alleviate oxidative stress and help prevent unsaturated fatty acid (UFA) loss, which had extremely developed valuable [10]. Additionally, we confirmed that purple corn pigment (PCP) could maintain UFA levels in milk in our previous study [11]. To date, there are few studies concerning the effect of anthocyanin from PCP on meat quality, muscle antioxidant capacity and fatty acid (FA) profiles in goats. We have hypothesized that the inclusion of PCP could improve meat quality, and enhance the antioxidative ability as well as UFA concentration of the goat. Accordingly, the present study was conducted to examine the effects of PCP anthocyanin on growth performance, meat quality, *Longissimus dorsi* muscle (LD) antioxidant status and FA content; as well as the relationship between muscle antioxidant status and UFA composition in growing goat.

Materials And Methods

Animals, diets, and experimental design

The feeding trial was carried out at the Xishuixianfuxingmuye Co. Ltd., Guizhou, China (106.198244 E, 28.26403 N). All procedures used in this study were approved by the Guizhou University, Experimental Animal Ethics (Guiyang, China).

The whole experiment stage was 74 d, which from 12 July to 24 September in 2020. The preparation period was 14 d and formal experiment period was 60 d. A total of eighteen Qianbei Ma wether kids (body weight, 21.38 ± 1.61 kg; mean ± standard deviation) were randomly allotted into three groups using a completely randomized design with six duplicates per group. The dietary treatments were: 1) the control group was provided with basal diet; 2) treatment 1 (LA) was provided basal diet with 0.5 g/d PCP; and 3) treatment 2 (HA) was provided basal diet with 1 g/d PCP. The PCP was purchased from Nanjing Herd Source Bio-technology Co., Ltd., Nanjing, China. The level of PCP was used in the research followed by Tian et al. [12]. All experimental kids were housed in clean individual pens and water was taken freely during the experimental period. The equal amount of rations was provided twice daily at 08:30 and 16:30 for *ad libitum* intake and 10% refusals on an as-fed basis. The nutrient requirement of experimental animals according to the NRC [13], and the diet formulations was listed in Table 1.

Determination of chemical composition

Approximately 100 g of experimental diet was collected once weekly and stored at -20°C. After the end of feeding trials, the basal diet of total mixed ration was dried at 65°C in a vacuum oven for 72 h, then ground and passed through a 1-mm sieve. The dry matter (DM), crude protein (CP), ether extract (EE), Ash, calcium (Ca), and phosphorus (P) were measured as per the method of AOAC [14]. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. [15] using a FT 122 Fibertec^{TM} analyzer (Foss, Hillerød, Denmark). The organic matter (OM) and hemicellulose were obtained by the 100 minus the Ash as well as NDF minus ADF, respectively. Gross energy (GE) was detected using a calorimeter (WGR-WR3, Changsha BENTE Instrument Co., Ltd., China). Each sample was run in triplicate.

Determination of anthocyanin composition

The anthocyanin composition of PCP was extract using 1.5 mole HCl dissolved in 95% ethanol solution (ethanol:HCl = 85:15) was detected by a HPLC-MS/MS according to Tian et al. [11]. The anthocyanin compositions of pelargonidin (Pel), peonidin (Peo), cyanidin (Cya), malvidin (Mal), petunidin (Pet), and delphinidin (Del) were determined in this study. Total anthocyanins (TA) content was calculated from the following formula: TA = Pel + Peo + Cya+ Mal + Pet + Del. The anthocyanin composition of commercial PCP was list in Table 2.

Determination of growth performance

Dry matter intake (DMI) was calculated per day throughout the entire study period. The body weight of each kid was weighted at 1th d and 74th d of the trial period before morning feeding. The average net gain (ANG), average daily gain (ADG) and feed conversion ratio (FCR) were calculated until the end of the experiment. Fecal sample was collected on the last 7 days (2 d of the adaptation period and 5 d of the digestion trial period) and proximate nutrients digestibility was determined by the method of acid-insoluble ash (AIA) [16] according to the following formula: nutrient apparent digestibility (%) =100%-(AIA in diet/AIA in fecal×nutrient in fecal/nutrient in diet) ×100. All fecal samples were oven-dried at 65 °C for 72 h, ground and passed through a 1-mm sieve, and kept at 4 °C until further analysis.

Assessment of meat quality

Six goats per group were slaughtered at the end of the experiment, the experimental kids were slaughtered, and the processing of carcass was described by National agricultural industry standard of the People's Republic of China [18]. The LD of kid on the left body side was separated for detection of meat quality. The pH of LD was measured at 45 min and 24 h (put into a chiller at 4°C) by a pH-star (Matthäus, Eckelsheim, Germany). The pH value was updated 2 times per second, and until the value was stable and data was recorded. Each sample at per time was run in triplicate. Percentage of water loss was detected by the pressure method [19]. Briefly, 1 cm thick sample was cut using a 2.532-cm diameter with 5 cm^2 area circular sampler and weighted the pre-pressure weight. Next, the sample was sandwiched between two layers of gauze, and was placed on a platform with 18 layers of qualitative medium-speed filter paper above and below, and pressurized to 35 kg (pressure gauge measuring range about 138) for 5 min. The platform was removed and immediately peeled meat sample from the gauze to weigh post-pressure weight. Percentage of water loss was calculated using the following formula: Percentage of water loss (%) = [(pre-pressure weight - post-pressure weight)/ pre-pressure weight] ×100. For drip loss, about 10 g and 3 cm length cube of LD was manually trimmed and weighed, and suspended by a fishhook in an inflated plastic bag, sealed and stored for 24 h at 4 °C. The sample was weighted after removing the fishhook and drying on filter paper. Drip loss was calculated as follows: drip loss (%)=[(initial weight−final weight)/initial weight]×100%. For cooked meat rate, about 100 g of LD was weighted without fascia, epimysium or fat. The sample was placed on the steamer and cooked for 30 min, and steamed meat sample was weighted after cooling 4 °C for 2 h. Cooked meat rate was calculated as follows: cooked meat rate (%)= (fresh weight- cooked weight)×100%. Meat color was measured using an Opto-Star equipment (Company MATTHÄUS, KLAUSA). The shear force of sample cores was measured using a digital display tenderness meter (Xielikeji co., ltd., Harbin, China) with a load cell of 15 kg and a 200-mm/min crosshead speed.

