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# Total methionine + cystine levels in diets for Muscovy ducks in housing

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**ABSTRACT.** The present study aimed to determine the ideal levels of total methionine + cystine for Muscovy ducks in confinement. Two hundred and forty Muscovy ducks of the creole strain were distributed in a completely randomized experimental design where the treatments consisted of six nutritional plans with different levels of total methionine + cystine, and four replicates (two with males only and two with females only), each with 10 Muscovy ducks. The nutritional plans considered the requirements in the initial, growing, and finishing stages. The birds had their performance evaluated weekly, and at 90 days of age, eight birds (four males and four females) from each treatment were slaughtered for the evaluation of carcass traits. Nutritional plan 3 provided a significant ($p < 0.05$) reduction in feed intake and an increase ($p < 0.05$) in weight gain, causing a proportional reduction ($p < 0.05$) in feed conversion. Levels above and below the requirements in this nutritional plan caused a significant ($p < 0.05$) loss in performance. Muscovy ducks fed with nutritional plan 3 also presented better ($p < 0.05$) carcass traits. A significant difference ($p < 0.05$) in carcass development was observed between males and females, with males showing better results.

**Keywords:** amino acid; *Cairina moschata*; carcass traits; performance; waterfowl.

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## Introduction

The order Anseriformes comprises 161 species of waterfowl distributed across 48 genera and 3 families (Anhimidae, Anseranatidae, and Anatidae). Among these, the Anatidae family includes two of the most significant waterfowl species for production, namely ducks (*Anas platyrhynchos*) and Muscovy ducks (*Cairina moschata domesticus*), with mule ducks representing the hybrid specimens resulting from the crossbreeding of these species (Yakubu, 2013; Rufino et al., 2017a; Tamsil, 2018; Arias-Sosa & Rojas, 2021). Muscovy ducks are very resilient waterfowl, displaying exceptional disease resistance when properly managed, and exhibiting impressive productivity, yielding a variety of products, including meat, eggs, feathers, and fatty livers (Rufino et al., 2017a; Tamsil, 2018; Wu et al., 2021).

In Brazil, the majority of the national duck and Muscovy duck production is concentrated in the South region, with only a small fraction being designated for the domestic market. The primary focus of this production is the international market, particularly in Europe and Asia (Rufino et al., 2017b; *Associação Brasileira de Proteína Animal* [ABPA], 2021; Arias-Sosa & Rojas, 2021; ABPA, 2022). Additionally, the limited number of producers and companies involved in Muscovy duck production in Brazil highlights the lack of crucial information concerning management, nutrition, reproduction, health, and facilities as the most significant challenges (Santos et al., 2012; Tanganyika & Webb, 2019).

In the nutritional aspect for poultry, including Muscovy ducks, the literature emphasizes the significance of methionine in their diets for meat production, with its effects varying based on factors such as bird capacity, age, and environmental conditions (Willemsen et al., 2011; Rufino et al., 2017a; 2017b). Dietary methionine restriction tends to increase energy cost and reduce body fat, decrease serum triglyceride and cholesterol concentrations, increase serum adiponectin, in addition to reduce body weight and feed efficiency (Zeng et al., 2015; Zhou et al., 2016; Jariyahatthakij, Chomtee, Poeikhampha, Loongyai, & Bunchasak, 2018; Wu et al., 2021; Wu et al., 2022). Front this, it is crucial to establish the optimal levels of total methionine, digestible methionine, digestible methionine + cystine, and other amino acid requirements for meat birds, given their substantial influence on performance and carcass characteristics (Akter, Islam, Zaman, Jahan, & Hossain, 2020; Pokoo-Aikins et al., 2021; Wu et al., 2021).

Recently, studies have determined some crucial requirements for formulating and manufacturing ideal diets for Muscovy ducks (Feijó et al., 2016; Rufino et al., 2017a; Costa et al., 2019; Santos et al., 2020). However, similar to other nutritional requirements for Muscovy ducks, research on amino acids has been quite limited, with diets typically formulated based on broiler requirements, especially for slow-growing broilers (Siregar & Farrell, 1980; Fouad et al., 2018; Wang et al., 2023). This promising outlook motivates researchers to enhance performance and carcass characteristics through improved nutrition and management practices (Arias-Sosa & Rojas, 2021; Wu et al., 2021). Considering the above, the present study aimed to determine the ideal levels of total methionine + cystine for Muscovy ducks in housing.

