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Effect of Farming System Type on Broilers' Antioxidant Status, Performance, and Carcass Traits: An Industrial-Scale Production Study

Evgenia Fotou [1], Vasiliki Moulasioti [1], Georgios A. Papadopoulos [2,*], Dimitra Kyriakou [1], Maria-Eleni Boti [1], Vassilios Moussis [1], Maria Papadami [1], Constantinos Tellis [1], Apostolos Patsias [3], Ioannis Sarrigeorgiou [4], Alexandros Theodoridis [5], Peggy Lymberi [4], Vasileios Tsiouris [3,6,*], Vassilios Tsikaris [1] and Demokritos Tsoukatos [1]

[1] Department of Chemistry, Section of Organic Chemistry and Biochemistry, University of Ioannina, University Campus, 45110 Ioannina, Greece; e.fotou@uoi.gr (E.F.); v.moulasioti@uoi.gr (V.M.)
[2] Laboratory of Animal Husbandry, School of Health Sciences, Faculty of Veterinary Medicine, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[3] Microbiology and Chemical Laboratory, Pindos APSI, Rodotopi, 45500 Ioannina, Greece
[4] Immunology Laboratory, Immunology Department, Hellenic Pasteur Institute (HPI), 127, Vasilissis Sofias Avenue, 11521 Athens, Greece
[5] Laboratory of Livestock Production Economics, School of Veterinary Medicine, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[6] Unit of Avian Medicine, Faculty of Veterinary Medicine, School of Health Sciences, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
* Correspondence: geopaps@vet.auth.gr (G.A.P.); biltsiou@vet.auth.gr (V.T.)

Abstract: The global demand for improvement in the welfare conditions of broilers has generated the necessity to implement alternative rearing systems as well as less intensive growth hybrids. The majority of the data on alternative farming methods, notwithstanding their abundance, are the result of small-scale experiments. The present extended field study examined the effect of two different industrial farming systems on broilers' antioxidant status, performance, and meat quality, including 13 replicates of each industrial breeding system (intensive conventional; free range) and two different chicken genotypes (fast growth; slow growth). The duration of the study was 51 months, and the total number of broilers was 260.000 for the conventional and 78.000 for the free-range system. The results showed that fast-growth chicks demonstrated a more satisfactory performance (in terms of body weight gain (BWG) and feed conversion ratio (FCR) with $p \leq 0.001$), reduced serum lipid oxidation ($p \leq 0.05$), and more tender meat. Contrarily, slow-growth chickens presented significantly higher total antioxidant capacity (TAC) in serum and thigh muscle ($p \leq 0.001$), significantly lower ($p \leq 0.05$) thigh muscle oxidation (in terms of thiobarbituric acid reactive substances, TBARS), increased protein and decreased fat content ($p \leq 0.05$), and better smell, taste, color, and texture. In conclusion, the free-range farming system for slow-growth chickens may result in an overall higher nutritional value, sensory score, and serum and thigh muscle antioxidant profile than the conventional farming system for fast-growth broilers. However, fast-growth broilers exhibit better performance and might undergo less stress.

Keywords: fast-growing chickens; slow-growing chickens; growth performance; antioxidant status; organoleptic characteristics; industrial production; oxidative stress; meat quality

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1. Introduction

Poultry meat is a product of increased consumer interest due to its high protein and low cholesterol and fat content [1]. Furthermore, the ever-growing global population, the fast production of poultry meat, and its low cost in comparison with other meat types have triggered increased consumer demand [2]. It is notable that global poultry meat production

increased by 123 million tons between 1961 and 2019 to satisfy the growing demand [3]. Furthermore, it is expected that production will increase by 16% in developing countries in 2025 [4].

The increasing consumer demand led the poultry industry to adopt intensive farming practices [3], where chickens may be raised at high stocking density and mass feeding to increase productivity [5]. However, intensive farming practices often contradict the animals' welfare. Broiler chicken welfare has gained increasing attention and raised concerns associated with broiler chicken farming, including housing conditions, genetic selection, and slaughter methods. Specifically, high stocking density, poor ventilation, early slaughter-age, and transport to the slaughterhouse, have been correlated with the impairment of broiler welfare and oxidative stress-induced pathologies, like increased lipid peroxidation rate, which lead to high rates of health problems and mortality, as well as reduced meat quality, sensory characteristics, and chicken performance [6].