Determination of antioxidant status

The procedures of LD homogenate as follow: the sample was washed with pre cooled PBS (0.01 M, pH = 7.4) to remove residual blood, and sample was cut up after weighing. The chopped tissue and PBS were added to the glass homogenizer according to the ratio of 1:9, the mixture was ground thoroughly with ice. The homogenate was broken by ultrasonic using a Bransonic® ultrasonic cleaner (Branson ultrasonics corporation, USA). The homogenate was centrifuged at 4,000 ×g for 10 min at 4°C, and the supernatant was transferred to a 1.5-mL tube and stored at -80°C.

The total antioxidant capacity (TAC), superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), reduced glutathione (GSH), catalase (CAT), peroxidase (POD), malondialdehyde (MDA), nitric oxide (NO), superoxide anion ($O_2^{\cdot-}$), and hydroxyl FR ($^{\cdot}OH$) were determined using commercial available kits from Nanjing Jiangcheng Bioengineering Institute (Nanjing, China; Product Codes were A015-1, A001-3, A005, A006-1-1, A007-1-1, A084-3-1, A084-3-1, A012-1, A052-1-1, A018-1-1, respectively). All measure operation procedures were strictly followed the manufacturers' protocol.

A FR parameter of 2,2-diphenyl-1-picrylhydrazyl (DPPH; Pcode: 101845869, Sigma-Aldrich, St. Louis, MO) scavenging activity was measured according to spectrophotometric method [17]. Briefly, an aliquot of 20 μL of sample was mixed with 0.6 mL of 0.1 mmol/L DPPH solution in a 1.5 mL tube. The mixture was centrifuged at 4,000 ×g for 10 min at 4°C, then 200 μL of supernatant was immediately transferred to a 96-well plate (TCP011096, JET-BIOFIL®, Beiden Biological Technology Co. Ltd., Nanjing, China) and incubated in the dark at 37°C for 30 min. The absorbance was analyzed at 517 nm via a microplate reader (Epoch, BioTek, Luzern, Switzerland). The equation for calculation was as follows: DPPH scavenging activity (%) = (Ac − As) ×100/Ac, where Ac as the absorbance of the control, As was the absorbance of the sample.

Determination of fatty acid profilesof *Longissimus dorsi*

A total of 50 mg of LD sample was weighted and was transferred to a 2-mL tube, 1 mL of chloroform methanol solution (2:1) and 2 steel balls were added, and the mixture was shaken vigorously using a tissuelyser with 60 Hz for 1 min, the ultrasonic extraction at room temperature for 30 min, and centrifuged at 12,000 ×g at 4°C for 5 min (H1850R, Hunan Xiangyi Centrifuge Instrument Co., Ltd., China), then supernatant was transferred to a 15-mL centrifuge tube. The sample was esterified in water bath at 80℃ for 30 min after extraction solution was thoroughly mixed with a volume of 2 mL of 1% sulfuric acid methanol solution. After cooling to room temperature, 1 mL n-hexane was added, tube was thoroughly mixed and left to stand for 5 min, then 5 mL distilled water was added and centrifuged at 12,000 ×g at 4°C for 5 min. 100 mg anhydrous sodium sulfate powder was added after a volume of 700 μL of supernatant was transferred to a 2-mL tube with sufficient mixing, then centrifuged at 12,000 ×g at 4°C for 5 min. Next, 300 μL supernatant was transferred to a 2-mL tube, and 15 μL of 500 ppm methyl salicylate was added and mixture was vortexed. The individual FA was detected using a trace 1310-ISQ 7000 gas chromatography-mass spectrometer (GC-MS; Thermo Fisher Scientific, USA). The GC-MS conditions were as follows: separation of FA by a Thermo TG-FAME capillary column (50 m × 0.25 mm × 0.20 μm), the injection volume was 1 μL, split ratio was 8:1; injection port temperature was 250°C, the ionization temperature was 230°C, transmission line temperature was 250°C, Quadrupole temperature was 150°C; temperature program was an initial temperature of 80°C for 1 min, a 20 °C/min rise to 160°C and held for 1.5 min; a 3°C/min rise to 196°C and held for 8.5 min, then a 20°C/min rise to 250°C and held for 3 min; helium gas as carrier, the flow rate of carrier gas was 0.63 mL/min; electron ionization, single ion monitoring, and the energy of ionization was 70 eV.

Statistical analysis

The sample size was calculated by Statistical Analysis System 9.1.3 software (SAS Institute, Cary, NC). Six replications were used in present study, which could make a significance level of 0.05 and a power greater than 0.80. The replicate was considered the experimental unit in all of the statistical analyses. All data analysis were performed through the SAS 9.1.3 according to the method of one-way analysis of variance model: $Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$, where Y_{ij} means the observation j (j = 1 to 6) in treatment i (i = control, LA, and HA), μ denotes the overall mean, τ_i describes the effect of treatment (denotes an unknown parameter), and ε_{ij} represents random error with mean 0 and variance σ^2. The relationship between antioxidant status and UFA profiles of LD was analyzed by Pearson correlation coefficients (r) [20]. The significant level was set at $P < 0.05$.

