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Carcass Yield and Meat Quality of Broiler Chicks Supplemented with Yeasts Bioproducts

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Abstract: The utilization of synthetic additives (vitamins, proteins, and pigments) in broiler chicks' feeds may cause problems in the future, such as competitive availability, extra productive induced costs, and human health risks relayed on sole ingredients commonly used on human and animal food and feeds. A total of 320-day-old broiler chicks were randomly assigned to eight experimental groups (a four × two factorial design), receiving two dietary yeasts, lyophilizate lysates yeasts:brewer's spent yeasts: *Saccharomyces cerevisiae* (SC: 0, 0.6, 1 and 1.3 g/kg) and *Rhodotorula mucilaginosa* (RM: with 0.3 kg/t or without), during a 42-day trial. The broilers' 24 h post–slaughtering performance, meat quality (pH, color, proximate chemical composition, texture profile analysis), and meat sensorial evaluation were performed at the end of the trial. Dietary SC supplementation had a significant effect on fat deposits ($p < 0.05$), thigh meat protein content ($p < 0.05$), and breast meat lightness ($p < 0.05$). Meanwhile, RM dietary supplementation positively affected all meat color parameters ($p < 0.05$). Considerable interactions (SC × RM) were obtained on the broilers' breast and thigh meat moisture and yellowing index. Dietary lyophilizes lysates yeasts supplementation had an effect on meat color and proximate chemical composition. Furthermore, investigation is needed to elucidate the effects of microbial pigment supplements on broiler meat biochemistry and its pigment metabolism.

Keywords: broiler meat; meat quality; meat color; pigment yeast; sensorial evaluation; texture profile

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1. Introduction

The future use of synthetic additives (vitamins, proteins, and pigments) in broiler chicks' feeds poses a number of problems [1] including competitive availability, increased productive induced costs, and health risks associated with sole ingredients commonly used in human and animal feeds and food. Moreover, the projection concerning the increased demand for broiler meat and meat products is directly affected by the consumer's choice. Recently, consumers' preferences are directed towards safe and high-quality broiler meat and meat products, often associated with slow-growing broiler breeds [2], reared in organic systems [3], obtained using an economic circular approach by introducing organic valuable waste and by-products [4].

After twelve–fifteen successive fermentation batches, the brewing biological catalyst *Saccharomyces cerevisiae* loses its vitality and viability and might be biologically compromised, being no longer appropriate for beer production. Brewers' spent yeast (SC) was previously described as a nutritive complex ingredient, an excellent source of protein (more than 40%) [5], presenting a high content of essential limitative amino acids, with high levels of biotin, folic acid, microelements, and intracellular flavoring compounds [6,7]. It is known that *Saccharomyces cerevisiae* (SC) consumption as a protein source for animal and human nutrition is restricted, due to the high level of nucleic acids (up to 15%), mainly causing

seric and tissue uric acid accumulation [8]. Despite these facts, SC was mainly subjected to debittering, efficiently valuing all biologic active compounds [9], that can conventionally be achieved by physical, chemical, and biological processes [10], while avoiding toxicity [11].

Poultry cannot synthesize carotenoids; synthetic pigment feed additives are often employed in order to adjust the retinoic acid ratio via carotenoid dietary supplementation. Most commonly used food and feed colorant additives in poultry nutrition are xanthophylls (canthaxanthin, astaxanthin, and zeaxanthin) that originate from almost 90% mainly synthetic resources. Nowadays, poultry meat consumers' preference is directing the meat producing sector towards organic and less intensive poultry rearing techniques, including the use of natural and organic feed coloring additives. Recent scientific evidence points out the advantages of employing microbial pigment sources, lowering the costs covering the geo-climate variability and time spent on the vegetal pigment producing industry, obtaining a short-time valuable pigment product, mostly based on waste fermentation, and low-cost materials [12–14]. Yeast such as *Rhodotorula mucilaginosa* (RM) represents a perfect choice as a natural resource of secondary metabolites: carotenoids, lipids, and extracellular enzymes [13,15,16].

Previous studies indicate an active/inactive SC dietary supplementation improves broiler growth performance [11,17,18], immunity response [13], carcass yield [17], and meat quality [19,20]. Scientific evidence for using RM on broiler chick feed is very limited [21], but recent studies suggest that it could have growth promoting, health promoting, and production quality effects on laying hens [22], fish [23], and swine [24].

The study was performed to probate the hypothesis that yeasts lyophilizate lysates dietary supplements might impair the carcass yield and the meat quality attributes. Therefore, the main goals were to evaluate the singular and the interaction effects of the dietary yeasts lyophilizate lysates supplements on the broiler carcass yield and breast and thigh meat quality attributes (pH, color, proximate chemical composition, texture profile analysis, and sensorial evaluation).

2. Materials and Methods

The Animal Ethics Committee approved the study protocol of the National Research and Development Institute for Animal Biology and Nutrition (INCDBNA-IBNA) Baloteşti, Romania, under the EU Directive 2010/63/EU and Romanian Law on Animal Protection (no. 199/2018). The bird's slaughtering was carried out following the applicable rules on handling animals at the time of slaughter, including humane treatment. We confirm that all engaged methods on chickens were carried out in accordance with relevant guidelines and regulations.

A total of 320-day-old unsexed Cobb 500 broiler chicks (body weight = 43.11 ± 0.7 g/bird) were randomly assessed in eight experimental groups (Table 1) to receive a corn-soybean meal based diet, supplemented with yeasts dietary lyophilizate lysates l: SC (0, 0.6, 1 and 1.3 g/kg) and RM (with 0.3 kg/t or without) as previously described [18], and listed in Table 2.

Table 1. Basal diets of broiler chicks, per each growth period [1].

Groups	Dietary Treatments
1	Negative control group − fed with basal diet (Corn-soybean meal);
2	Basal diet + SC 0.6 g/kg feed;
3	Basal diet + SC 1.0 g/kg feed;
4	Basal diet + SC 1.3 g/kg feed;
5	Positive control group − fed with basal diet (Corn-soybean meal) + RM (0.3 kg/t feed);
6	Basal diet + SC 0.6 g/kg feed + RM (0.3 kg/t feed);
7	Basal diet + SC 1.0 g/kg feed + RM (0.3 kg/t of feed);
8	Basal diet + SC 1.3 g/kg feed + RM (0.3 kg/t feed);

[1] after [18].

Table 2. Basal diets of broiler chicks, per each growth period [1].