In response to these welfare concerns [7] and the trend of "green" products [1], the industry focused on improving the welfare of broiler chickens in commercial farming systems. In this direction, the raising of conventional fast-growth broilers following welfare practices includes improved housing conditions (better ventilation and improved litter quality), reduced stocking densities (provision of more space), and selected traits for better health and welfare, which can reduce the risk of injury, improve the broiler chickens' mobility, and reduce stress and susceptibility to disease [8,9].

Furthermore, alternative farming systems such as free-range or organic have been exploited to achieve these goals. In general, these systems use slow-growth genotypes and provide outdoor access and low energy-protein corn-based diets to the chickens, which could decrease the stress of the broiler chickens, trigger inherent physical behavior, and improve animal welfare [2,10].

Nevertheless, the implications of free-range systems on the antioxidant status and growth performance of broiler chickens, as well as on the quality and sensory characteristics of poultry meat between conventional and outdoor systems are still controversial. The discrepancy in the results among studies could be attributed to the outdoor access days and pasture intake [11], the different methods used in free-range and organic systems, and also the production scale of the study [12]. Regarding the latter and according to the literature, intensive industrial poultry production could present differences in antioxidant status compared to the small experimental-scale systems [13]. At the same time, alternative farming systems are less standardized than conventional ones [2], and farming conditions vary among countries, industries, and smaller-scale producers.

A comprehensive analysis of welfare criteria demonstrated the superiority of free range in sustaining better welfare conditions [14]. Furthermore, switching from a fast-growing breed to a slower-growing breed improved animal welfare and reduced the need for antibiotics, creating a synergistic effect [15]. Recently, a thorough elaboration of research findings by the University of Perugia, showed that the onset of carcass abnormalities and behavioral changes together with the greater degree of lipid oxidation caused concerns regarding the viability of employing commercial hybrids such as Ross 308 chosen for different housing conditions and urged researchers to investigate a more appropriate broiler breed for use in free-range conditions [2]. In general, it is well-accepted that oxidative stress has a negative impact on animal health and welfare. In this sense, it was hypothesized that the extensive rearing systems, defined by outdoor access, may be advantageous for animals' health and welfare, correlated to antioxidant status, compared to intensive systems. However, there is a lack of evidence to support this claim, particularly in industrial broiler chicken production in relation also to the appropriate breed selection. Our study was designed to contribute to addressing this knowledge gap by comparing the antioxidant profiles of different broiler breeds raised in two common industry practices: intensive and extensive farming systems. Hence, we aimed to gain a better understanding of how oxidative stress affects animal health, welfare, and performance.

This work presents a broad study including 13 replicates of each industrial breeding and two chicken farming systems, aiming to evaluate the antioxidant status, growth performance, meat quality, sensory characteristics, and meat chemical parameters of conventional fast-growth and free-range slow-growth chickens raised under conditions of industrial-scale production systems. To the best of our knowledge, this is the first study reporting on the antioxidant status, performance, and meat quality of Sasso genotype broilers raised under commercial conditions.

2. Materials and Methods

2.1. Broiler Chickens, Housing, and Diet

The experimental design of the study included the use of two different farming systems: free-range and conventional.

Broiler chickens were initially categorized according to their genotype, namely the Sasso genotype (Hendrix Genetics BV, Sabres, France) as free-range slow-growth chicks and the Ross 308 genotype (Aviagen Group, Huntsville, AL, USA) as conventional fast-growth chicks. Broiler chickens were placed in commercial poultry farms, which were fully equipped with automatic ventilation, heating, lighting, and feeding systems. Water and feed were offered to all broiler chickens ad libitum, whereas the lighting program and microenvironmental conditions (temperature, humidity, CO_2, NH_3) were automatically regulated for all houses according to the current European Union legislation (Council Directive 2007/43/EC) [16].

The main characteristics of the free-range farming system were the slow-growth type, the indoor stocking density of 13 broiler chickens/m^2, and the release of chickens for free pasture for half of their lives in a stocking density of 1 broiler chicken/m^2 of forage paddock. On the other hand, the main characteristics of the conventional farming system were the fast-growth type and the indoor stocking density of 15 broiler chickens/m^2 (Table 1). The two farming systems comply with European Union guidelines.