Results

Growth performance

There was no differences ($P > 0.05$) in the DMI, ANG, ADG and FCR among three groups, whereas BW (%) and g/kg $BW^{0.75}$ (%) in LA and HA groups were significantly higher ($P < 0.05$) than the control (Table 3). The apparent digestibilities of DM, OM, EE, NDF, ADF, Ca, and P were not affected ($P > 0.05$) by anthocyanin, but GE and CP digestibilities were significantly higher ($P < 0.05$) in PCP groups than that in control (Table 4).

Meat quality

During the growing goat phase, addition of PCP did not affect ($P > 0.05$) pH_{1h}, pH_{24h}, percentage of water loss, drip loss, cooked meat rate and meat color significantly, whereas tended to drop ($P < 0.05$) shear force (Table 5).

Antioxidant status parameters

No significant differences ($P > 0.05$) were noted in TAC, SOD, GSH-Px, MDA, and NO among all groups (Table 6). GSH and DPPH scavenging activity in HA group were greater ($P < 0.05$) than that of the control. Similarly, LA group showed significantly higher ($P < 0.05$) POD relative to the control and HA. HA exhibited significantly higher $O_2^{-\cdot}$ and $^{\cdot}OH$ concentrations compared to the other groups.

Muscle fatty acid profiles

As shown in Table 7, control group showed higher ($P < 0.05$) levels of C10:0, C12:0, C14:0, C15:0, C16:0, C17:0 and SFA compared with the two treatments. The C11:0, C21:0 and C23:0 were unable to be detected for all groups.

In terms of individual UFA, the inclusion of PCP of goats tended to increase various individual UFA (C14:1, C16:1, C17:1, C18:1n9, C18:1n12, C18:2n6, C18:3n3, C20:4n6, C22:1n9, C22:4, C22:5n6, C22:6n3, and C24:1) with significant ($P < 0.05$) statistical difference (Table 8). In contrast, C15:1, C18:1n7, C20:1, C20:2, C20:3n6, C20:5n3, C22:5n3 did not differ ($P > 0.05$) among all groups. The C18:3n6, C20:3n3 and C22:2 were not detected during three groups. Regarding total UFA, the feeding of HA led to a significant ($P < 0.05$) increase of monounsaturated fatty acid (MUFA) compared to control and LA group. The PUFA, n-6 PUFA, MUFA/SFA and PUFA/SFA were more ($P < 0.05$) in goat receiving PCP relative to the control.

Relationship between muscle antioxidant status and unsaturated fatty acids

Significant ($P < 0.05$; Table 9) negative correlations were noted between several antioxidants and UFA profiles (TAC and C17:1; SOD and C14:1, C18:1n9, C18:2n6, C20:4n6, C22:1n9, C22:5n6, C24:1, MUFA, PUFA, n-6 PUFA, MUFA/SFA, PUFA/SFA). Positive correlations ($P < 0.05$) were found between some antioxidants (GSH-Px, GSH, CAT, DPPH scavenging activity) and various UFA (C14:1, C15:1, C16:1, C18:1n9, C20:4n6, C22:1n9, C22:4,

C22:5n6, C24:1, MUFA and MUFA/SFA etc.) in LD. There were significant ($P < 0.05$) negative correlations between MDA and C16:1, C18:3n3, C22:4; as well as between NO and C14:1, C15:1, C16:1, C18:1n9, C18:3n3, C20:4n6, C22:1n9, C22:4, C24:1, MUFA, MUFA/SFA. Significant ($P < 0.05$) positive correlations were observed between some FR concentrations and UFA profiles ($O_2^{\cdot-}$ and C14:1, C18:1n12, C18:2n6, C20:4n6, C22:1n9, C22:6n3, MUFA, PUFA, n-6 PUFA, n-6/n-3, MUFA/SFA, PUFA/SFA; ·OH and C16:1, C18:3n3).

Discussion

Anthocyanin may decrease DMI because its astringent property, negatively effecting on the growth performance of ruminants [21]. Our findings indicated that the consumption of PCP did not side effect on DMI and growth performance in goats, suggesting that anthocyanin had no side effects on production performance. Consistent with our research results, Khonkhaeng and Cherdthong [22] who demonstrated that the feeding of anthocyanin-rich purple field corn stover did not differ DMI, body weight (BW) kg/d and g/kg $BW^{0.75}$ in beef cattle. Furthermore, Ban [23] who reported that the addition of phenolic-rich mangosteen peel powder was no effect on DMI of meat goats. Similar result has also been shown after feeding of phenolic-rich grape pomace and grape seed of lambs had no effect on growth performance [24]. Anthocyanins in natural plant comprised of anthocyanidin and sugar, which was the sugar structure might be involved in digestion and metabolism of the body. As a result, additional of PCP could improve GE digestibility in present study. In addition, anthocyanins in industrial extraction might increase N content linked to cell wall owing to Maillard reaction, the use of anthocyanin could help increase CP digestibility [25]. Furthermore, anthocyanin could bind to dietary proteins and reduce their rumen fermentation, thereby increasing nitrogen utilization. As expected, we found that the feeding of PCP could increase CP digestibility, which may be related to high content of anthocyanins in PCP. Consistent with our results, Nudda et al. [26] who demonstrated that ewes receiving polyphenol-rich plant had the ability to increase nitrogen utilization and CP digestibility.