## Material and methods

The study was developed in facilities of the Poultry Sector, Faculty of Agrarian Sciences, Federal University of Amazonas, Manaus, Amazonas State, Brazil. The experimental procedures were approved by the Ethics Committee in Animals Use (protocol number 042/2018) of the Federal University of Amazonas.

Muscovy ducks (n = 240) of creole strain were distributed into an experimental design was completely randomized, where the treatments were constituted by six nutritional plans with different levels of total methionine + cystine levels (Table 1), with three stages (initial, growing and finishing) and four replicates with 10 Muscovy ducks. It is important to mention that 2 pens of each treatment contained only male Muscovy ducks, while the other 2 pens contained only female Muscovy ducks. Experimental diets (Table 2) were calculated according to the levels of total methionine + cystine established by the treatments, and used ideal requirements of energy and protein (Rufino et al., 2015; Rufino et al., 2017a), calcium (Feijó et al., 2016), available phosphorus (Costa et al., 2019), and sodium (Santos et al., 2020) for Muscovy ducks. The other requirements were provided by Rostagno et al. (2017).

The experimental aviary presented measures of 25 x 8 m, ceiling height of 3.25 m, being subdivided into pens with 4 $m^2$ each, and using a natural ventilation system (completely wooded in its surroundings). Each pen had it floor covered with pine shavings, containing pendulum drinkers and tube feeders. Birds started the experimental period with 1-day old and were evaluated until 90 days old, receiving water and food *ad libitum*. The light program was adjusted according to the stages (initial = 23 hours of light + 1 hour of dark, growing = 20 hours of light + 4 hour of dark, and finishing = 22 hours of light + 2 hour of dark).

For performance, birds and diets were weekly weighed to calculate performance variables in each stage (feed intake, weight gain and feed conversion). At 90 days of age, eight birds from each treatment group (comprising four males and four females) were randomly selected and weighed. Subsequently, these birds were humanely stunned using an electrical method (40 V; 50 Hz) and then slaughtered via the jugular vein cut. The carcasses were promptly immersed in hot water (maintained at 60ºC for 62 s), followed by plucking and evisceration. Carcass weights were recorded while still hot and again after a 30 min. cooling period. To determine carcass yield, the weight of the cold eviscerated carcass (excluding the head, feet, neck, and abdominal fat) was used relative to the live bird's weight. For assessing yield of specific cuts (such as neck, wing, thigh, drumstick, breast, and back), the weight of the cold eviscerated carcass served as the reference (Mendes & Patrício, 2004; Gomide, Alencar, & Macedo, 2012).

Before performing data statistical analysis, all data were tested by normality and transformed, if necessary. All data were analyzed by one-way ANOVA using the R software (version 4.1.3). All commands were performed according to Logan (2010). Tukey's test at $p < 0.05$ was used to test the significant differences among the means.

**Table 1.** Experimental levels of total methionine + cystine.

| Treatments | Levels of total methionine + cystine (%) | | |
|---|---|---|---|
| | Initial (1 – 35 days) | Growing (36 – 70 days) | Finishing (71 – 90 days) |
| Nut. Plan 1 | 1.00 | 0.90 | 0.80 |
| Nut. Plan 2 | 0.95 | 0.85 | 0.75 |
| Nut. Plan 3 | 0.90 | 0.80 | 0.70 |
| Nut. Plan 4 | 0.85 | 0.75 | 0.65 |
| Nut. Plan 5 | 0.80 | 0.70 | 0.60 |
| Nut. Plan 6 | 0.75 | 0.65 | 0.55 |

