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Pectoral angle: a glance at a traditional phenotypic trait in chickens from a new perspective

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Abstract

In meat-type poultry breeding, pectoral angle (PA) is a conventional anatomical indicator for changes in body conformation and meat traits; its correlation to egg performance is however deemed controversial. In this context, we revisited, assessed and put forward evidence for the usefulness of this classic phenotypic variable and its specific integrative index of pectoral angle-to-body weight ratio (PA/BW). Specifically, we identified respective correlations and used them for distinguishing the major categories (production types) of diverse chicken breeds under the traditional classification model (TCM) and genotypic clustering models of the global chicken gene pool subdivision. Also, the usefulness of the supplementary integrative egg mass yield index (EMY) for this objective was demonstrated. Because of estimating the total mass of eggs laid (i.e. egg number times egg weight), EMY can serve as an indicator of egg production. Direct approximation of EMY values by PA and BW values did not lead to significant correlation dependences between these indicators in each of the four breed utility types according to TCM. However, using the ratio of PA to BW, instead of PA and BW alone, resulted in significant correlation of EMY with PA/BW, allowing for distinction between egg-type and non-productive breeds. The validity of the proposed correlation-based models was supported by PCA and Neighbor Joining clustering analyses. Collectively, we suggested that PA can be a potentially correlated trait for selecting hens and roosters in breeding flocks to boost egg yield. These results can also be applied to chicken breeding as well as conservation- and phenome-related research.

Introduction

In chickens (*Gallus gallus* (L.)), breast angle, or pectoral angle (PA), is one of the most commonly scored anatomical and conformational traits used in the selection of meat-type breeds (MTB; e.g. Siegel, 1962a, 1962b, 1963; Siegel and Siegel, 1963; Mishra and Singh, 2011; Softić *et al*., 2011; Das *et al*., 2016; Pandey *et al*., 2018). With defining it as the angle that the height of the keel makes to the chest shape, its investigation has been carried out, as a rule, within single breeds. Although a few dual purpose (DPB; those bred for more than one definite selected performance trait) and native breeds (e.g. Chatterjee *et al*., 2007; Das *et al*., 2014, 2015a, 2015b, 2017) have been looked at, features of PA variability across a wide range of breeds developed by divergently oriented selection and for different purpose of use have not been well considered.

Based on studying lines of New Hampshire (of DPB) fryers, Abplanalp *et al*. (1960) hypothesized that mass selection for breast width would result in a decrease in egg number (EN), while keeping individuals with genotypes of relatively low fitness. Their report, however, offered no concrete evidence to support this assumption. Comparing two lines of White Plymouth Rocks mass selected for PA in divergent directions, no concurrent variations in egg production were discovered (Siegel, 1963), suggesting further investigation of any correlation between PA and egg performance was required. In the following decades, PA, within a set of many other performance and phenotypic characteristics, was often included in breeding and research programmes for meat and dual purpose poultry (e.g. Miguel *et al*., 2008; Mueller *et al*., 2018), as well as in molecular studies of expectable associations of genes (Lei *et al*., 2008; Han *et al*., 2011; Cao *et al*., 2019) and miRNAs (Li *et al*., 2015a, 2015b) with growth and carcass traits.

Due to investigations by Vakhrameev and Makarova (2021) and Vakhrameev *et al.* (2022), PA has just recently come back under serious observation and examination as a single phenotypic variable. As described in more detail by Vakhrameev *et al.* (2022), PA is considered a very important anatomical phenotypic indicator in the poultry industry. Its extreme values, from an obtuse angle, almost 180°, in final broiler crosses to an ultra-sharp one, i.e., 15–20°, are inherent in sick birds with an eloquent characteristic of 'rusks' or 'dried up' birds. In addition, PA characterizes the fullness of the thoracic region with muscles. The muscularity of the thoracic region of a bird can serve as a reliable indicator of the development of general muscles. A bird with well-developed muscles is active and strong, which allows it to reliably get along in a flock and confidently receive food, drink and rest. All this contributes to the formation of an intensive metabolism in the bird's body for the formation of high egg productivity. Thus, one can assume that there should be a biological relationship between PA and egg production rate. Therefore, studying a quantitative significance of this relationship is relevant to the poultry breeding progress and deserves a further research.