In current study, supplementation of anthocyanin could drop shear force, perhaps because anthocyanin was involved in lipid metabolism of animals, promoting adipose tissue was deposited in muscle and making connective tissue loosen, and ultimately improved muscle tenderness [35]. This was also might be associated with the protective effect of anthocyanins on proteolytic enzyme oxidation during the ageing process [36]. Similar results are also expected after the inclusion of anthocyanin-rich plant in ruminant diets, as evidenced in the Tayengwa and Mapiye [21], suggesting that anthocyanin-rich plant without affecting meat pH, cooking loss and drip loss, whereas it could reduce shear force and increase the instrumental tenderness.

Oxidative stress was the main cause of various metabolic diseases because it was directly affected on growth performance and dropped the health issues in ruminant [27]. This might due to oxidative stress was a condition which was the imbalance of between oxidants and antioxidants, producing abnormally high levels of FR, declining antioxidant defense mechanisms for small ruminant [28]. The excessive FR could react with DNA, protein and lipid, causing cell and organization organ hurt, and resulting in various diseases in animals [29]. Antioxidants, as FR scavengers can effectively complement the deficiencies of vivo antioxidant, play a significant role in alleviating oxidative stress status of ruminants [30]. These previous reports suggested that the use of antioxidant substances in ruminant feed could help prevent production loss due to oxidative stress. Anthocyanin was potent natural antioxidant that could inhibit oxidative stress and inflammation by regulating peroxidation reaction and scavenging the FR in ruminants [17]. Based on the results of the present study, it was suggested that adding anthocyanin-rich PCP could improve LD antioxidant status. As discussed elegantly by Hosoda et al. [31], who demonstrated that sheep fed anthocyanin-rich PCP could suppress oxidation resistance and enhance plasma SOD content. Moñino et al. [32] who suggested that the feeding of phenolic-rich plant could increase meat antioxidant capacity of the lamb. Similar result has also been shown after feeding dairy cows with anthocyanin-rich purple corn silage may heighten antioxidation property by increasing SOD level [33]. In short, anthocyanin was the major factor affecting antioxidant activity because it was positive correlation with antioxidant activity [34].

The UFA in muscle tissue might strengthen human immune system, playing an important role for body health, whereas it was prone to be oxidized influenced by promoting oxidation components [37]. HA group exhibited higher $O_2^{\cdot-}$ and $^{\cdot}OH$ concentrations in LD, perhaps due to UFA was unable to bind tightly owing to the bending of the carbon chain in the presence of double bonds, leading to UFA had an increased susceptibility to lipid oxidation [38]. To note, we also found PCP could enhance antioxidant activity in LD, suggesting that these antioxidant enzymes can remove excessive FR to maintain UFA content, retarding lipid oxidation in muscle. Our results were agreement with those of Paulina et al. [39], who revealed that the addition of polyphenol-rich chokeberry pomace in lamb diet could enhance GSH-Px and decline MDA levels in muscle tissue. Similarly, Zhao et al. [36] who showed that phenolic-rich grape pomace could increase the TAC, SOD, and GSH-Px4 and decreasing reactive oxygen species and MDA content in LD of lambs.

Our data provided evidence that adding PCP in goat diet brought many benefits linked with antioxidative protection for muscle, which may be caused by the high bioavailability of anthocyanin compounds for goats [40]. López-Andrés et al. [41] who displayed that the feeding of phenolics-rich grass could transfer of phenolic compounds from grass to animal tissues and increase antioxidant capacity. Hence, anthocyanin from purple corn had being possibility of transferring anthocyanin composition to the organs, thus affecting antioxidant status of goats. The authors on this topic are necessary to think about the metabolism of anthocyanin in ruminants in future studies.

Ruminants had high SFA content because the extensive microbial biohydrogenation in rumen [42]. It was advisable to drop SFA and enhance UFA in ruminant products. Bryszak et al. [43] who revealed that anthocyanin-rich plant could alter the biohydrogenation pathway, resulting in increasing ruminal fluid *trans* C18:1 and MUFA of dairy cows. In current study, supplementation of PCP in basal diet for growing goats led to decline SFA content, perhaps because anthocyanin had the ability to inhibit the process of biohydrogenation in the rumen [44]. Purba et al. [45] who revealed that flavonoid-

rich plant in the diet of dairy goats could drop milk individual SFA and total SFA concentrations, whereas increase various UFA profiles. Resconi et al. [24] who displayed that lambs receiving phenolic-rich grape pomace could decrease meat C16:0 and C17:0 levels, and increase C18:2 n-6 content.

The UFA would oxidation lipid radical, followed by oxidation peroxyl radical with oxygen, and then changed FA hydroperoxide with hydrogen, thus negatively effecting on body antioxidant enzymes. A previous study has been shown that adding natural antioxidant in goat diet could improve the proportions of C18:1 *trans*-11, C18:2n6, PUFA and the ratios of n6:n3 in muscle of lambs [46]. Anthocyanins belong to the class of water-soluble phenolic compounds, which also might prevent lipid oxidation [47]. Indeed, anthocyanin had the ability to provide H-atom to peroxy radical, thus inhibiting the oxidation of UFA by chain radical termination [48]. As a consequence, we found that goats receiving anthocyanin-rich PCP could increase UFA concentration in this study. Consistent with our findings, Rana et al. [49] did suggest that phenolic-rich plant extract led to increase MUFA, PUFA concentrations in LD of crossbred kids. Bryszak et al. [43] who found that anthocyanin-rich plant additive was supplemented into the ration for dairy cows could improve C18:2 *cis*-9, *trans*-11, PUFA, n-6 PUFA, n-3 PUFA concentration, and PUFA to SFA ratio.