**Table 2.** Ingredients and nutritional composition of experimental diets.

| Diets[4] | Nutritional plans with different levels of total methionine + cystine for muscovy ducks | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plan 1 | | | Plan 2 | | | Plan 3 | | | Plan 4 | | | Plan 5 | | | Plan 6 | | |
| Ingredients | Ini. | Gro. | Fin. | Ini. | Gro. | Fin. | Ini. | Gro. | Fin. | Ini. | Gro. | Fin. | Ini. | Gro. | Fin. | Ini. | Gro. | Fin. |
| Corn 7.88% | 58.948 | 68.025 | 71.493 | 58.892 | 68.099 | 71.437 | 58.837 | 68.011 | 71.382 | 58.782 | 67.988 | 71.326 | 58.726 | 67.932 | 71.272 | 58.656 | 67.878 | 71.347 |
| Soybean meal 46% | 34.574 | 26.151 | 22.452 | 34.650 | 26.369 | 22.529 | 34.727 | 26.440 | 22.605 | 34.803 | 26.521 | 22.682 | 34.880 | 26.597 | 22.758 | 34.956 | 26.674 | 22.760 |
| Limestone | 1.045 | 2.408 | 1.094 | 1.045 | 1.036 | 1.094 | 1.045 | 1.036 | 1.094 | 1.045 | 1.036 | 1.093 | 1.044 | 1.036 | 1.093 | 1.061 | 1.035 | 1.091 |
| Dicalcium phosphate | 2.903 | 1.306 | 2.163 | 2.903 | 2.407 | 2.162 | 2.902 | 2.407 | 2.161 | 2.901 | 2.406 | 2.161 | 2.901 | 2.406 | 2.160 | 2.900 | 2.405 | 2.163 |
| Common salt | 0.777 | 0.659 | 0.537 | 0.777 | 0.659 | 0.537 | 0.777 | 0.696 | 0.537 | 0.777 | 0.659 | 0.537 | 0.777 | 0.659 | 0.537 | 0.777 | 0.659 | 0.537 |
| DL-methionine 99% | 0.346 | 0.317 | 0.252 | 0.295 | 0.265 | 0.201 | 0.243 | 0.214 | 0.150 | 0.192 | 0.163 | 0.099 | 0.141 | 0.112 | 0.047 | 0.089 | 0.060 | 0.000 |
| Vit./Mineral Supp. | 0.500[1] | 0.500[2] | 0.500[3] | 0.500[1] | 0.500[2] | 0.500[3] | 0.500[1] | 0.500[2] | 0.500[3] | 0.500[1] | 0.500[2] | 0.500[3] | 0.500[1] | 0.500[2] | 0.500[3] | 0.500[1] | 0.500[2] | 0.500[3] |
| Soybean oil | 0.907 | 0.634 | 1.509 | 0.938 | 0.665 | 1.540 | 0.969 | 0.696 | 1.571 | 1.000 | 0.727 | 1.602 | 1.031 | 0.758 | 1.633 | 1.061 | 0.789 | 1.602 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | Nutritional Levels[5] | | | | | | | | | | | | | | | | | |
| M. energy, kcal $kg^{-1}$ | 2,900 | 3,000 | 3,100 | 2,900 | 3,000 | 3,100 | 2,900 | 3,000 | 3,100 | 2,900 | 3,000 | 3,100 | 2,900 | 3,000 | 3,100 | 2,900 | 3,000 | 3,100 |
| Crude Protein, % | 21.000 | 18.000 | 16.500 | 21.000 | 18.000 | 16.500 | 21.000 | 18.000 | 16.500 | 21.000 | 18.000 | 16.500 | 21.000 | 18.000 | 16.500 | 21.000 | 18.000 | 16.500 |
| Calcium, % | 1.250 | 1.100 | 1.050 | 1.250 | 1.100 | 1.050 | 1.250 | 1.100 | 1.050 | 1.250 | 1.100 | 1.050 | 1.250 | 1.100 | 1.050 | 1.250 | 1.100 | 1.050 |
| Av. phosphorus, % | 0.650 | 0.550 | 0.500 | 0.650 | 0.550 | 0.500 | 0.650 | 0.550 | 0.500 | 0.650 | 0.550 | 0.500 | 0.650 | 0.550 | 0.500 | 0.650 | 0.550 | 0.500 |
| Sodium, % | 0.350 | 0.300 | 0.250 | 0.350 | 0.300 | 0.250 | 0.350 | 0.300 | 0.250 | 0.350 | 0.300 | 0.250 | 0.350 | 0.300 | 0.250 | 0.350 | 0.300 | 0.250 |
| Meth. + Cystine, % | 1.000 | 0.900 | 0.800 | 0.950 | 0.850 | 0.750 | 0.900 | 0.800 | 0.700 | 0.850 | 0.750 | 0.650 | 0.800 | 0.700 | 0.600 | 0.750 | 0.650 | 0.550 |
| Methionine, % | 0.660 | 0.600 | 0.518 | 0.617 | 0.550 | 0.467 | 0.567 | 0.500 | 0.420 | 0.516 | 0.449 | 0.367 | 0.466 | 0.399 | 0.319 | 0.415 | 0.348 | 0.269 |
| Lysine, % | 1.108 | 0.901 | 0.802 | 1.110 | 0.903 | 0.804 | 1.112 | 0.905 | 0.806 | 1.114 | 0.907 | 0.808 | 1.116 | 0.909 | 0.810 | 1.118 | 0.911 | 0.811 |
| Threonine, % | 0.809 | 0.692 | 0.635 | 0.811 | 0.694 | 0.636 | 0.812 | 0.695 | 0.637 | 0.813 | 0.696 | 0.639 | 0.814 | 0.697 | 0.640 | 0.815 | 0.698 | 0.640 |
| Tryptophan, % | 0.260 | 0.211 | 0.188 | 0.260 | 0.212 | 0.189 | 0.261 | 0.212 | 0.189 | 0.261 | 0.213 | 0.190 | 0.262 | 0.213 | 0.190 | 0.262 | 0.214 | 0.190 |