Table 1. Presentation of the design of the study for the two tested groups.

System	**Extensive** [1]		**Intensive** [2]
Genotype	Sasso		Ross 308
Farming type	Free-range		Conventional
Growth type	Slow growing		Fast growing
Diet	Standard [3]		Standard [4]
Stocking density	Indoor	outdoor	indoor
	13 broiler chickens/m^2	1 broiler chicken/m^2	15 broiler chickens/m^2
N [5]	6.000		20.000
Slaughter age	67		47

[1] Slow-growth chicks; [2] Fast-growth chicks; [3] Standard dietary specification for Sasso genotype; [4] Standard dietary specifications for Ross 308 genotype; [5] Number of broilers included in each group per replicate.

Special diets were formulated for each group, age period, and genotype (Table 2). Animal feeds' composition and chemical analyses are shown in Tables S1–S3 (Supplementary Materials). Diets were wheat- and maize-based composed. Slow-growth chicks were released for outdoor pasture from the 28th day of age until their slaughter (67th day).

The tested groups were: group (A) six thousand slow-growth broilers (Sasso) were raised free-range and fed the free-range diets; group (B) twenty thousand conventional fast-growth broilers (Ross 308) were raised conventionally and fed the conventional diets (Table 2). Thirteen replicates per group were performed.

Table 2. Diet formulation of the tested groups: A. free-range slow-growth chickens; B. conventional fast-growth chickens.

Ingredients (kg/ton)	Starter (Days 1–17)		Grower (Days 17–35)		Finisher (Days 36–Slaughter)	
	A [1]	B [2]	A [1]	B [2]	A [1]	B [2]
Corn	329	200	423	150	650	0
Wheat	300	392	250	478	68	714
Soya-meal	314	335	273	305	236	230
Phosphoric acid	6.0	8.5	6.8	5.8	7.0	3.8
Limestone	14	14	13	12	11	10
Palm oil	0	4	10	14	17	18
Soya oil	17	25	9	19	0	10
Premix [3]	19.9	20.0	15.7	16.3	11.8	14.4

[1] Slow-growth chicks; [2] Fast-growth chicks; [3] Premix refers to a mix of Vitamins and Minerals and was provided by the integrated poultry company "Agricultural Poultry Cooperation of Ioannina, PINDOS".

2.2. Growth Performance

The mortality was noted on a daily basis, whereas the cumulative values for Body Weight (BW), Feed Conversion Ratio (FCR), and European Production Efficiency Factor (EPEF) were calculated at the end of the farming cycle. Average Daily Feed intake (ADFI) and Body Weight Gain (BWG) were tracked throughout the growth phase. Equations (1) and (2) were utilized to determine FCR and EPEF, correspondingly.

$$\mathrm{FCR} = \frac{\mathrm{FI}}{\mathrm{BWG}} \tag{1}$$

$$\mathrm{EPEF} = \frac{[\mathrm{BW(kg)} \times \mathrm{Liveability(\%)}]}{\mathrm{FCR} \times \text{slaughter age(d)}} \times 100 \tag{2}$$

2.3. Materials

Potassium phosphate was obtained from Sigma Aldrich (Sigma-Aldrich, St Louis, MO, USA); sodium phosphate from Fluka (Fluka Chemie GmbH, Buchs, Switzerland); thiobarbituric acid (TBA) and malondialdehyde (MDA) from Sigma Aldrich (Sigma-Aldrich Company, Cambridge, UK); trichloroacetic acid (TCA) from Fisher chemical (Fisher Scientific GmbH, Schwerte, Germany); hexane and methanol from Merck (Merck KGaA, Darmstadt, Germany); ethanol from Fisher Scientific (Fisher Scientific, Leicestershire, UK); 2,2-diphenyl-1-picrylhydrazyl (DPPH) and α-tocopherol from Sigma Aldrich (Sigma-Aldrich Chemie GmbH, Taufkirchen, Germany).