	Starter	Grower	Finisher
Ingredients (g/kg)			
Corn	557.9	567.3	629.6
Soybean meal	331.0	311.0	255.0
Corn gluten	43.0	43.0	35.0
Soybean oil	14.6	29.8	34.0
Monocalcium phosphate	16.9	16.6	14.5
Calcium carbonate	16.9	14.6	13.2
Salt	2.8	2.8	2.8
L-lysine HCl	3.3	1.8	2.7
Dl-methionine	2.8	2.3	2.5
Choline-chloride 50%	0.8	0.8	0.7
Vitamin − mineral mixture *	10.0	10.0	10.0
RM [2]	+/−	+/−	+/−
SC [3]	0/0.6/1 or 1.3	0/0.6/1 or 1.3	0/0.6/1 or 1.3
Calculated composition			
ME (MJ/kg)	12.55	13.02	13.40
CP (%)	23.0	22.0	20.0
Lysine, total (%)	1.41	1.24	1.05
Lysine, digestible (%)	1.28	1.16	0.98
Methionine + cysteine, total (%)	1.02	0.95	0.86
Methionine + cysteine, digestible (%)	0.94	0.87	0.75
Ca (%)	1.00	0.90	0.80
Available P (%)	0.45	0.45	0.45
Crude fat (%)	4.34	5.85	6.23
Crude fiber (%)	2.85	2.77	2.56

* Supplied per kg diet: 12,000 IU vitamin A, 5000 IU vitamin D3, 75 mg vitamin E, 3 mg vitamin K3, 3 mg vitamin B1, 8 mg vitamin B2, 5 mg vitamin B6, 0.016 mg vitamin B12, 13 mg pantothenic acid, 55 mg nicotinic acid, 2 mg folic acid, 0.2 mg biotin, 120 mg Mn, 100 mg Zn, 40 mg Fe, 16 mg Cu, 1.25 mg I and 0.3 mg Se, 70 mg Monteban G100. [1] after [18]; [2] RM—*Rhodotorula mucilaginosa*— lyophilized lysed yeast 0.3 kg/T feed − = not supplemented in the broilers' diet; + = supplemented in the broilers' diet; [3] SC—*Saccharomyces cerevisiae*—not included or supplemented as 0.6, 1, or 1.3 in the broilers' diet.

2.1. Slaughtering and Post–Slaughtering Performance

At the end of the experimental trial (day 42), all birds were individually weighed using a commercial scale. Five birds from each pen were electrically stunned and slaughtered by carotid amputation. Carcasses were plucked, eviscerated, and individually weighed. For the carcass yield, slaughter performance and the rates of retailed meat cuts (carcass yield, feet and hock joint removed carcass, front part of carcass, back part of carcass, breast fillets, breast tenders, leg quarters, thighs, drumsticks, and whole wings) and internal organs (heart, liver, and gizzard) were weighed and reported as a percentage from the commercial carcass weight.

The deboned breast (n = 40) and thigh (n = 40) were collected [25], vacuum sealed, and refrigerated (2 ± 2 °C) for further analysis.

2.2. pH

After 24 h of refrigeration, the pH of the breast and thigh meat samples (n = 5) were recorded (SR ISO 2917:2007) using a calibrated (4.01, 7.00 and 9.21 buffer solutions, at 20 °C) pH-meter (WTW 315i, Weilheim, Germany).

2.3. Meat Color

Breast and thigh meat colors (n = 5) were surface measured using the portable, calibrated (white ceramic tile) CR 410 color meter (Konica Minolta INC, Osaka, Japan) on middle area of the left-side breast–pectoralis major and left thigh (homogeneous, and fat–free area–8 mm). The broiler meat colors were reported in the CIE Lab system (L^*, a^*, b^*) [26] and calculated for yellowness index (YI), browning index (BI), chroma (C), and hue (h) [27].

2.4. Proximate Chemical Composition

For the proximate chemical composition, the breast and thigh meat samples were minced and individually analyzed (n = 5) using the DA6200 automatic analyzer (PerkinElmer, Inc., Waltham, MA, USA) equipped with a magnetic tray (14 mm height and 170 mL volume) and diode array detector (λ = 850–1050 nm). To minimize the sampling error, the replicates (n = 5) were analyzed in triplicate. Optical calibration was performed before meat sample analysis, using the polystyrene check sample.

2.5. Texture Profile Analysis

The texture profile analysis (TPA) of raw breast and thigh meat samples (n = 5) was individually analyzed, employing the texture analyzer (Brookfield CT3, Massachusetts, USA). The double cycle compression method was adopted on the cylinder-catted meat samples (20 mm diameter and 5 ± 0.2 mm height). The analyzer was supplied with a 50 kg loading cell, a cylinder probe (76.2 × 10 mm), and a fixture bare table. The experimental physical conditions were set as previously described [28,29], pre-test (speed = 2.0 mm s^{-1}), test (speed = 1.0 mm s^{-1}), and post-test (speed = 2.0 mm s^{-1}).

2.6. Sensorial Evaluation

Sensorial raw meat analysis was performed on the breast and thigh meat samples (n = 3) by employing ten naive assessors (ISO 5492: 2008, gender-balanced, aged between 20–25 years), chosen for their ability to perform a sensory test, acquainted with meat and meat product quality traits. The sensorial evaluation was by the environmental guidelines set up for this purpose (ISO 8589:2007). The descriptive analysis was applied, using a scoring scale (ISO 6658:2017; sored between 1–5; 1 for indicating the lowest score and 5 for indicating the highest score). The scale parameters included meat appearance (MFA), fat appearance (FTA), odor (ODO), consistency (CON), juiciness (JCY), and meat tenderness (TEN); the scoring scale included the quality sensorial attributes description as standing from 1–unaccepted, unrecommended, up to 5—very desirable, recommended [30].

2.7. Statistics

The experimental data RM was analyzed using the General Linear Model procedure (SPSS v25, IBM) and reported as means and standard error of the means (SEM). The one-way ANOVA for the differences among the experimental groups and Tukey's multiple range of tests for differencing the significant means at $p < 0.05$ level were employed. The relationships between characteristics were evaluated trough Pearson correlations and Principal Component Analysis (PCA), the significance level being $p < 0.05$.

The factorial design equation:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + e_{ijk} \quad (1)$$

μ = general mean, α_i = the effect of SC, having the levels i = 1–4; β_j = the effect of RM, having the levels j = 1–2; $\alpha\beta_{ij}$–the interaction of SC and RH, having 2 × 4 levels; and e_{ijk} = the experimental unit associated error, having the levels k = 1–8.

3. Results

3.1. Post-Slaughtering Performance

The post-slaughtering performance of dietary supplemented broiler chicks are detailed in Table 3. The RM dietary supplement had no significant effect ($p > 0.05$) on the broiler's carcass yield, slaughter performance, nor the rates of retailed meat cuts. Although, supplementing SC on the broiler chick's diet had significant effect on gizzard weight (p = 0.04) and abdominal fat accumulation (p = 0.001). Considerably higher differences were observed in groups four and eight, when compared with all experimental groups. Through dietary supplementation, different levels of SC linearly decreased the abdominal

fat deposits, having the lowest values on the 1.3 g/kg SC supplemented groups (four and eight), when compared with all experimental groups.

Table 3. Carcass yield and retailed body parts of broilers' [1] diet supplemented with yeast.