[1]Vit./mineral supplement – initial – content in 1 kg = Folic Acid 800 mg, Pantothenic Acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vit. A 6,700,000 UI, Vit. B1 1,750 mg, Vit. B12 9,600 mcg, Vit. B2 4,800 mg, Vit. B6 2,500 mg, Vit. D3 1,600,000 UI, Vit. E 14,000 mg, Vit. K3 1,440 mg. Mineral supplement – content in 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [2]Vit./mineral supplement – growing – content in 1 kg = Folic Acid 650 mg, Pantothenic Acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vit. A 5,600,000 UI, Vit. B1 0.550 mg, Vit. B12 8,000 mcg, Vit. B2 4,000 mg; Vit. B6 2,080 mg, Vit. D3 1,200,000 UI, Vit. E 10,000 mg, Vit. K3 1,200 mg. Mineral supplement – content in 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [3]Vit./mineral supplement – finishing – content in 1 kg = Pantothenic Acid 7,070 mg, Antioxidant 0.5 g, Niacin 20,400 mg, Selenium 200 mg, Vit. A 1,960,000 UI, Vit. B12 4,700 mcg, Vit. B2 2,400 mg, Vit. D3 550,000 UI, Vit. E 5,500 mg, Vit. K3 550 mg. Mineral supplement – content in 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [4]Ini. = Initial; Gro. = Growing; Fin. = Finishing. [5] Estimated levels in Dry Matter. The amino acids requirements are calculated based in total values.

# Results and discussion

In the performance results (Table 3), a significant effect ($p < 0.05$) was observed among the nutritional plans for all variables analyzed. The use of nutritional plan 3 (Initial: 0.90% of Met+Cys; Growing: 0.80 of Met+Cys; and Finishing: 0.70 of Met+Cys) caused a significant reduction in feed intake and an increase in weight gain, resulting in a lower (better) feed conversion. Levels above or below this nutritional plan caused a significant loss in Muscovy ducks' performance. Regarding sex, male Muscovy ducks showed higher feed intake and weight gain but had a lower feed conversion compared to female Muscovy ducks. No significant interaction ($p > 0.05$) was observed between the factors in the results.

In the results of carcass traits (Table 4), were observed a significant influence ($p < 0.05$) of methionine + cystine levels and sex on all variables. Birds fed nutritional plan 3 presented better results of carcass traits. Levels above or below of the requirements proposed by this nutritional plan caused worst results on carcass traits. In addition, male ducks presented larger carcasses, indicating the sex as an influence factor on carcass development of Muscovy ducks. There was not observed a significant interaction ($p > 0.05$) between the factors on the results.

Methionine + cystine levels also affected ($p < 0.05$) the breast, wing, thigh, drumstick and back yields of Muscovy ducks (Table 5), where birds fed the nutritional plan 3 presented larger results. Levels above or below of this nutritional plan presented larger accumulation of carcass on back. Like observed in the carcass traits results, male Muscovy ducks presented larger ($p < 0.05$) results on commercial cuts, except on back. It is important to mention that, regardless of sex, Muscovy ducks presented 50% or more of its carcass constituted by breast and back. There was not observed a significant interaction ($p > 0.05$) between the factors on the results.