2.4. Sampling and Preparation of Serum and Homogenized Muscle Tissue Extracts

Blood and muscle tissue samples were gathered at the 47th and 67th days of age in the fast-growth and slow-growth chickens, respectively. Sera from 15 broiler chickens per group were taken and kept at -80 °C. Thigh muscle tissue samples (*Iliobitalis* muscle of thigh) from 20 broiler chickens (weighing 100 mg each) were homogenized in 400 μL of KH_2PO_4 solution (pH 7.5) by using a homogenizer (Polytron Biotrona, Kinematica AG, Malters, Switzerland), and centrifuged at 9520× *g* for 15 min. The supernatants were preserved at -80 °C.

2.5. Antioxidant Status

Total Antioxidant Capacity (TAC) and thiobarbituric acid reactive substances (TBARS) methods were used to assess non-enzymatic antioxidant status in chicken serum and thigh muscle, while α-tocopherol levels were only measured in serum. Total Antioxidant Capacity (TAC) was used to assess the overall ability of the serum and thigh muscle samples to counteract oxidative stress caused by free radicals of DPPH [17]. Thiobarbituric Acid Reactive Substances (TBARS) assay was used to estimate the occurring oxidative stress

within the samples in terms of lipid peroxidation in serum and thigh muscle samples by measuring the concentration of the existing malondialdehyde (MDA) [18].

2.5.1. Total Antioxidant Capacity (TAC)

The DPPH assay was carried out to evaluate the total antioxidant capacity (TAC) of the samples, as previously described by Fotou et al. [19]. A DPPH reference sample was made by mixing (500 μL) DPPH solution (stock DPPH solution: 0.1 mM DPPH in methanol) with (500 μL) sodium phosphate buffer (10 mM, pH 7.4). The experimental samples were formed by adding serum (20 μL) or homogenized muscle extract (40 μL) to sodium phosphate buffer (480 or 420 μL, respectively), followed by (500 μL) DPPH solution. The samples were incubated at room temperature for 30 min. Absorbance was measured at 520 nm, and the (%) Radical Scavenging Activity (% RSA) was calculated using the Equation (3):

$$\% \text{ RSA} = \frac{\text{Absorbance}_{\text{Reference}} - \text{Absorbance}_{\text{Sample}}}{\text{Absorbance}_{\text{Reference}}} \times 100 \quad (3)$$

The higher the % RSA, the greater the proportion of antioxidants contained in the sample, namely the higher total antioxidant capacity.

2.5.2. TBARS Assay

The thiobarbituric acid reactive substances (TBARS) assay was used to evaluate the lipid oxidation of the samples. The standard MDA solutions of 0.0625, 0.125, 0.25, 0.5, 1, 2.5, 5, 7.5, and 10 μM were prepared from a stock MDA (aqueous) solution (200 μM). 1 mL of 10% (*w*/*v*) TCA aqueous solution and 1 mL of 0.67% (*w*/*v*) TBA aqueous solution were added to tubes containing either standard MDA solutions or 100 μL of serum or homogenized muscle tissue, vortexed, and placed in a water bath at 90 °C for 30 min. After reaching room temperature, the samples were centrifuged for 15 min at 915× *g*. The absorbance of the supernatants was measured at a λ of 532 nm. The samples' TBARS were calculated using the MDA reference curve (resulted from standard solutions measured at 532 nm). The greater the MDA concentration in the sample, the greater the lipid oxidation.

2.5.3. α-Tocopherol

The α-tocopherol levels were determined using the method reported previously by Fotou et al. [19]. In a tube, 0.2 mL of stock α-tocopherol methanol solution (20 g/mL) was added, followed by 1.2 mL of H_2O and 1.8 mL of ethanol (Reference sample). A blank sample was made by adding 1.2 mL of H_2O to 2 mL of ethanol. Then, 0.2 mL of serum, 1 mL of H_2O, and 2 mL of ethanol were mixed to make the experimental samples. Each tube was then filled with 5 mL of hexane and vortexed. The samples were centrifuged at 381× *g* for 5 min. Excitation at 295 nm and fluorescence detection at 330 nm were used to estimate the α-tocopherol in hexane layers. The α-tocopherol content (g/mL) was computed by using the Equation (4) [20]:

$$\text{Free Vitamin E}(\mu\text{g/mL}) = \frac{\text{Fluorescence}_{\text{Sample}} - \text{Fluorescence}_{\text{Blank}}}{\text{Fluorescence}_{\text{Standard}} - \text{Fluorescence}_{\text{Blank}}} \times 20 \quad (4)$$