Group	SC	RM	LW [2]	CW [2]	CY [3]	Breast [3]	Thigh [3]	Drumsticks [3]	Liver [3]	Gizzard [3]	Heart [3]	Abd. Fat [3]
1	**0**	**No**	2761.80	2070.40	74.98	41.59	12.51	10.35	2.83	1.90	0.620	2.61
2	**0.6**	**No**	2789.60	2064.00	74.06	41.76	12.08	10.39	2.73	2.04	0.589	2.11
3	**1**	**No**	2723.80	2049.40	75.24	41.94	12.37	10.57	2.81	2.06	0.628	1.64
4	**1.3**	**No**	2525.80	1902.40	75.38	41.88	12.51	10.95	3.08	2.20	0.685	1.44
5	**0**	**Yes**	2744.60	2046.20	74.57	41.32	12.10	10.84	2.61	1.58	0.529	2.12
6	**0.6**	**Yes**	2659.40	1975.00	73.61	41.65	12.13	10.97	2.78	1.71	0.643	2.16
7	**1**	**Yes**	2555.80	1925.20	75.32	41.71	12.53	10.79	2.74	1.85	0.638	1.96
8	**1.3**	**Yes**	2463.00	1872.60	75.93	41.97	12.81	10.35	2.96	2.89	0.644	1.47
SEM			75.102	62.267	1.018	1.153	0.507	0.363	0.167	0.195	0.041	0.205
***p* value**			0.751	0.798	0.956	0.999	0.906	0.366	0.865	0.060	0.390	0.263
Main effect—SC levels												
0			2753.20 ^{a}	2058.30 ^{a}	74.77	41.46	12.31	10.60	2.74	1.88 ^{b}	0.56	2.37 ^{a}
0.6			2724.50 ^{a}	2010.30 ^{ab}	73.84	41.71	12.11	10.68	2.76	1.88 ^{b}	0.62	2.14 ^{ab}
1			2639.80 ^{ab}	1987.30 ^{ab}	75.28	41.88	12.45	10.68	2.78	1.96 ^{b}	0.63	1.80 ^{bc}
1.3			2494.40 ^{b}	1888.30 ^{b}	75.66	41.93	12.66	10.65	3.03	2.54 ^{a}	0.66	1.45 ^{c}
SEM			53.105	44.029	0.720	0.815	0.359	0.257	0.118	0.138	0.029	0.145
***p* value**			0.007	0.066	0.327	0.977	0.739	0.995	0.288	0.004	0.201	0.001
Main effect—RM addition												
No			2700.25	2022.05	74.92	41.79	12.37	10.56	2.86	2.05	0.633	1.95
Yes			2605.70	1950.25	74.86	41.69	12.39	10.74	2.77	2.08	0.614	1.92
SEM			37.551	31.133	0.509	0.576	0.254	0.182	0.084	0.098	0.021	0.102
***p* value**			0.085	0.113	0.933	0.895	0.942	0.507	0.427	0.841	0.516	0.884

SC—*Saccharomyces cerevisiae*, g/kg feed; RM—*Rhodotorula mucilaginosa* 0/0.3 kg/t of feed; [1] LW—final live weight; [2] CW—eviscerated carcass weight; [3] CY—carcass yield; Abd. Fat—abdominal fat; SEM—standard error mean; SC × RM—interaction between the dietary supplements; [1] n = 5/replicate pen; [2] expressed in gram; [3] expressed as percentage of CW; [abcd] Columns means with different superscripts differ significantly at $p < 0.05$.

3.2. Meat pH and the Chemical Proximate Analysis

The broiler raw breast and thigh meat pH and the proximate chemical composition (PCC) results are displayed in Table 4. There was no significant difference ($p > 0.05$) on the interaction of the yeasts (SC × RM) dietary supplemented broiler meat samples after 24 h post-mortem refrigerated breast and thigh meat samples. No significant effects ($p > 0.05$) were observed on the broiler breast and thigh meat obtained with SC dietary supplementation, nor on the broiler breast and thigh meat that received RM dietary supplementation.

Data concerning dietary yeasts supplementation on the broiler breast and thigh meat samples are indicating significant differences among the PCC on all the experimental groups. There were significant linear differences in the SC main effects groups, resulting in lower protein and fat percent on the breast and thigh meat, indicating that SC dietary linear increasement (0, 0.6, 1 and 1.3 g/kg feed) decreases the meat protein and fat percentage. Conversely, the broiler breast and thigh meat were significantly influenced ($p < 0.05$) by the dietary linear supplementation of SC, indicating a direct proportionality between moisture and collagen percentage and the SC dietary increasement (0, 0.6, 1 and 1.3 g/kg feed).

Table 4. Yeasts supplemented broiler's breast [1] and thigh meat pH and PCC.

			Broiler Breast Meat					Broiler Thigh Meat				
Group	**SC**	**RM**	**pH**	**Protein ***	**Fat ***	**Moisture ***	**Collagen ***	**pH**	**Protein ***	**Fat ***	**Moisture ***	**Collagen ***
1	**0**	**No**	6.02	21.77	2.23	76.17	0.84	5.91	19.31	10.44	70.10	0.98
2	**0.6**	**No**	5.99	21.63	2.27	75.76	0.87	5.96	18.59	8.83	71.26	1.09
3	**1**	**No**	6.02	21.17	1.87	76.99	0.89	6.00	18.85	8.26	71.64	1.11
4	**1.3**	**No**	6.01	20.87	1.70	76.89	0.93	6.01	17.68	8.99	71.03	1.25
5	**0**	**Yes**	5.99	21.54	2.67	76.95	0.83	5.97	19.07	10.25	69.75	0.98
6	**0.6**	**Yes**	5.99	21.42	2.61	78.55	0.85	5.99	18.41	9.48	71.87	1.02
7	**1**	**Yes**	5.97	21.03	2.23	76.74	0.88	6.02	18.90	8.77	72.92	1.11
8	**1.3**	**Yes**	6.00	20.82	1.99	76.88	0,90	5.99	17.48	8.42	72.47	1.24
SEM			0.032	0.151	0.058	0.072	0.833	0.033	0.077	0.276	0.205	0.021
***p* value**			0.889	0.938	0.900	<0.000	0.600	0.663	0.232	0.109	<0.000	0.342
Main effect—SC levels												
0			6.00	21.66 ^{a}	2.48 ^{a}	76.76 ^{c}	0.83 ^{d}	5.94	19.19 ^{a}	10.35 ^{a}	69.93 ^{c}	0.98 ^{c}
0.6			5.99	21.53 ^{a}	2.44 ^{a}	77.16 ^{a}	0.86 ^{c}	5.98	18.45 ^{c}	9.15 ^{b}	71.56 ^{b}	1.05 ^{b}
1			5.99	21.10 ^{b}	2.05 ^{b}	76.87 ^{b}	0.89 ^{b}	6.01	18.87 ^{b}	8.51 ^{b}	72.28 ^{a}	1.11 ^{b}
1.3			6.01	20.86 ^{c}	1.85 ^{c}	76.89 ^{b}	0.91 ^{a}	6.00	17.58 ^{d}	8.70 ^{b}	71.75 ^{ab}	1.25 ^{a}
SEM			0.22	0.107	0.041	0.051	0.006	0.023	0.054	0.195	0.145	0.015
***p* value**			0.867	<0.000	<0.000	<0.000	<0.000	0.133	<0.000	<0.000	<0.000	<0.000
Main effect—RM addition												
No			6.01	21.36	2.03 ^{b}	76.45 ^{b}	0.88	5.97	18.61 ^{a}	9.13	71.01 ^{b}	1.11
Yes			5.99	21.21	2.38 ^{a}	77.23 ^{a}	0.87	5.99	18.47 ^{b}	9.23	71.75 ^{a}	1.09
SEM			0.022	0.107	0.041	0.051	0.006	0.16	0.038	0.138	0.103	0.011
***p* value**			0.300	0.159	<0.000	<0.000	0.110	0.380	0.013	0.606	<0.000	0.282

[1, *] n = 5/replicate pen; SC—*Saccharomyces cerevisiae*, g/kg feed; RM—*Rhodotorula mucilaginosa*, 0/0.3 kg/t of feed; SEM—standard error mean; SC × RM—interaction between the dietary supplements; [abcd] Columns means with different superscripts differ significantly at $p < 0.05$.