**Table 3.** Performance of Muscovy ducks in housing fed nutritional plans with different levels of total methionine + cystine.

| Factors | Variables | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | | | Growing | | | Finishing | | | General | | |
| | FI | WG | FC | FI | WG | FC | FI | WG | FC | FI | WG | FC |
| Nut. Plans | | | | | | | | | | | | |
| Nut. Plan 1 | 2,581$^{a}$ | 0,564$^{c}$ | 4,580$^{a}$ | 5,472$^{a}$ | 1,195$^{b}$ | 4,580$^{a}$ | 2,271$^{c}$ | 0,496$^{c}$ | 4,580$^{a}$ | 10.324$^{a}$ | 2.254$^{c}$ | 4.588$^{a}$ |
| Nut. Plan 2 | 2,413$^{c}$ | 0,591$^{ab}$ | 4,085$^{b}$ | 5,128$^{b}$ | 1,255$^{a}$ | 4,085$^{b}$ | 2,514$^{a}$ | 0,615$^{a}$ | 4,085$^{b}$ | 10.054$^{b}$ | 2.461$^{b}$ | 4.086$^{b}$ |
| Nut. Plan 3 | 2,400$^{c}$ | 0,648$^{a}$ | 3,704$^{c}$ | 4,801$^{c}$ | 1,296$^{a}$ | 3,704$^{c}$ | 2,400$^{b}$ | 0,648$^{a}$ | 3,704$^{c}$ | 9.601$^{c}$ | 2.592$^{a}$ | 3.706$^{c}$ |
| Nut. Plan 4 | 2,401$^{c}$ | 0,606$^{a}$ | 3,960$^{c}$ | 4,802$^{c}$ | 1,213$^{a}$ | 3,960$^{c}$ | 2,401$^{b}$ | 0,606$^{a}$ | 3,960$^{c}$ | 9.604$^{c}$ | 2.425$^{b}$ | 3.968$^{c}$ |
| Nut. Plan 5 | 2,499$^{b}$ | 0,580$^{b}$ | 4,310$^{a}$ | 4,897$^{c}$ | 1,136$^{b}$ | 4,310$^{a}$ | 2,598$^{a}$ | 0,603$^{a}$ | 4,310$^{a}$ | 9.994$^{bc}$ | 2.319$^{bc}$ | 4.326$^{c}$ |
| Nut. Plan 6 | 2,422$^{c}$ | 0,548$^{c}$ | 4,421$^{a}$ | 5,147$^{b}$ | 1,164$^{b}$ | 4,421$^{a}$ | 2,523$^{a}$ | 0,571$^{b}$ | 4,421$^{a}$ | 10.093$^{a}$ | 2.283$^{c}$ | 4.426$^{ab}$ |
| Sex | | | | | | | | | | | | |
| Male | 2,746$^{a}$ | 0,695$^{a}$ | 3,950$^{b}$ | 6,328$^{a}$ | 1,602$^{a}$ | 3,950 | 2,866$^{a}$ | 0,726$^{a}$ | 3,950 | 11,94$^{a}$ | 3,023$^{a}$ | 3,950 |
| Female | 1,749$^{b}$ | 0,347$^{b}$ | 5,044$^{a}$ | 4,293$^{b}$ | 0,851$^{b}$ | 5,044 | 1,908$^{b}$ | 0,378$^{b}$ | 5,044 | 7,95$^{b}$ | 1,576$^{b}$ | 5,044 |
| Effect | | | | | | | | | | | | |
| Nut. Plans | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* |
| Sex | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* |
| Interaction | 0.31$^{ns}$ | 0.26$^{ns}$ | 0.36$^{ns}$ | 0.25$^{ns}$ | 0.23$^{ns}$ | 0.36$^{ns}$ | 0.39$^{ns}$ | 0.27$^{ns}$ | 0.36$^{ns}$ | 0.31$^{ns}$ | 0.21$^{ns}$ | 0.36$^{ns}$ |
| CV (%) | 5.45 | 5.38 | 5.81 | 5.53 | 5.49 | 5.81 | 5.48 | 5.39 | 5.81 | 5.55 | 5.36 | 5.92 |

CV – Coefficient of variation; *Means followed by lowercase letters in column differ in 1% by Tukey test ($p < 0.01$); ns – non-significant.