2.6. Meat Quality

2.6.1. Meat Chemical Analysis

The meat was analyzed by determining the percentages of protein, fat, moisture, ash content, water holding capacity (WHC), and pH (24 h after the slaughter). In brief, protein content was assessed using the Kjeldahl Method (Nx6,25), fat using solid-liquid extraction (Soxhtherm Gerhardt, C. Gerhardt GmbH & Co. KG, Königswinter, Germany), ash gravimetrically at 650 °C to constant weight using the Linn Electrotherm Furnace (Linn High Temp GmbH, Eschenfelden, Germany), and moisture using the Moisture Analyzer DAB KERN (KERN & SOHN GmbH, Balingen, Germany) [21]. WHC was determined using gravimetric analysis. Specifically, weight loss was assessed by submitting 10 g of

each sample to low-speed centrifugation (1000× *g* for 30 min, ScanSpeed 416G, Bio-Medical Science Co., Ltd., Seoul, Korea). A pH meter (HACH HQ 11d) was used to measure the pH of 50 g of homogenized samples diluted with H_2O (1/1, *v*/*v*).

2.6.2. Organoleptic Characteristics

The organoleptic properties of chicken thighs cooked under identical conditions (200 °C for 30 min) were noted. A trained panel of eight participants gave individually and anonymized roasted chicken samples from the two bird groups. To avoid communication with other members, each taster was placed in a different room. Between each sample, water and crackers were offered. Each panelist was given an evaluation paper to rate the taste, odor, flavor, tenderness, color, and texture of the meat from 0 to 5 points.

2.7. Statistical Analysis

A statistical analysis was carried out to compare free-range slow-growth chickens to conventional fast-growth chickens. The results were analyzed using both parametric and non-parametric statistical approaches. The Shapiro–Wilk test was used to determine the data's normality. When the population was normally distributed, an independent sample T-test was employed; however, when the population was not normally distributed, a Mann–Whitney U-test was utilized. The means are presented, followed by the standard error of means (SEM). The software IBM® SPSS® Statistics 26 was used to examine all the data. The significance threshold was set at $p \leq 0.05$.

3. Results

3.1. Performance

Performance analysis (Table 3) revealed that the free-range chickens (A) presented significantly lower BWG ($p \leq 0.001$) and EPEF ($p \leq 0.01$) but higher FCR ($p \leq 0.01$) compared to the conventional chicks (B). The other performance parameters were not significantly different.

Table 3. Performance analysis of the tested groups (n = 13 per group). Results are shown as mean ± SEM.

System	Extensive [1]	Intensive [2]	*p* Value
Mortality%	4.60 ± 0.62 [a]	3.96 ± 0.28 [a]	0.365
BW (kg)	2.48 ± 0.04 [a]	2.60 ± 0.06 [a]	0.142
ADFI	89.70 ± 5.34 [a]	106.82 ± 8.79 [a]	0.096
BWG (g)	36.55 ± 1.75 [A]	61.51 ± 3.57 [B]	<0.001
FCR	2.43 ± 0.01 [A]	1.74 ± 0.02 [B]	<0.001
EPEF	145 ± 2.31 [A]	314 ± 3.66 [B]	<0.001

[1] Slow-growth chicks; [2] Fast-growth chicks; [A,B] Mean values within the same row with different superscripts differ significantly ($p \leq 0.001$). [a,b] Mean values within the same row with different superscripts differ significantly ($p \leq 0.05$).

3.2. Total Antioxidant Capacity

Table 4 displays the total antioxidant capacity results in terms of (%) radical scavenging activity. TAC in serum as well as in thigh muscle was significantly higher in the free-range (A) chickens compared to the conventional (B) chickens, with significance $p \leq 0.01$ and $p \leq 0.05$, respectively.

3.3. Thiobarbituric Acid Reactive Substances (TBARS)

Although serum TBARS of the free-range (A) broilers were significantly higher ($p \leq 0.05$) compared to the conventional ones (B) (Table 4), the opposite was observed in the thigh muscle, where TBARS were significantly lower ($p \leq 0.05$) in the free-range slow-growth chickens compared to the conventional ones fast-growth.

3.4. α-Tocopherol

Levels of α-tocopherol in broilers' serum did not show significant differences among the tested breeding systems ($p > 0.05$) as presented in Table 4.