3.3. Broiler Breast and Thigh Color Profile

Manipulating broiler meat color by dietary supplementation of different inactive yeast sources resulted in significant changes in the breast and thigh meat color parameters (Table 5). Significant interactions ($p < 0.05$) between both of the main dietary supplements (SC × RM) were shown on broiler breast (YI) and thigh meat (a^*, b^*, C, BI, YI and ΔE). The results show a bifactorial positive interaction on the broiler meat color parameters values, which linearly increased within the dietary supplementation.

As expected, the dietary RM supplement had highly significant effects ($p < 0.005$) on all analyzed color parameters of the broiler breast meat. Our results shows that broiler dietary RM supplementation significantly lowers the breast meat color parameters: a^* ($p < 0.000$), b^* ($p < 0.000$), C ($p = 0.001$), BI ($p < 0.000$), YI ($p < 0.000$), and ΔE ($p < 0.000$) of the experimental groups (five, six, seven, eight), while the L^* ($p < 0.000$) and h ($p < 0.000$) increases, when compared with the control group (1).

The SC dietary supplementation was found to have significant influence ($p < 0.05$) on the broiler breast meat L^*, YI, BI, and ΔE. The SC dietary supplementation showed that L^* values were lowered in the broiler breast meat experimental groups (two, three, and four) than the control (one), while higher values were obtained for the total color difference. Although conversely, the broiler thigh meat brightness (L^*) values were higher in the control group than in the experimental groups (two, three, and four), indicating that SC treatment might influence the carotenoid muscular accumulation, thus carotenoid abundance. The SC × RM interaction had an effect ($p < 0.05$) on the broiler thigh meat L^*, a^*, b^*, C, BI, YI, and ΔE.

Table 5. Yeasts supplemented broilers' breast [1] and thigh meat color.

			Broiler Breast Meat								Broiler Thigh Meat							
Group	**SC**	**RM**	***L****	***a****	***b****	***h***	***C***	**BI**	**YI**	**ΔE**	***L****	***a****	***b****	***h***	***C***	**BI**	**YI**	**ΔE**
1	**0**	**No**	54.14	10.05	13.18	0.92	16.58	41.00	34.75	43.80	57.95	12.62	11.50	0.74	17.12	37.12	28.11	40.20
2	**0.6**	**No**	56.16	10.77	12.29	0.85	16.35	38.26	31.27	41.89	57.47	14.61	12.25	0.70	19.07	41.09	30.45	41.98
3	**1**	**No**	55.51	10.36	13.80	0.93	17.26	41.78	35.51	42.73	54.73	13.38	12.87	0.77	18.57	41.43	31.73	41.23
4	**1.3**	**No**	56.85	10.68	12.83	0.88	16.72	38.82	32.21	41.35	57.81	11.91	11.50	0.77	16.55	36.72	28.41	40.54
5	**0**	**Yes**	48.52	12.16	14.16	0.86	18.71	52.21	34.75	49.86	56.99	13.52	10.85	0.68	17.35	39.55	28.35	43.82
6	**0.6**	**Yes**	51.35	12.83	14.27	0.84	19.20	50.25	39.70	47.41	56.67	12.12	10.23	0.70	15.86	34.98	25.78	41.44
7	**1**	**Yes**	51.20	12.72	14.13	0.84	19.01	49.92	39.45	47.48	58.99	12.58	11.23	0.73	16.87	37.53	28.16	41.48
8	**1.3**	**Yes**	50.69	12.97	14.66	0.85	19.58	52.25	41.32	48.15	55.58	13.84	11.77	0.70	18.19	41.15	30.07	43.07
SEM			0.540	0.295	0.360	0.018	0.334	0.736	0.709	0.456	0.303	0.357	0.309	0.021	0.310	0.779	0.794	0.271
***p* value**			0.336	0.954	0.096	0.188	0.274	0.009	0.005	0.167	<0.000	<0.000	0.003	0.303	<0.000	<0.000	0.001	<0.000
Main effect—SC levels																		
0			51.33 ^{b}	11.11	13.67	0.89	17.64	46.6	38.17	48.82 ^{a}	57.47 ^{a}	13.07	11.18 ^{b}	0.71	17.23	38.34	28.23	42.00
0.6			53.75 ^{a}	11.80	13.28	0.85	17.78	44.26	35.48	44.65 ^{b}	57.07 ^{ab}	13.37	11.24 ^{ab}	0.69	17.47	38.44	28.12	41.71
1			53.35 ^{a}	11.83	13.97	0.88	18.14	45.85	37.48	45.10 ^{b}	56.61 ^{ab}	12.98	12.05 ^{a}	0.75	17.73	39.48	29.94	43.36
1.3			53.77 ^{a}	11.80	13.74	0.86	18.15	45.54	36.76	44.75 ^{b}	56.84 ^{ab}	12.87	11.63 ^{ab}	0.74	17.38	38.94	29.24	41.81
SEM			0.382	0.209	0.255	0.013	0.236	0.521	0.502	0.322	0.214	0.252	0.219	0.015	0.219	0.551	0.562	0.191
***p* value**			<0.000	0.072	0.306	0.081	0.335	0.072	0.081	<0.000	0.048	0.560	0.029	0.089	0.456	0.449	0.087	0.128
Main effect—RM addition																		
No			55.66 ^{a}	10.47 ^{b}	13.02 ^{b}	0.89 ^{a}	16.73 ^{b}	39.96 ^{b}	33.43 ^{b}	42.44 ^{b}	57.93 ^{a}	13.13	12.03 ^{a}	0.744 ^{a}	17.83 ^{a}	30.30	29.68 ^{a}	40.99 ^{b}
Yes			50.44 ^{b}	12.67 ^{a}	14.31 ^{a}	0.85 ^{b}	19.13 ^{a}	51.16 ^{a}	40.52 ^{a}	48.23 ^{a}	56.06 ^{b}	13.02	11.02 ^{b}	0.702 ^{b}	17.07 ^{b}	38.31	28.09 ^{b}	42.45 ^{a}
SEM			0.270	0.148	0.180	0.009	0.167	0.368	0.355	0.228	0.152	0.179	0.155	0.010	0.155	0.389	0.397	0.135
***p* value**			<0.000	<0.000	<0.000	0.001	<0.000	<0.000	<0.000	<0.000	<0.000	0.657	<0.000	0.008	0.002	0.082	0.008	<0.000

SC—*Saccharomyces cerevisiae*, g/kg feed; RM—*Rhodotorula mucilaginosa* 0/0.3 kg/t of feed; *L**—meat brightness, *a**—meat redness, *b**—meat yellowness, *h*—meat hue; *C*—meat chroma; BI—meat browning index; YI—meat yellowing index; ΔE—meat total color difference; SEM—standard error mean; SC × RM—interaction between the dietary supplements; ^{ab} Columns means with different superscripts differ significantly at $p < 0.05$.