The phenolic compounds had an indirect effect for improving the antioxidant capacity of tissues [50]. Moreover, the polyphenols could regulate rumen PUFA biohydrogenation to improve lipid fraction via decreasing the rumen skatole biosynthesis, enhancing the beneficial of FA content, and increasing the oxidation stability of the product [25]. Guerra-Rivas et al. [51] who revealed that ruminant feeding anthocyanin-rich feedstuff might drop lipid peroxidation parameters and improve meat PUFA content. Flores et al. [52] who suggested that the feeding of grape pomace silage in lamb diet could increase the n-6 PUFA and maintain the stability of meat lipid and protein. Therefore, various muscle antioxidant status and UFA profile were positively correlated in current study. Consistent with our results, Ponnampalam et al. [53] who demonstrated that a significant positive linear relationship between antioxidant enzyme activity (SOD and GSH-Px) and alpha linolenic acid were noted in muscle tissue of sheep.

Lipid oxidation in muscle was a chain reaction that produced and participated in FR, producing low molecular weight volatile compounds and dropping meat quality [54]. The UFA could enhance lipid oxidation due to presence of unsaturated bonds and FR [55]. Anthocyanins had hydroxyl groups in the aromatic ring, which can provide extra hydrogen or electron donors and eliminate excessive FR in the body, maintaining PUFA concentration [56]. Buffa et al. [57] who demonstrated that phenolic-rich grape marc could improve antioxidant status and decline MDA concentration, as well as increase milk C18:2n-6 level of dairy ewes. Thus, negative correlations between some FA profiles and lipid oxidation products (NO, MDA) and FR ($O_2^{-\cdot}$ and ·OH) were noted in LD. Accordingly, PCP supplementation in kid feed could increase FA content, particularly UFA concentration, probably because of the increased antioxidant capacity in LD. Collectively, this is an effective and convenient method for anthocyanin can preserve the antioxidant activity of tissue system, delaying UFA oxidation in muscle and subsequently making sure no peculiar smell and quality keep preferably.

Conclusion

This was the first study to investigate the effects of anthocyanin from purple corn on growth performance, meat quality, muscle antioxidant status and fatty acid profiles in growing goats. The current study results indicated that PCP anthocyanin had the potential to improve meat quality and prevent lipid oxidation by promoting antioxidant status and UFA concentration in *Longissimus dorsi* muscle of the growing goats. However, to clearly identify its reasons for related mechanisms need further experiments to prove it. Future research is required to study the bioavailability of anthocyanin in the body, and to understand the possible mechanism of anthocyanin in improving antioxidant status and preventing lipid oxidation of ruminants.

Abbreviations

Pel: pelargonidin; Peo: peonidin; Cya: cyanidin; Mal: malvidin; Pet: petunidin; Del: delphinidin; TA: total anthocyanins; TAC: total antioxidant capacity; SOD: superoxide dismutase; GSH-Px: glutathione peroxidase; GSH: reduced glutathione; CAT: catalase; POD: peroxidase; MDA: malondialdehyde; DPPH: 2,2-diphenyl-1-picrylhydrazyl; NO: nitric oxide; $O_2^{-\cdot}$: superoxide anion; ·OH: hydroxyl free radical; FA: fatty acid; SCFA: short-chain fatty acid; MCFA: medium-chain fatty acid; LCFA: long-chain fatty acid; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

Declarations

Acknowledgements

Not applicable.

Authors' contributions

XT initiated the idea. XT and QL were responsible for writing, editing, and proofreading of the manuscript. JL, DZ, QL, and XW measured the chemical composition and antioxidant activity parameters. XC directed the slaughter experiment. All authors read and approved the final manuscript.

Funding

Funding for the current report was provided by the Start-up Funds of Guizhou University (2016-76), the Cultivating Project of Guizhou University (2019-33), the State Key Laboratory of Animal Nutrition (2004DA125184F1914), the National Natural Science Foundation of China (31760652), and the Science and Technology Support Project of GuiZhou province ([2019]2279).

Availability of data and materials

All relevant data are available within the article.

Ethics approval and consent to participate

All procedures were handled in accordance with the Inspection Form for the Guizhou University, Experimental Animal Ethics (EAE-GZU-2020-7009).

Consent for publication

Not applicable.

Competing interests

The authors have declared that no conflict of interests exist in this study.

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Tables

Table 1 Ingredients and nutrient composition of experimental diets (DM basis)

Ingredients, %	Content	Chemical composition, %	Content
Peanut vines	50.00	DM	90.17
White distiller's grains	10.00	CP	13.82
Soybean residues	10.00	GE, kJ/g	13.32
Green hay	9.30	NDF	43.54
Corn	14.00	ADF	29.23
Soybean meal	5.00	Hemicellulose	14.31
Mineral premix[1]	0.50	EE	2.27
Vitamin premix[2]	0.50	OM	91.53
NaCl	0.50	Ash	8.47
Limestone	0.20	Ca	1.04
Total	100.00	P	0.18

[1]Vitamin premix was purchased Guangzhou Everrich Animal Health Co., Ltd., Guangzhou, China. Vitamin premix contained (per kg of premix): vitamin A 4000000 IU, vitamin D 600000 IU, vitamin E 25000 mg, DL-methionine 7000 mg, L-lysine 5000 mg.

[2]Mineral premix was obtained the Earth Animal Nutrition and Health Products Co., Ltd., Chongqing, China. Mineral premix contained (per kg of premix): Cu 1300 mg, Fe 1000 mg, Zn 1575 mg, Mn 595 mg.