Table 4. Presentation of the total antioxidant capacity (TAC) and thiobarbituric acid reactive substances (TBARS) statistical analysis in serum and thigh muscle, expressed as (%) radical scavenging activity and MDA (nmol/mL), respectively, as well as the levels of α-tocopherol in chicken serum for the tested groups (n = 171 for extensive reared chickens and n = 184 for intensive reared chickens). Results are presented as mean ± SEM.

System	Extensive [1]	Intensive [2]	*p* Value
Serum RSA %	33.27 ± 1.03 [A]	29.19 ± 0.87 [B]	<0.001
Thigh RSA%	50.42 ± 0.77 [a]	44.29 ± 1.14 [b]	0.004
Serum MDA (nmol/mL)	4.70 ± 0.16 [a]	3.98 ± 0.14 [b]	0.005
Thigh Muscle MDA (nmol/mL)	2.63 ± 0.08 [a]	3.03 ± 0.11 [b]	0.017
α-tocopherol (μg/mL)	21.38 ± 1.18 [a]	21.47 ± 0.93 [a]	0.261

[1] Slow-growth chicks; [2] Fast-growth chicks; [A,B] Mean values within the same row with different superscripts differ significantly ($p \leq 0.001$). [a,b] Mean values within the same row with different superscripts differ significantly ($p \leq 0.05$).

3.5. Meat Quality

3.5.1. Chemical Analysis of the Meat

Chemical analysis of the meat revealed that the free-range broilers (A) had higher protein content ($p \leq 0.05$) but lower fat content ($p \leq 0.05$), WHC ($p \leq 0.001$), moisture ($p \leq 0.001$), ash ($p \leq 0.05$), and pH value ($p \leq 0.001$) than the conventional (B) ones (Table 5).

Table 5. Meat chemical analysis of the tested groups (n = 13 per group). Results are shown as mean ± SEM.

System	Extensive [1]	Intensive [2]	*p* Value
Protein%	21.20 ± 0.03 [a]	20.90 ± 0.11 [b]	0.016
Fat%	12.20 ± 0.25 [a]	13.20 ± 0.21 [b]	0.019
Moisture%	65.20 ± 0.11 [A]	66.20 ± 0.12 [B]	<0.001
Ash%	1.10 ± 0.01 [a]	1.20 ± 0.02 [b]	0.002
pH	5.20 ± 0.01 [A]	5.60 ± 0.07 [B]	<0.001
WHC%	3.10 ± 0.02 [A]	4.10 ± 0.01 [B]	<0.001

[1] Slow-growth chicks; [2] Fast-growth chicks; [A,B] Mean values within the same row with different superscripts differ significantly ($p \leq 0.001$). [a,b] Mean values within the same row with different superscripts differ significantly ($p \leq 0.05$).

3.5.2. Organoleptic Characteristics

The analysis of sensory properties showed that the free-range chickens (A) presented better smell, taste, color, and texture compared to the conventional chickens (B), but the latter ones showed greater tenderness (Figure 1).

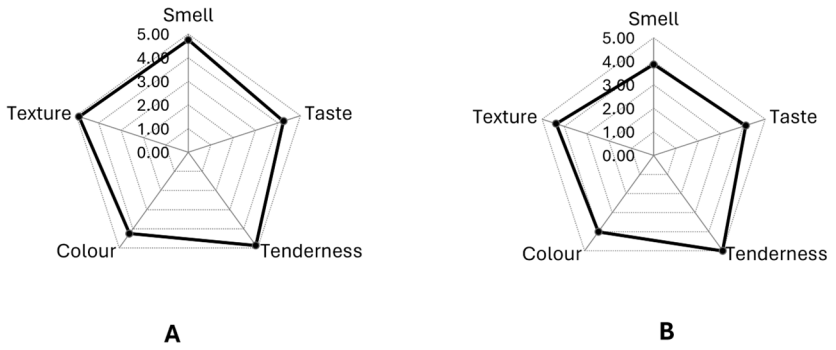

Figure 1. Presentation of the arachnograms resulted from the organoleptic characteristics' analysis of the roasted chicken thighs of the tested groups by tasters, with score from 0 to 5. (**A**) Extensive system including slow-growth and free-range chickens, (**B**) Intensive system including fast-growth, conventional chickens.