3.4. Texture Profile Analysis

The broiler breast and thigh meat texture profiles analysis are displayed in the Tables 6 and 7. In this study, the broiler breast and thigh meat texture profiles were not affected by the SC ($p > 0.05$) nor the RM dietary supplementation ($p > 0.05$). Similar results for hardness, adhesiveness, chewiness, cohesiveness, springiness, gumminess, and resilience were found on all experimental groups (1–8).

Table 6. Yeasts supplemented broilers' breast meat texture profile.

Group	SC	RM	Hard	Adhe	Cohe	Spri	Gumm	Chew	Resi
1	**0**	**No**	2806.00	0.266	0.260	2.238	729.69	13.27	0.204
2	**0.6**	**No**	2789.20	0.264	0.238	2.280	665.52	12.10	0.186
3	**1**	**No**	2721.00	0.266	0.266	2.392	724.54	13.17	0.203
4	**1.3**	**No**	2720.60	0.278	0.262	2.216	711.07	12.93	0.199
5	**0**	**Yes**	2779.40	0.264	0.240	2.390	667.35	12.34	0.187
6	**0.6**	**Yes**	2758.80	0.266	0.256	2.194	709.41	12.90	0.198
7	**1**	**Yes**	2709.40	0.270	0.252	2.268	683.92	12.44	0.191
8	**1.3**	**Yes**	2709.60	0.280	0.236	2.316	635.26	11.55	0.178
SEM			82.146	0.010	0.012	0.074	39.473	0.718	0.011
***p* value**			0.999	0.992	0.279	0.186	0.439	0.439	0.439
Main effect—SC levels									
0			2792.70	0.265	0.250	2.314	698.52	12.70	0.195
0.6			2774.00	0.270	0.247	2.237	687.47	12.50	0.192
1			2715.20	0.268	0.259	2.330	704.23	12.80	0.197
1.3			2714.90	0.279	0.249	2.266	673.16	12.24	0.188
SEM			58.086	0.007	0.008	0.052	27.911	0.507	0.008
***p* value**			0.700	0.467	0.759	0.571	0.867	0.867	0.867
Main effect—RM addition									
No			2759.10	0.269	0.257	2.28	707.71	12.87	0.20
Yes			2739.30	0.270	0.246	2.29	673.98	12.25	0.19
SEM			41.073	0.005	0.006	0.037	19.98	0.359	0.006
***p* value**			0.735	0.835	0.225	0.841	0.236	0.236	0.236

SC—*Sacchharomyces cerevisiae*, g/kg feed; RM—*Rhodotorula mucilaginosa*, 0/0.3 kg/t of feed; SEM—standard error mean; SC × RM—interaction between the dietary supplements; Adhe—adhesiveness; Cohe—cohesiveness; Spri—springiness; Gumm—gumminess; Chew—chewiness; Resi—resilience;

Table 7. Yeasts supplemented broilers' thigh meat texture profile.

Group	SC	RM	Hard	Adhe	Cohe	Spri	Gumm	Chew	Resi
1	**0**	**No**	4124.82	0.458	0.335	2.563	1732.19	30.36	0.209
2	**0.6**	**No**	4189.36	0.444	0.307	2.611	1620.02	28.40	0.196
3	**1**	**No**	3953.39	0.434	0.343	2.739	1713.82	30.04	0.207
4	**1.3**	**No**	3915.09	0.492	0.338	2.537	1668.12	29.24	0.202
5	**0**	**Yes**	4022.42	0.463	0.310	2.737	1573.22	27.58	0.190
6	**0.6**	**Yes**	4264.88	0.414	0.330	2.512	1775.92	31.13	0.215
7	**1**	**Yes**	4108.10	0.438	0.325	2.597	1677.89	29.41	0.203
8	**1.3**	**Yes**	4119.53	0.468	0.304	2.652	1565.94	27.45	0.189
SEM			246.213	0.038	0.015	0.084	99.064	1.736	0.012
***p* value**			0.929	0.945	0.279	0.186	0.425	0.425	0.425

Table 7. *Cont.*

Group	SC	RM	Hard	Adhe	Cohe	Spri	Gumm	Chew	Resi
Main effect—SC levels									
0			4073.62	0.460	0.323	2.650	1652.71	28.97	0.200
0.6			4227.12	0.429	0.319	2.561	1697.97	29.76	0.205
1			4030.75	0.436	0.334	2.668	1695.86	29.73	0.205
1.3			4017.31	0.480	0.321	2.595	1617.03	28.34	0.195
SEM			174.099	0.027	0.011	0.060	70.049	1.228	0.008
***p* value**			0.821	0.533	0.759	0.571	0.822	0.822	0.822
Main effect—RM addition									
No			4045.66	0.457	0.331	2.612	1683.54	29.51	0.204
Yes			4128.73	0.446	0.317	2.624	1648.23	28.89	0.199
SEM			123.107	0.019	0.008	0.042	49.532	0.868	0.006
***p* value**			0.637	0.685	0.255	0.841	0.618	0.618	0.618

SC—*Saccharomyces cerevisiae*, g/kg feed; RM—*Rhodotorula mucilaginosa*, 0/0.3 kg/t of feed; SEM—standard error mean; SC × RM—interaction between the dietary supplements; Adhe—adhesiveness; Cohe—cohesiveness; Spri—springiness; Gumm—gumminess; Chew—chewiness; Resi—resilience;

No considerable interaction (SC × RM) was observed on the broiler breast or thigh meat texture profile.

3.5. Sensorial Evaluation

The dietary yeast supplemented broiler breast and thigh raw meat sensorial evaluation is presented in Figure 1.