DM = dry matter; CP = crude protein; GE = gross energy; NDF = neutral detergent fiber; ADF = acid detergent fiber; EE = ether extract; OM = organic matter; Ca = calcium; P = phosphorus.

Table 2 The anthocyanin composition of the purple corn pigment

Items[1], μg/g DM	Content
Pel	45.33±1.93
Peo	ND
Cya	1974.75±8.41
Mal	0.1±0.01
Pet	7.93±0.12
Del	590.93±11.91
TA	2619.04±13.04

[1]Values represent the means of 3 replicates (n = 3). Values are means ± standard deviation.

Pel = pelargonidin; Peo = peonidin; Cya = cyanidin; Mal = malvidin; Pet = petunidin; Del = delphinidin; TA = total anthocyanins; ND = not detected.

Table 3 Effect of purple corn pigment on DMI and growth performance of goats[1]

Items[2]	Group[3]			SEM	*P*-value
	Control	LA	HA		
DMI, g/d	701.84	714.67	720.62	6.5231	0.1188
BW, %	3.22^{b}	3.35^{a}	3.43^{a}	0.0304	<0.0001
g/kg $BW^{0.75}$, %	69.57^{b}	71.98^{a}	73.43^{a}	0.6547	0.0002
Initial weight, kg	21.80	21.34	21.01	0.5827	0.6363
Final weight, kg	25.18	24.59	24.50	0.5824	0.6748
ANG, kg	3.38	3.24	3.49	0.1611	0.5750
ADG, g	56.25	54.06	58.08	2.6849	0.5772
FCR	12.75	13.34	12.61	0.6036	0.6687

[1]Different letters within a row are significantly different (P < 0.05).

[2]Values represent the means of six replicates (n = 6).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

DMI = dry matter intake; BW = body weight; ANG = average net gain; ADG = average daily gain; FCR = feed conversion ratio.

Table 4 Effect of purple corn pigment on apparent digestibility of dairy goats[1]

Items[2], %		Group[3]		SEM	*P*-value
	Control	LA	HA		
DM	85.65	87.41	85.52	0.6928	0.1788
OM	73.45	76.98	72.59	1.3725	0.1331
GE	73.40^{c}	77.28^{a}	74.93^{b}	0.0819	<0.0001
CP	69.92^{b}	73.67^{a}	71.24^{ab}	0.7483	0.0318
EE	75.36	71.49	69.29	3.3277	0.4723
NDF	49.61	51.39	43.81	2.2568	0.1201
ADF	42.30	45.99	42.60	1.6063	0.2732
Ca	53.19	53.19	58.46	2.7940	0.3677
P	57.13	57.21	59.70	1.2390	0.3201

[1]Different letters within a row are significantly different ($P < 0.05$).

[2]Values represent the means of six replicates ($n = 6$).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

DMI = dry matter; OM = organic matter; GE = gross energy; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; ADF = acid detergent fiber; Ca = calcium; P = phosphorus.

Table 5 Effect of purple corn pigment on meat quality of goats[1]

Items[2]		Group[3]		SEM	*P*-value
	Control	LA	HA		
pH_{1h}	5.58	6.03	5.39	0.2227	0.1471
pH_{24h}	4.97	5.70	4.65	0.3361	0.1795
Percentage of water loss, %	4.61	4.39	4.41	0.5898	0.9576
Drop loss, %	1.30	1.05	1.36	0.2410	0.7073
Cooked meat rate, %	68.85	65.89	65.69	1.4077	0.2382
Meat color	55.27	58.33	52.90	3.7658	0.6030
Shear force, kg	5.31^{a}	4.24^{b}	4.61^{b}	0.2012	0.0063

[1]Different letters within a row are significantly different ($P < 0.05$).

[2]Values represent the means of six replicates ($n = 6$).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

Table 6 Effect of purple corn pigment on muscle antioxidant status of goats[1]

Items[2]		Group[3]		SEM	*P*-value
	Control	LA	HA		
TAC, U/mL	14.88	12.17	14.96	1.5088	0.3884
SOD, U/mL	22.98	22.46	22.38	0.3795	0.5215
GSH-Px, U/mL	127.23	131.28	140.53	5.5066	0.2899
GSH, mg/L	14.47^{b}	20.45^{b}	27.69^{a}	2.2231	0.0075
CAT, U/mL	14.29^{b}	18.66^{a}	19.02^{a}	0.4236	<0.0001
POD, U/mg	4.61^{b}	6.69^{a}	5.31^{b}	0.3115	0.0035
MDA, nmol/mL	2.59	2.93	2.12	0.3325	0.2975
NO, μmol/L	42.20	38.17	30.46	4.7138	0.2770
DPPH scavenging activity, %	4.39^{b}	6.17^{ab}	11.67^{a}	1.6469	0.0469
O_2^{-}, U/L	184.59^{b}	197.44^{a}	195.96^{a}	2.4031	0.0033
·OH, U/mL	81.84^{ab}	80.19^{b}	83.41^{a}	0.6286	0.0090

[1]Different letters within a row are significantly different ($P < 0.05$).

[2]Values represent the means of six replicates ($n = 6$).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

TAC = total antioxidant capacity; SOD = superoxide dismutase; GSH-Px = glutathione peroxidase; GSH = reduced glutathione; CAT = catalase; POD=peroxidase; MDA = malondialdehyde; DPPH = 2,2-diphenyl-1-picrylhydrazyl; NO = nitric oxide; O_2^{-}· = superoxide anion; ·OH = hydroxyl free radical.