4. Discussion

Consumers prefer poultry meat instead of other meat products because it possesses high protein and low fat content [7], but it also has a much lower price than other meat products [2]. This was the reason for the significant increase in the poultry industry in terms of broiler chicken population and meat [3,5], which in turn led to the adoption of some practices for fast-growing breeds. Intensive farming and high stocking density impact the animals' welfare, meat quality, and performance due to the development of oxidative stress [22,23]. Intensive farming provokes a chain effect that starts with impaired animal welfare, which may be associated with deteriorated meat quality. Thus, there is an effort to inverse the practices of farming. Alternative farming systems, such as free-range farming, provide chickens with access to the outdoors for at least some part of the day, whether the chickens choose to go outside or not [2,10]. Various studies have been conducted to evaluate the influence of the farming system on chickens' health, performance, and meat quality [1–3,7,11,24,25]. However, most of the studies have been performed in small experimental-scale systems, and the results might be different from the real conditions [12,13,19,26].

This study presents the effect of two farming systems, i.e., conventional fast-growth chickens and free-range slow-growth chickens, on the chickens' antioxidant status, performance, meat quality, and organoleptic characteristics in industrial-scale production. The ultimate goal of our study was to contribute to bridging the available literature with the actual industry practices regarding the broiler raising system and its impact on animal antioxidant profile, health, and welfare by directly comparing antioxidant levels between intensive and extensive rearing systems. By investigating the differences in antioxidant profiles associated with each farming system, our findings have implications for understanding the potential health and welfare outcomes for broiler chickens raised under different management practices. Variations in antioxidant profiles may reflect differences in dietary composition, environmental stressors, or metabolic demands, all of which can impact the overall well-being of broiler chickens.

According to performance results, free-range slow-growth chicks had significantly increased FCR and lower EPEF and BWG compared to conventional fast-growth (Table 3). These findings agree with published results and were expected since the fast-growth chicks, like Ross 308, have been selected genetically for rapid growth and feed efficiency, which allows them to reach market weight quickly with lower feed consumption compared to other breeds [12,24,25,27–29]. Though not statistically significant, the numerical differences in ADFI and BWG between the two groups are ascribed to their different BW [30] and rearing systems [28]. The gap in performance between the two production systems could be attributed to the differences in rearing conditions and environmental challenges. Furthermore, compared to conventionally raised broilers, free-range ones exhibit walking, running, and ground pecking behaviors more frequently; hence, inferior performance was linked to greater activity [31]. In addition, performance differences could be attributed to the hybrids used, as the slow-growth one is characterized by a delayed achievement of production indexes compared to the conventional fast-growing one. According to Yamak et al., [32] both productive features as well as meat quality traits must be taken into account while creating new breeds appropriate for alternative and organic systems. In this view, we further analyzed the effects of both systems on meat antioxidant capacity and meat sensory profile.

Organoleptic characteristics gained an overall better score in the slow-growth broiler chicks compared to the conventional ones, except for tenderness (Figure 1). These findings were expected due to the outdoor access of the free-range broiler chickens [28,33]. The meat of fast-growth chickens has been characterized as more tender compared to slower-growth breeds. The better flavor of the free-range chickens is attributed mainly to their increased PUFAs and being more mature than the fast-growth chicks, while toughness is attributed to their increased kinetic activity and lower intramuscular fat [34]. The more desirable color is connected to genetic and growth type effects; e.g., slow-growth chickens are redder

than fast-growth ones because the former are older [34,35], but the acceptability of the color depends on consumers' preferences [1]. Similar results to our findings have also been reported in the literature [3,36].

Meat chemical analysis revealed that the free-range chickens had increased protein content (by 0.3%) and lower moisture (by 1%), ash (by 0.1%), WHC (by 1%), pH (by 0.4 points), and fat (by 1%) compared to the conventional chickens (Figure 1). The increased protein and decreased fat content found in the free-range chicks could be attributed to their physical and foraging activity, genotype, and rearing system, even though protein is much less affected by the rearing system than fat content [28,37]. Also, their lower % WHC and moisture are ascribed to the lower pH value, which is known to affect them [1,34], and go along with the lower tenderness observed, as abovementioned (Sensory characteristics). Furthermore, lower WHC has been reported for slow-growing compared to fast-growing genotypes, attributed to the broiler chickens' slow growth and the metabolically less mature tissues at harvest than the fast-growth chicks [38–40]. The lower pH could be due to the rigor mortis process (i.e., a more rapid rate of post-mortem glycolysis), which transforms muscle into meat and affects its biochemical and physicochemical properties but could also be influenced by genetic selection, pre-slaughter conditions, and induced shackling stress, which results in rapid muscle acidification [1,34,41]. However, others have found a lower pH value in slower-growing chicks [42]. Overall, metabolic biochemical processes and chemical composition are strongly influenced by the rearing system, i.e., outdoor access and foraging, genotype, fattening period, diet formulation, and pasture quality, which result in modifications in tissues and organs [28].