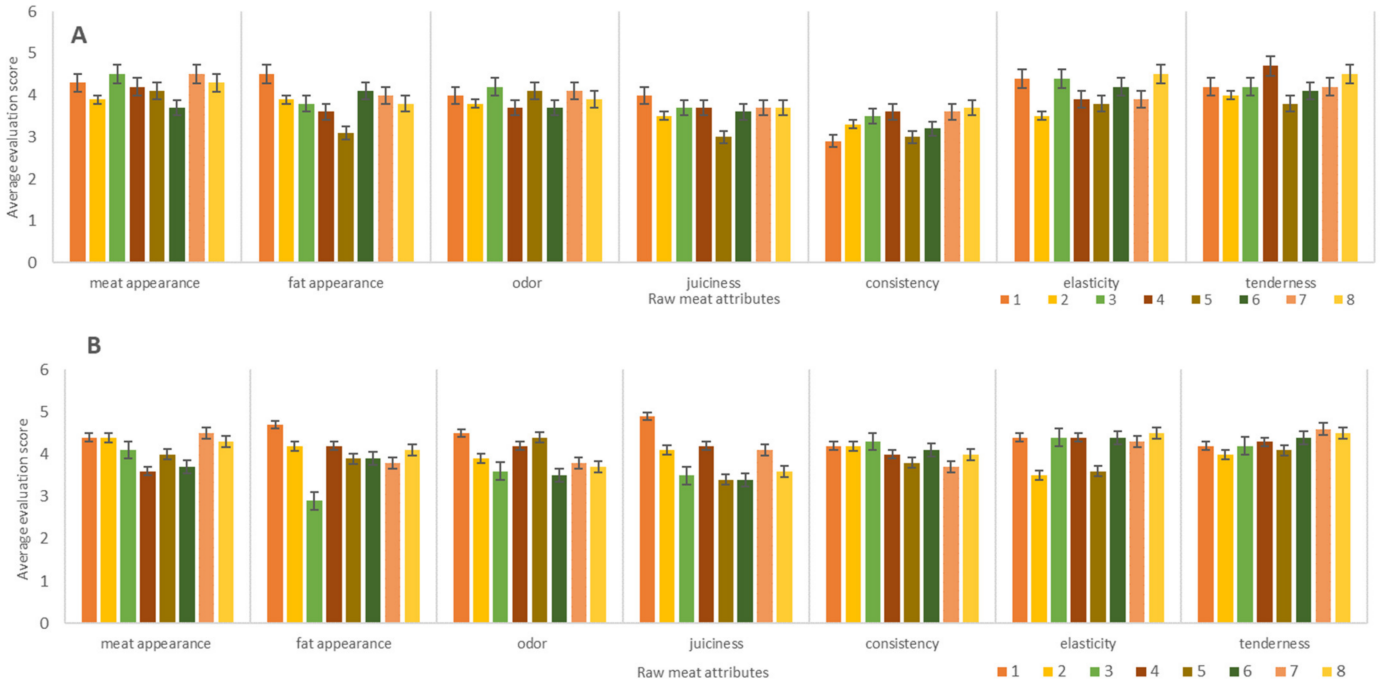


Figure 1. Yeasts supplemented broiler's breast (**A**) and thigh (**B**) meat sensorial attributes. 1—Negative control group–fed with basal diet (Corn-soybean meal); 2—Basal diet + SC 0.6 g/kg feed; 3—Basal diet + SC 1.0 g/kg feed; 4—Basal diet + SC 1.3 g/kg feed; 5—Positive control group–fed with basal diet (Corn-soybean meal) + RM (0.3 kg/t feed); 6—Basal diet + SC 0.6 g/kg feed + RM (0.3 kg/t feed); 7—Basal diet + SC 1.0 g/kg feed + RM (0.3 kg/t of feed); 8—Basal diet + SC 1.3 g/kg feed + RM (0.3 kg/t feed).

Compared with the control, similar values for the broiler breast meat appearance and odor were obtained. Significant differences ($p < 0.05$) were shown for the broilers' raw breast meat fat appearance, consistency, juiciness, elasticity, and tenderness. The highest evaluation fat appearance score was found in the control group, and the lowest in the experimental group five (RM positive control). The same trend was observed for the meat juiciness attribute. Meat consistency was found to be influenced by the dietary SC linear increasement (0, 0.6, 1, and 1.3 g/kg feed), showing a direct influence on the evaluation average score, having the lowest values in the control groups (one and five), and the highest in groups four and eight. Similar score evaluation was found in the broiler thigh meat appearance, consistency, elasticity, and meat tenderness. Although, fat appearance, odor, and juiciness were significantly influenced by the dietary SC supplementation.

3.6. Correlations and Principal Component Analysis

The Principal Component Analysis bi-plot (Figure 2) revealed the relationships between the studied variables and the samples. A total of 85.06% of the data variance was explained by the two principal components: 67.87% being attributed to the first component (PC1) and 17.19% to the second one (PC2). The first component, PC1, was associated with the chemical composition parameters (moisture, protein, fat, collagen content), texture parameters (springiness, adhesiveness, hardness, gumminess, chewiness, and cohesiveness) and some color parameters (b^*, YI, h). The second component, PC2, was associated with pH, resilience, a^* and C. As it can be seen in Figure 2, the breast samples were clustered on the left quadrants of the graphic, while the thigh samples were grouped on the right side. Significant correlations at $p < 0.05$ can be observed between some of the characteristics (Table 8, Figure 2).

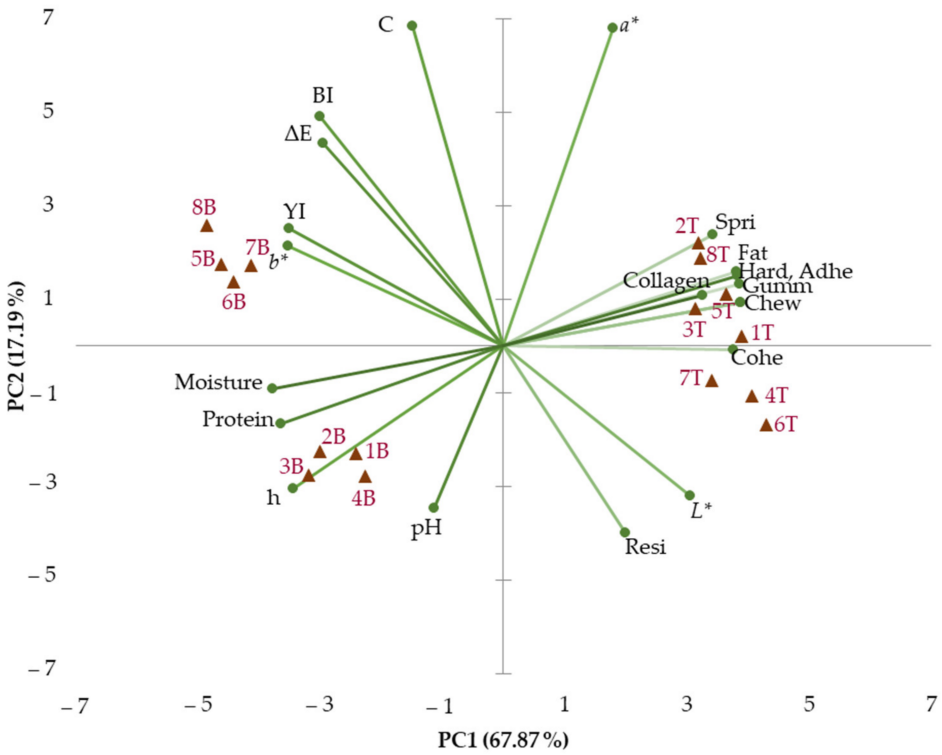


Figure 2. Principal Component Analysis bi-plot: red triangles represent the chicken groups (B—breast (1–8 groups), T—thigh (1–8 groups)) and green dots represent the variables; Adhe—adhesiveness, Cohe—cohesiveness, Spri—springiness, Gumm—gumminess, Chew—chewiness, Resi—resilience, L^*, a^*, b^*—color parameters.