Table 7 Effect of purple corn pigment on saturated fatty acid profile in the *Longissimus dorsi* muscle of goats[1]

Items[2], μg/g		Group[3]		SEM	*P*-value
	Control	LA	HA		
C6:0	1.11	1.34	1.31	0.1316	0.4961
C8:0	1.17	0.73	0.61	0.1262	0.1031
C10:0	6.59[a]	1.83[b]	2.24[b]	0.7421	0.0346
C11:0	ND	ND	ND	-	-
C12:0	4.97[a]	1.76[b]	1.87[b]	0.6447	0.0426
C13:0	2.32	2.85	2.99	0.3906	0.5193
C14:0	66.96[a]	23.76[b]	29.79[b]	4.5316	0.0123
C15:0	20.27[a]	8.75[b]	8.51[b]	2.2208	0.0428
C16:0	1042.34[a]	938.14[b]	950.55[ab]	20.6959	0.0473
C17:0	62.08[a]	27.18[b]	27.93[b]	3.2845	0.0077
C18:0	917.63	810.63	838.33	29.1474	0.1581
C20:0	8.32	9.12	8.88	1.3487	0.9136
C21:0	ND	ND	ND	-	-
C22:0	1.14	1.18	1.07	0.1395	0.8586
C23:0	ND	ND	ND	-	-
C24:0	0.76	0.57	0.54	0.0914	0.3312
SFA	2135.64[a]	1827.82[b]	1874.62[b]	52.7945	0.0479

[1]Different letters within a row are significantly different ($P < 0.05$).

[2]Values represent the means of six replicates ($n = 6$).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

ND = not detected; SFA = sum of all the saturated fatty acid. SFA: all saturated fatty acids from C6:0 to C18:0 without any double bond.

Table 8 Effect of purple corn pigment on unsaturated fatty acid profile in the *Longissimus dorsi* muscle of goats[1]

Items[2], μg/g		Group[3]		SEM	*P*-value
	Control	LA	HA		
C14:1	9.13[b]	13.51[a]	14.77[a]	0.5237	0.0095
C15:1	2.85	3.43	4.36	0.3839	0.1462
C16:1	26.44[b]	23.01[b]	56.50[a]	5.5310	0.0411
C17:1	13.58[b]	17.13[a]	14.84[ab]	0.7602	0.0970
C18:1n7	55.91	49.90	54.15	3.4065	0.5189
C18:1n9	469.41[c]	625.23[b]	905.70[a]	32.3347	0.0055
C18:1n12	446.86[b]	679.68[a]	571.23[ab]	43.9167	0.0737
C18:2n6	134.91[b]	222.88[a]	199.66[a]	8.4089	0.0107
C18:3n3	11.08[b]	8.88[b]	18.66[a]	0.7202	0.0049
C18:3n6	ND	ND	ND	-	-
C20:1	9.59	7.35	8.48	0.9370	0.3649
C20:2	3.17	2.83	3.49	0.3422	0.4809
C20:3n3	ND	ND	ND	-	-
C20:3n6	14.19	15.52	15.39	2.6377	0.9272
C20:4n6	194.35[b]	232.57[a]	245.63[a]	7.4716	0.0343
C20:5n3	8.35	8.11	7.25	1.5941	0.8802
C22:1n9	63.70[b]	78.15[a]	83.21[a]	2.8658	0.0351
C22:2	ND	ND	ND	-	-
C22:4	22.29[b]	23.40[b]	31.28[a]	0.7052	0.0052
C22:5n3	30.24	35.30	29.28	1.6220	0.1434
C22:5n6	4.45[b]	5.67[ab]	6.52[a]	0.3478	0.0543
C22:6n3	3.55[b]	5.64[a]	4.89[ab]	0.3876	0.0685
C24:1	8.09[b]	10.62[ab]	13.15[a]	1.0700	0.0974
MUFA	1105.58[c]	1508.01[b]	1726.41[a]	25.1898	0.0009
PUFA	426.57[b]	560.80[a]	562.05[a]	14.8078	0.0117
n-6 PUFA	347.90[b]	476.65[a]	467.20[a]	12.1957	0.0085
n-3 PUFA	53.22	57.93	60.07	3.7931	0.5084
n-6/n-3	6.60	8.23	7.80	0.4308	0.1490
MUFA/SFA	0.52[b]	0.83[a]	0.92[a]	0.0264	0.0035
PUFA/SFA	0.20[b]	0.31[a]	0.30[a]	0.0056	0.0015

[1]Different letters within a row are significantly different ($P < 0.05$).

[2]Values represent the means of six replicates ($n = 6$).

[3]LA = basal diet + 0.5 g/d purple corn pigment; HA = basal diet + 1 g/d purple corn pigment; SEM = standard error of mean.

ND = not detected; MUFA = sum of all the monounsaturated fatty acid; PUFA = sum of all the polyunsaturated fatty acid; SFA = sum of all the saturated fatty acid. SFA: all saturated fatty acids from C6:0 to C18:0 without any double bond; MUFA: all monounsaturated fatty acids from C14:1(n-5) to C18:1(n-9) with single double bond; PUFA: all polyunsaturated fatty from acids from C18:2(n-6) to C20:4(n-6) with two or more double bonds.