**Table 4.** Slaughter weight (SW), carcass yield (CY), liver (LV), heart (HT), and gizzard (GZ) of Muscovy ducks in housing fed nutritional plans with different levels of total methionine + cystine.

| Factors | Variables | | | | |
|---|---|---|---|---|---|
| | SW (kg) | CY (%) | LV (g) | HT (g) | GZ (g) |
| Nut. Plans | | | | | |
| Nut. Plan 1 | 2.383$^{ab}$ | 67.425$^{c}$ | 38.875$^{b}$ | 62.625$^{ab}$ | 17.250$^{b}$ |
| Nut. Plan 2 | 2.395$^{ab}$ | 69.075$^{b}$ | 39.750$^{b}$ | 64.500$^{a}$ | 18.500$^{a}$ |
| Nut. Plan 3 | 2.420$^{a}$ | 72.019$^{a}$ | 43.125$^{a}$ | 64.500$^{a}$ | 18.500$^{a}$ |
| Nut. Plan 4 | 2.395$^{b}$ | 69.942$^{b}$ | 38.750$^{b}$ | 60.625$^{b}$ | 17.750$^{b}$ |
| Nut. Plan 5 | 2.353$^{b}$ | 69.522$^{b}$ | 35.625$^{bc}$ | 59.500$^{bc}$ | 17.250$^{b}$ |
| Nut. Plan 6 | 2.331$^{c}$ | 69.190$^{b}$ | 33.000$^{c}$ | 57.625$^{c}$ | 15.375$^{c}$ |
| Sex | | | | | |
| Male | 3.103$^{a}$ | 70.774$^{a}$ | 50.958$^{a}$ | 77.333$^{a}$ | 21.791$^{a}$ |
| Female | 1.656$^{b}$ | 68.284$^{b}$ | 25.416$^{b}$ | 45.791$^{b}$ | 13.416$^{b}$ |
| Effect | | | p-value | | |
| Nut. Plans | 0.04* | 0.04* | 0.05* | 0.05* | 0.01** |
| Sex | 0.01** | 0.02* | 0.01** | 0.01** | 0.01** |
| Interaction | 0.23$^{ns}$ | 0.14$^{ns}$ | 0.20$^{ns}$ | 0.16$^{ns}$ | 0.17$^{ns}$ |
| CV (%) | 7.82 | 10.31 | 6.87 | 9.08 | 8.11 |

CV – Coefficient of variation; *Means followed by lowercase letters in column differ in 5% by Tukey test ($p < 0.05$); **Means followed by lowercase letters in column differ in 1% by Tukey test ($p < 0.01$); ns – non-significant.

**Table 5.** Commercial cuts of Muscovy ducks in housing fed nutritional plans with different levels of total methionine + cystine.

| Factors | Variables | | | | | |
|---|---|---|---|---|---|---|
| | Neck (%) | Breast (%) | Wing (%) | Thigh (%) | Drumstick (%) | Back (%) |
| Nut. Plans | | | | | | |
| Nut. Plan 1 | 5.413 | 26.130$^{b}$ | 16.599$^{c}$ | 12.583$^{b}$ | 8.016$^{bc}$ | 31.259$^{a}$ |
| Nut. Plan 2 | 5.204 | 26.232$^{b}$ | 16.700$^{c}$ | 12.681$^{b}$ | 8.521$^{ab}$ | 30.662$^{b}$ |
| Nut. Plan 3 | 5.455 | 27.458$^{a}$ | 18.329$^{a}$ | 13.048$^{a}$ | 8.676$^{a}$ | 27.034$^{c}$ |
| Nut. Plan 4 | 5.233 | 27.453$^{a}$ | 17.962$^{b}$ | 12.619$^{b}$ | 8.114$^{c}$ | 28.619$^{bc}$ |
| Nut. Plan 5 | 5.167 | 25.465$^{c}$ | 17.901$^{b}$ | 12.495$^{bc}$ | 8.048$^{bc}$ | 30.924$^{b}$ |
| Nut. Plan 6 | 5.392 | 25.200$^{c}$ | 17.801$^{b}$ | 12.180$^{c}$ | 7.846$^{c}$ | 31.581$^{a}$ |
| Sex | | | | | | |
| Male | 5.532$^{a}$ | 27.970$^{a}$ | 17.794$^{a}$ | 12.687$^{a}$ | 8.446$^{a}$ | 27.571$^{b}$ |
| Female | 5.089$^{b}$ | 24.676$^{b}$ | 17.302$^{b}$ | 12.515$^{b}$ | 7.961$^{b}$ | 32.457$^{a}$ |
| Effect | | | | p-value | | |
| Nut. Plans | 0.32$^{ns}$ | 0.05* | 0.04* | 0.01** | 0.01** | 0.01** |
| Sex | 0.05* | 0.02* | 0.01** | 0.01** | 0.01** | 0.01** |
| Interaction | 0.22$^{ns}$ | 0.25$^{ns}$ | 0.13$^{ns}$ | 0.17$^{ns}$ | 0.20$^{ns}$ | 0.15$^{ns}$ |
| CV (%) | 12.89 | 14.69 | 9.39 | 14.06 | 14.40 | 12.40 |