Table 8. Pearson correlations coefficients.

Variables	Hard	Adhe	Cohe	Spri	Gumm	Chew	Resi	*L**	*a**	*b**	*h*	*C*	BI	YI	ΔE	pH	Prot	Fat	Moist	Coll
Hard	**1.00**																			
Adhe	**0.96**	**1.00**																		
Cohe	**0.92**	**0.92**	**1.00**																	
Spri	**0.89**	**0.90**	**0.83**	**1.00**																
Gumm	**0.99**	**0.97**	**0.97**	**0.88**	**1.00**															
Chew	**0.99**	**0.97**	**0.97**	**0.88**	**0.99**	**1.00**														
Resi	0.44	0.35	**0.66**	0.23	**0.52**	**0.52**	**1.00**													
*L**	**0.65**	**0.66**	**0.70**	**0.60**	**0.67**	**0.67**	0.46	**1.00**												
*a**	**0.59**	**0.59**	0.41	**0.63**	**0.54**	**0.54**	−0.20	0.06	**1.00**											
*B**	**−0.84**	**−0.79**	**−0.77**	**−0.65**	**−0.82**	**−0.82**	−0.47	**−0.76**	−0.18	**1.00**										
h	**−0.93**	**−0.89**	**−0.76**	**−0.82**	**−0.89**	**−0.89**	−0.18	**−0.51**	**−0.76**	**0.77**	**1.00**									
C	−0.23	−0.19	−0.32	−0.04	−0.25	−0.26	**−0.54**	**−0.56**	**0.61**	**0.67**	0.05	**1.00**								
BI	**−0.63**	**−0.60**	**−0.68**	−0.45	**−0.65**	**−0.65**	**−0.63**	**−0.88**	0.18	**0.87**	0.44	**0.83**	**1.00**							
YI	**−0.82**	**−0.77**	**−0.78**	**−0.68**	**−0.81**	**−0.82**	**−0.52**	**−0.76**	−0.11	**0.95**	**0.69**	**0.68**	**0.88**	**1.00**						
ΔE	**−0.61**	**−0.61**	**−0.71**	−0.46	**−0.65**	**−0.65**	**−0.64**	**−0.89**	0.11	**0.74**	0.39	**0.68**	**0.95**	**0.78**	**1.00**					
pH	−0.35	−0.32	−0.23	−0.27	−0.32	−0.32	−0.01	0.07	−0.49	0.21	0.46	−0.20	0.03	0.19	0.06	**1.00**				
Prot	**−0.92**	**−0.95**	**−0.87**	**−0.84**	**−0.92**	**−0.92**	−0.32	**−0.63**	**−0.59**	**0.74**	**0.87**	0.15	**0.55**	**0.71**	**0.57**	0.19	**1.00**			
Fat	**0.98**	**0.97**	**0.93**	**0.89**	**0.98**	**0.98**	0.43	**0.62**	**0.59**	**−0.83**	**−0.92**	−0.23	**−0.61**	**−0.81**	**−0.58**	−0.42	**−0.90**	**1.00**		
Moist	**−0.94**	**−0.95**	**−0.89**	**−0.89**	**−0.94**	**−0.94**	−0.37	**−0.70**	**−0.51**	**0.83**	**0.86**	0.29	**0.66**	**0.82**	**0.65**	0.44	**0.86**	**−0.96**	**1.00**	
Coll	**0.80**	**0.88**	**0.79**	**0.74**	**0.81**	**0.81**	0.25	**0.63**	0.49	**−0.61**	**−0.71**	−0.13	**−0.52**	**−0.62**	**−0.58**	0.01	**−0.94**	**0.76**	**−0.73**	**1.00**

Values in bold are significant at $p < 0.05$, Adhe—adhesiveness, Cohe—cohesiveness, Spri—springiness, Gumm–gumminess, Chew—chewiness, Resi—resilience, Prot—protein, Mois—moisture, Coll—collagen content, *L**—meat brightness, *a**—meat redness, *b**—meat yellowness, *h*–meat hue; *C*—meat chroma; BI—meat browning index; YI—meat yellowing index; ΔE—meat total color difference.

The color parameters L^*, a^*, b^*, h, BI, YI, and ΔE exhibited some significant correlations ($p < 0.05$) with the texture parameters such as adhesiveness, cohesiveness, springiness, gumminess, and chewiness (Table 8).

The chemical composition showed significant correlations ($p < 0.05$) with the texture parameters, except for resilience, and with the color parameters, except for C and a^* which were not correlated with collagen content. In addition, some significant relationships ($p < 0.05$) can be observed between the chemical components of the groups (Table 8).

4. Discussion

No research appears to have been reported on the effect of inactive *Rhodotorula mucilaginosa* biomass supplementation on broilers' carcass yield and meat quality. Furthermore, our study's aim could be considered as a novel applied investigation subject, providing new insights on valuable microbial pigment additives usage in poultry nutrition.

In this study, the yeasts dietary supplementation affected the gizzard weight and the abdominal fat deposits of broiler chicks. Gizzard weight was significantly influenced by the highest level of SC supplementation (1.3 g/kg feed), when compared with all experimental groups. Lower abdominal fat deposits were observed by increasing the level of SC dietary supplementation (up to 1.3 g/kg diet). Similar to our findings, Paryad's results [17] suggest that supplementing different levels of SC dietary supplements significantly affects the broiler chicks' gizzard weights and abdominal fat accumulations. Relying on our previous results [18], a possible explanation could be attributed to the SC growth promotive effect, having a direct correlation between the final live body weight and the abdominal fat deposits, rather than lipogenic modulative effects, having no correlation with the broilers' serum triglycerides nor with their serum cholesterol.

In our study, pH was not influenced by the inactive yeasts dietary supplementation. The raw broiler meat pH mean values ranged for raw breast (5.97–6.02) and thigh (5.91–6.02) and fitted in the 24 h raw refrigerated broiler's meat normal range of values [31,32] without abnormality encounters such as pale soft exudative and wooden-like meat characteristics. Generally, the meat pH is an important quality indicator, firmly associated with slaughtering, meat processing, and storage management. In addition, meat pH is strongly correlated with color and appearance attributes [19], indicating the main meat quality characteristics and abnormalities. It is known that darker breast meat is related to high pH values [20,32].