TAC was significantly higher for the free-range compared to the conventional chicks, both in serum and thigh muscle (Table 4). These results suggest that free-range chickens had a greater amount of antioxidants than conventional ones, as also stated by other researchers. It could be hypothesized that pasture could provide some nutritional advantages in poultry meat in terms of the higher antioxidant, vitamin, and mineral content included in grass, insects, and earthworms [2,36].

TBARS in serum was significantly lower in conventional compared to free-range chickens. On the other hand, TBARS in thigh muscle were significantly lower in the free-range slow-growth broiler chickens (Table 4). The higher TBARS value in free-range chickens' serum could be attributed to stress induced in slow-growth broilers either by outdoor (weather, predator attacks, kinetic activity) or preslaughter conditions [2,36]. These conditions may induce a higher metabolic rate, which in turn results in higher levels of free radical production and oxidation of the nutrient substrates [36]. However, the significantly lower TBARS in the slow-growth chickens' thigh muscle may indicate that the stress was not shifted to muscle tissue or that the antioxidants passed through the diet to the muscle and protected it from oxidation.

Finally, serum α-tocopherol did not show significant differences between the tested groups (Table 4). Although it is expected that grazing increases α-tocopherol content [36], the lack of differences between farming systems may be attributed to the fact that α-tocopherol consumption resulted from increased PUFA content in the free-range chicks while protecting muscle from oxidation, a fact that agrees with the abovementioned findings in TBARS. It should be noted that α-tocopherol and other fat-soluble antioxidants have been proven to be more active against lipid oxidation while working as chain-breakers in the hydroperoxide formation that begins with PUFAs [36].

In conclusion, the results of our extensive study, which included 13 replicates of each industrial breeding and two chicken genotypes, suggest that the type of farming system used in industrial-scale production affects the performance, antioxidant capacity, organoleptic characteristics, and meat quality of the chickens.

Particularly, the farming system of conventional, fast-growth chickens yields improved performance and chicken meat tenderness, and lower induced stress. On the other hand, the farming system of free-range, slow-growth chickens yields improved nutritional value and total sensory properties and an increased chicken serum and thigh muscle antioxidant

profile. To the best of our knowledge, this is the first study reporting on the antioxidant status, performance, and meat quality of slow-growth genotype broilers raised under commercial conditions.

Finally, our study reveals findings regarding the systems that are used by the industry and are important because of their large-scale estimation in farming systems that can benefit consumers as well as the poultry industry by increasing the added and nutritional value of the final products. However, more industrial-scale studies are needed in order to evaluate the effect of farming systems on welfare, immunity, and health parameters. Meanwhile, as weather conditions such as rainfall, radiation, and wind speed all may have an adverse influence on free-range usage, further studies may be needed to assess the effects of such factors on the antioxidant status and meat quality of the specific genotypes. In conclusion, the free-range farming system for slow-growth chickens may result in an overall higher nutritional value, sensory score, and serum and thigh muscle antioxidant profile than the conventional farming system for fast-growth broilers. However, fast-growth broilers exhibit better performance and might undergo less stress.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16114782/s1, Table S1: Nutrient composition of the free-range chickens' feed; Table S2: Nutrient composition of the conventional chickens' feed; Table S3: Chemical analysis of the animal feeds.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. The samples were collected at commercial poultry farms of the integrated poultry company Agricultural Poultry Cooperation of Ioannina "PINDOS", located in the prefecture of Epirus, Greece, without the use of experimental animals.

Data Availability Statement: The original contributions presented in the study are included in the article and Supplementary Materials, further inquiries can be directed to the corresponding authors.

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