CV – Coefficient of variation; *Means followed by lowercase letters in column differ in 5% by Tukey test ($p < 0.05$); **Means followed by lowercase letters in column differ in 1% by Tukey test ($p < 0.01$); ns – non-significant.

In light of the results from this study, it was evident that Muscovy ducks exhibited either similar or lower requirements for total methionine + cystine compared to the requirements specified by Rostagno et al. (2017) for broilers with regular or higher genetic potential at all growth stages (Agostini, Dalibard, Mercier, Van der Aar, & Van der Klis, 2016; Park, Pasquetti, Malheiros, Ferket, & Kim, 2018; Akter et al., 2020; Pokoo-Aikins et al., 2021; Lugata, Ortega, & Szabó, 2022). These results contrast with the established recommendations for other dietary components such as energy, protein, calcium, phosphorus, and sodium in Muscovy ducks, where the typical trend has been for Muscovy ducks to manifest higher requirements compared to broilers (Rufino et al., 2015; Feijó et al., 2016; Rufino et al., 2017a; Costa et al., 2019; Santos et al., 2020).

Total methionine + cystine requirements above or lower them observed in the nutritional plan 3 had a notably adverse impact on performance and carcass development. This finding underscores the significance of precisely meeting these requirements in poultry diets. Wen, Jiang, Ding, Wang, and Zhou (2017), in their extensive research on the dietary methionine requirements for both fast- and slow-growing broilers, illuminated the critical nature of these requirements. They reported that even slight variations in methionine levels, especially when utilizing lower methionine concentrations, could result in detrimental effects on broiler performance, regardless of the specific broiler strain under consideration.

National Research Council (NRC, 1994) and Rostagno et al. (2017) have highlighted the higher methionine requirements in broilers, stemming from their larger body size and accelerated growth rates. Therefore, determining the optimal methionine levels becomes a stage-specific and nutrition plan-dependent endeavor. This phenomenon is closely linked to the critical physiological roles of methionine in poultry, particularly in muscle development, as emphasized by Albrecht et al. (2017) and Lugata et al. (2022). Consequently, these methionine-related effects have a direct impact on carcass traits. Additionally, the studies by Jankowski, Kubińska, and Zduńczyk (2014), Wen et al. (2017), and Lugata et al. (2022) suggest that broilers exhibit heightened sensitivity to methionine supplementation. This heightened sensitivity results in improved growth, attributable to increased growth hormone secretion and enhanced muscle protein deposition triggered by methionine supplementation.

Determining the optimal methionine and cystine requirements, both individually and in tandem, holds significant importance for enhancing growth while minimizing fat accumulation in bird carcasses, as indicated by a body of research (Zhang, Saremi, Gilbert, & Wong, 2017; Zhao et al., 2018; Lugata et al., 2022; Pokoo-Aikins et al., 2022). This need is particularly pronounced in the case of Muscovy ducks, as literature lacks precise or ideal requirements specific to this bird. Moreover, broiler diets specifically rely on sulfur-containing amino acids as their primary limiting factors, with methionine playing a central role in this context, underscoring its critical importance (Zhang et al., 2017; Park et al., 2018; Zhao et al., 2018).