Table 9 Pearson correlation coefficients (r) between antioxidant status and unsaturated fatty acid profiles in the *Longissimus dorsi* muscle of goats

Items[1]	TAC	SOD	GSH-Px	GSH	CAT	POD	MDA	NO	DPPH	$O_2^{-\cdot}$	·OH
C14:1	-0.2729	-0.9736**	0.8427*	0.9135*	0.9669**	0.5893	-0.2967	-0.8636*	0.8092	0.9278**	0.1948
C15:1	0.1353	-0.7334	0.8467*	0.8474*	0.7068	0.1726	-0.5802	-0.8492*	0.8402*	0.6147	0.5100
C16:1	0.5624	-0.4971	0.8665*	0.7942	0.4493	-0.2578	-0.8859*	-0.8499*	0.8879*	0.3003	0.8473*
C17:1	-0.8235*	-0.6082	0.1205	0.2656	0.6453	0.8880*	0.4980	-0.1588	0.0637	0.7410	-0.5743
C18:1n7	0.5659	0.3767	-0.0398	-0.1383	-0.4032	-0.5945	-0.3670	0.0657	-0.0016	-0.4727	0.4152
C18:1n9	0.1853	-0.8343*	0.9826***	0.9785***	0.8020	0.1713	-0.6928	-0.9842***	0.9769***	0.6914	0.6136
C18:1n12	-0.7550	-0.7433	0.3035	0.4420	0.7727	0.8851*	0.3455	-0.3406	0.2480	0.8434*	-0.4338
C18:2n6	-0.6687	-0.9040*	0.5243	0.6541	0.9240**	0.8778*	0.1591	-0.5597	0.4704	0.9641**	-0.2617
C18:3n3	0.6828	-0.4156	0.8566*	0.7633	0.3622	-0.3848	-0.9631**	-0.8345*	0.8861*	0.1985	0.9350**
C18:3n6	-	-	-	-	-	-	-	-	-	-	-
C20:1	0.5980	0.5547	-0.2051	-0.3137	-0.5789	-0.6881	-0.2940	0.2341	-0.1617	-0.6380	0.3606
C20:2	0.5509	-0.0689	0.4141	0.3310	0.0324	-0.4122	-0.6177	-0.3934	0.4430	-0.0753	0.6214
C20:3n3	-	-	-	-	-	-	-	-	-	-	-
C20:3n6	-0.1217	-0.2167	0.1497	0.1749	0.2191	0.1797	-0.0023	-0.1567	0.1389	0.2216	-0.0216
C20:4n6	-0.2342	-0.9390**	0.8308*	0.8945*	0.9307**	0.5453	-0.3165	-0.8497*	0.8000	0.8877*	0.2188
C20:5n3	-0.0956	0.2163	-0.2844	-0.2760	-0.2050	-0.0066	0.2294	0.2829	-0.2855	-0.1676	-0.2098
C22:1n9	-0.2293	-0.9375**	0.8323*	0.8952*	0.9289**	0.5408	-0.3208	-0.8510*	0.8018	0.8851*	0.2233
C22:2	-	-	-	-	-	-	-	-	-	-	-
C22:4	0.4160	-0.6817	0.9675**	0.9232**	0.6387	-0.0707	-0.8431*	-0.9585**	0.9773***	0.4997	0.7834
C22:5n3	-0.8457*	-0.2083	-0.3091	-0.1724	0.2566	0.7529	0.7604	0.2742	-0.3595	0.3930	-0.7974
C22:5n6	-0.0731	-0.8866*	0.8765*	0.9138*	0.8694*	0.3970	-0.4538	-0.8886*	0.8556*	0.8016	0.3644
C22:6n3	-0.6898	-0.8063	0.4096	0.5398	0.8301*	0.8573*	0.2397	-0.4448	0.3564	0.8830*	-0.3330
C24:1	0.0244	-0.8186*	0.8663*	0.8866*	0.7969	0.2934	-0.5151	-0.8740*	0.8521*	0.7173	0.4343
MUFA	-0.1425	-0.9698**	0.9199**	0.9703**	0.9550**	0.4840	-0.4309	-0.9356**	0.8936*	0.8922*	0.3319
PUFA	-0.4581	-0.9670**	0.7207	0.8199*	0.9721**	0.7343	-0.0989	-0.7486	0.6771	0.9677**	-0.0059
n-6 PUFA	-0.5230	-0.9608**	0.6739	0.7829	0.9702**	0.7836	-0.0273	-0.7042	0.6269	0.9783***	-0.0782
n-3 PUFA	-0.1118	-0.5924	0.5465	0.5812	0.5849	0.3154	-0.2373	-0.5571	0.5291	0.5511	0.1764
n-6/n-3	-0.5822	-0.7853	0.4547	0.5677	0.8028	0.7636	0.1395	-0.4855	0.4078	0.8379*	-0.2287
MUFA/SFA	-0.2603	-0.9832***	0.8605*	0.9296**	0.9755***	0.5830	-0.3156	-0.8809*	0.8275*	0.9332**	0.2130
PUFA/SFA	-0.5260	-0.9760***	0.6879	0.7978	0.9852***	0.7917	-0.0333	-0.7185	0.6404	0.9925***	-0.0737

[1]Values represent the means of eight replicates (n = 18).

*P < 0.05, **P < 0.01, ***P < 0.001.

TAC = total antioxidant capacity; SOD = superoxide dismutase; GSH-Px = glutathione peroxidase; GSH = reduced glutathione; CAT = catalase; POD=peroxidase; MDA = malondialdehyde; DPPH = 2,2-diphenyl-1-picrylhydrazyl; NO = nitric oxide; $O_2^{-\cdot}$ = superoxide anion; ·OH = hydroxyl free radical; MUFA = sum of all the monounsaturated fatty acid; PUFA = sum of all the polyunsaturated fatty acid; SFA = sum of all the saturated fatty acid.