Color is an important meat attribute since it is directly influencing the consumer's perception, often associated with meat freshness [33] and rearing nutritional conditions [34]. Results obtained on this work suggest that dietary supplementation of SC increases the meat brightness and total color differences ($p < 0.05$), causing the meat's visual appearance to shift to a paler nuance, when compared with the control group. In accordance with our findings, Hou et al. [35] found that yeast dietary supplementation increases the broiler meat lightness (L^*). However, a recent study [36] reports that live *Saccharomyces sp*. supplementation decreases effects on the lightness (L^*) and yellowness (b^*) attributes, and increases the broiler chickens meat redness (a^*). Moreover, red yeast (RM) dietary supplementation had a major influence on the broiler meat color parameters. Previous studies confirm our results [37,38], indicating significant effects of red yeast administration on broiler's meat brightness (L^*) and pronounced redness nuance (a^*). A brief explanation for the opposite effect and the color variations in this study concerning the RM dietary supplement on the broiler breast and thigh meat brightness could be attributed to the RM carotenoid complex, mainly constituted by the xanthophylls (torularhodin) and less carotenoids (β-carotene) [39], which has a greater pigmentation capacity [40], thus, directing the broiler carotenoid metabolism towards retinol accumulation via β-carotene conversion and extending the flesh and skin xanthophylls deposits [35]. The broiler meat color was significantly influenced by both SC and RM supplementation, presenting an interaction ($p < 0.05$) with the thigh meat L^*, a^*, b^*, C, BI, YI, and ΔE. The broiler thigh meat lightness, redness, chroma, and total color values were increased, while the yellowness, yellow index, and browning index were decreased, when comparing all experimental groups.

Furthermore, the raw broiler meat is strongly correlated with physical-chemical characteristics and meat functional properties, depending on the post-slaughtering treatments [9] and sarcoplasmic myoglobin content [40,41].

The chemical proximate analysis (total protein, fat, moisture, and collagen) was significantly influenced by the dietary supplementation. The broiler breast and thigh meat moisture were significantly higher on the experimental groups supplemented with SC (0, 0.6, and 1 g/kg feed). The highest values of moisture and fat content could be attributed to the growth promoting effect of SC and correlated with the final live body weight. The lowest fat content was observed in the 1.3 g/kg diet supplemented group, indicating that a higher supplementation dosage of SC might not only influence the final body weight but also the meat fat content. It is postulated that higher levels of SC administration could negatively influence the growth performance and the meat quality, due to the high levels of nucleic acids, disturbing the protein metabolism.

Supplementing the experimental broiler diets with high protein sources (SC) significantly decreased the meat protein content, when compared with the negative control group ($p < 0.05$). Opposite to our findings, Hou et al.'s [35] results indicate that the dietary supplementation of live SC could positively modulate the meat protein content. A possible explanation could be connected with the SC amino acids content, which has higher levels of lysine, leucine, and methionine [42], and lower cystine levels [43], when compared with the soybean meal. In broiler diets, the most important and expensive component is the protein source, and it is known that the ideal vegetal resource is soybean meal, having all essential amino acids, especially those that birds need the most: sulphuric amino acids lysine, methionine and cystine [44].

Meat collagen is an important attribute for broiler meat quality and it is the main abundant protein in the broiler chicks' connecting tissues and body [45], and directly contributes to the meat tenderness and gumminess [46]. In our study, the results show that dietary SC supplementation (0.6, 1, and 1.3 g/kg diet) on broiler chicks' diets significantly increases the meat collagen, when compared with the negative control group. Lysine, glycine, and proline are the major amino acid constituents in the collagen [47]. We strongly believe that the SC dietary supplementation influenced the meat collagen synthesis, due to the supplementary levels of lysine and proline, enhancing the hydroxyproline and hydroxylysine accumulation, thus the collagen formation.

The RM dietary supplementation had significantly increased the broiler breast meat moisture and fat content, when compared with the negative and positive control groups ($p < 0.05$). There is a deficit of information regarding the chemical proximate composition of the broiler chicks' diet supplemented with inactive RM, and indeed, with lyophilizate lysates pigment yeasts. To the best of our knowledge, this is the first study about the effects of dietary RM supplementation on broiler chicks' meat quality attributes and carcass yields. Therefore, future studies are needed to determine the effects of inactive yeasts dietary supplementation on broiler metabolism, thus the meat proximate chemical composition.

Meat textural profile analysis is generally associated with meat processing proprieties [48] and consumer eating satisfaction [26]. This current study revealed similar textural properties ($p > 0.05$) for all broilers' breast and thigh meat samples. All the texture parameters were highly correlated with each other ($0.83 < r < 0.99$, $p < 0.05$), except for resilience which was correlated significantly only with cohesiveness, gumminess, and chewiness ($0.52 < r < 0.66$, $p < 0.05$). Moreover, meat textural profile analysis and sensorial correlation could not be appropriate for evaluation, considering the fact that the mechanical force applied differs and could not be an exact replica of the consumer's compressive experience.

Significant differences were recorded for broilers' raw breast meat fat appearance, consistency, juiciness, elasticity, and tenderness. The opposite trend was observed for fat appearance and juiciness meat attributes, that were significantly decreased when compared with the control groups. In discordance with our results, recent investigations [27,28] indicate that live yeast culture (*SC*) supplementation significantly increased the sensorial broiler tenderness and juiciness and odor meat attributes. The meat fat appearance score

was decreased, when compared with the negative control group. The meat fat appearance was influenced by the RM dietary supplement, with the positive control group in thigh meat samples having the lowest score. On combining these results with the RM significant effect on the color parameter a^* (responsible for red–green spectra), it could be concluded that the meat's fat appearance was influenced, inducing a darker nuance. It is very likely that xanthophylls present in the RM dietary supplement were very quickly metabolized, and deposited in the body fat, due to the fact that carotenoids mainly conjugate with fatty acids and esters, forming chylomicrons [49,50].

The meat tenderness, elasticity, and consistency are directly related to the meat collagen content. The dietary yeasts supplemented groups were more appreciated in the consumer's preference score than in the control groups, indicating a positive modulative effect of yeasts dietary supplementation on the consumer's perception. Similar to our findings, Ma et al. [51] show that supplementing SC could modulate the broiler meat elasticity, gumminess, and tenderness. In meat sensorial attributes, juiciness is generally correlated with the meat moisture content, but also could be influenced by the meat cutting processes. In our study, the juiciest meat score was obtained from the negative control group (1), with the interpretation as least juicy from the experimental group who received inactive yeast supplements (2–8). In discordance with our results, there could be a positive effect of administrating inactive SC on broiler cooked meat quality, due to the fact that SC possesses 5′-guanosine monophosphate and 5′-inosine monophosphate enzymatic nucleases [52], that might be appropriate as flavor enhancers, featuring the supposed umami taste.

5. Conclusions

This current paper indicated that inactive yeasts SC and RM are valuable nutritional supplements for broilers, in physical and mechanical meat attributes. In addition, bivalent yeast supplementation could synergically enhance meat quality attributes and might positively modulate the consumer's preference, increasing meat moisture, lightness, redness, and decreasing the browning index. Furthermore, based on the sensorial meat texture, elasticity, consistency attributes, and collagen content we validate our dietary yeasts supplements as possible alternatives for feed additives, having both growth promoting and product quality enhancing benefits. Further investigations are required in order to elucidate the effects of microbial pigment supplements on broiler meat biochemistry and pigment metabolism.

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