Amino acid efficiency plays a pivotal role in poultry physiology, necessitating a precise determination of total and digestible amino acid requirements to achieve the right balance in poultry diets, as highlighted in research by Waititu et al. (2014), Agostini et al. (2016) and Millecam, Khan, Dedeurwaerder, and Saremi (2021). Notably, the existing literature contains a scarcity of studies examining amino acid efficiency in Muscovy duck diets, primarily relying on research involving birds with comparable productive traits such as slow-growing broilers (Sangali et al., 2014; Wen et al., 2017; Machado et al., 2018) and ducks (Zeng et al., 2015; Zhao et al., 2018; Wu et al., 2021), with a specific emphasis on the Pekin duck (Xue et al., 2018; Zhang et al., 2019; Wu et al., 2021).

In the context of amino acid supplementation, Kluge, Gessner, Herzog, and Eder (2016), in their study comparing DL-methionine hydroxy analogue-free acid with DL-methionine in diets for male white Pekin ducks during the growing phase, found that when methionine requirements fell short, feed conversion rates either deteriorated or remained unaltered. Additionally, their research indicated that DL-methionine and DL-methionine hydroxy analogue-free acid exhibited similar efficacy as methionine sources in influencing duck performance responses, reinforcing the importance of precisely determining amino acid requirements to optimize poultry growth and production.

On the other hand, studies using Pekin ducks reported that the excess of methionine may reduce feed intake and weight gain (Xue et al., 2018; Zhang et al., 2019), like also observed in the results of this study. About the methionine source, DL-methionine is the most methionine source used in poultry diets (Kluge et al., 2016). This is a racemic (50:50) mixture of D- and L-methionine. L-methionine could be incorporated directly into body proteins, and it is assumed to be 100% efficacious, but D-methionine must be converted to L-methionine before it is incorporated into protein (Xie et al., 2017).

The results of this study also reported a great difference between male and female carcasses, where the male presented a very larger carcass than female. Previous studies reported the occurrence of an evident sexual dimorphism on body development and carcass fatness deposition of ducks and muscovy ducks (Baéza, Williams, Guémené, & Duclos, 2001; Yakubu, 2011; Oguntunji & Ayorinde, 2015; Rufino et al., 2017a,b). Lin, Zhu, Hao, Yang, and Hou (2018) using Pekin ducks observed that the sex significantly affected the carcass development, where males tend to present larger carcass than females.

Furthermore, other studies have suggested that this sexual dimorphism can be attributed to the superior feed efficiency of males, particularly when considering the same developmental stage as females. This inherent sexual dimorphism becomes especially evident when assessing carcass mean weights, with males averaging 3.80 kg and females 2.22 kg (Baéza et al., 2001; Yakubu, 2011; Gois, Almeida, Farias Filho, & Silva Filha, 2012; Yakubu, 2013). Interestingly, Yakubu (2013), Oguntunji and Ayorinde (2014), Mohamed (2017) and Önk, Sarı, Gürcan, and Işık (2018) reported that females tend to reach adult weights more rapidly, resulting in a more favorable distribution of commercial cuts and expedited fat deposition on the carcass, even though they attain a lower final weight than their male counterparts. This multifaceted interplay of factors underscores the complexity of sexual dimorphism in poultry, with feed efficiency, carcass traits, and growth patterns contributing to the nuanced dynamics between male and female birds.

Oguntunji and Ayorinde (2015) and Önk, Sarı, Gürcan, and Işık (2018) still underscore that females exhibit greater fat deposition on the carcass, attributed to their larger adipocytes compared to males, indirectly affecting feed efficiency. This difference in sex proves particularly influential in the breast region (Ogah & Kabir, 2014). Extensive research encompassing broilers, ducks, and Muscovy ducks reveals that males consistently demonstrate higher breast development relative to females, a trend observed over a 42 day management period. This growth pattern extends to various other cuts as well, as documented in studies by Yakubu (2013), Oguntunji and Ayorinde (2015), van der Heide et al. (2016), Müsse, Louton, Spindler, and Stracke (2022), and Zhang et al. (2023).

## Conclusion

From the results of this study, it can be concluded that nutritional plan 3, which includes the initial, growing, and finishing phases with methionine + cystine levels set at 0.90, 0.80, and 0.70%, respectively, represents the optimal dietary regimen for Muscovy ducks in a housing environment. This particular plan, with its meticulously calculated total methionine + cystine requirements, consistently yielded superior performance and carcass development, underscoring its suitability for achieving optimal results in Muscovy duck production.

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