In our previous work (Vakhrameev *et al.*, 2022), we suggested that PA, and especially its specific integrative index, i.e. the angle-to-body weight ratio (PA/BW), has a positive relationship with egg productivity, specifically, EN produced during the period of egg laying in egg-type breeds (ETB). At the same time, this correlation decreased and became negative as the selection direction of flocks moved away from the egg type. In those analytical studies, we relied on data from Larkina *et al.* (2021a), who proposed and explored the following four models of the evolutionarily determined subdivision of the global chicken gene pool: traditional classification model (TCM), phenotypic clustering model (PCM) and genotypic clustering models 1 and 2 (GCM1, GCM2). In particular, within TCM, Larkina *et al.* (2021a) described five traditionally accepted classes of chicken breeds '*in terms of productivity and purpose of use, i.e., egg-type breeds (ETBs), meat-type breeds (MTBs), dual purpose breeds (DPBs), game breeds (GBs), and fancy breeds (FBs; also, ornamental or "decorative" breeds)*'. While ETB and MTB are those developed for egg or meat production, egg-meat (EMB) and meat-egg (MEB) breeds, being transitional between ETB and MTB, are two kinds of DPB. They can be classified as either MEB (if meat productivity qualities are the primary goals of selection; Bratishko *et al.*, 2012; Bondarenko and Khvostyk, 2020) or EMB (if egg performance features are the primary targets of selection), despite the fact that their body weight and appearance hardly differ in any significant way (e.g. Khvostyk *et al.*, 2017; Kulibaba *et al.*, 2018 Mueller *et al.*, 2018; Gal'pern *et al.*, 2020; Larkina *et al.*, 2021b).

Clustering patterns of breeds within three other models (PCM, GCM1 and GCM2) showed both similarities and dissimilarities as compared to TCM (Larkina *et al.*, 2021a). Of the four above models, Vakhrameev *et al.* (2022) chose the PCM variant, which, in our opinion, was optimal for such a subdivision of utility types among various chicken breeds. This was because PCM took into account a wide range of phenotypic (productive) traits: EN, egg weight (EW), BW and 13 morphometric parameters (including PA).

However, given the fact that it was not possible to answer unequivocally whether the assignment of breeds to a specific breed type within each model was carried out correctly (Larkina *et al.*, 2021a), one can guess that previous results on the prospective use of PA and PA/BW (Vakhrameev *et al.*, 2022) were only adequate for PCM. In this regard, we aimed here to evaluating the potential for using the PA trait and/or its specific integrative PA/BW index for the other subdivision models of the world chicken gene pool as reported by Larkina *et al.* (2021a). Since one of the aforementioned models, GCM2, did not allow us to assess the degree of belonging to ETB in the studied breed sampling (Larkina *et al.*, 2021a), in the present investigation, we focused on TCM as outlined below and additionally tested GCM1 (see Supplementary Material S1 for further details).

Thus, the purpose of this study was to revisit the PA trait and develop alternative, mathematically justified prerequisites that can be used as integrative indices for breed type-relevant clustering and further possible selection. Based on this, we considered a new mathematical model suitable for establishing an alternative and potential indicator of clustering/selection. As an immediate objective, we set a goal to study the relationship between the value of PA and its modified integrative index, i.e. the PA/BW ratio, on the one hand, and egg performance indicators, i.e. EN and egg mass yield (EMY), on the other, when grouping breeds using the TCM and GCM1 models.

Materials and methods

The main experimental details, methods and original datasets are described elsewhere (Romanov *et al.*, 2021; Vakhrameev and Makarova, 2021; Larkina *et al.*, 2021a; Vakhrameev *et al.*, 2022). Briefly, a total of 759 chickens from 39 breeds were used for collecting and analysing phenotypic (performance) traits: Amrock (Ar), Aurora Blue (AB), Australorp Black (AoB), Australorp Black Speckled (ABS), Bantam Mille Fleur (or Russian Korolyok; BMF), Brahma Buff (BB), Brahma Light (BL), Cochin Bantam (or Pekin Bantam; CB), Faverolles Salmon (FS), Frizzle (F), Hamburg Silver Spangled Dwarf (HSSD), Leghorn Light Brown (or Italian Partridge; LLB), Leningrad Golden-and-gray (LGG), Leningrad Mille Fleur (LMF), Minorca Black (MB), Moscow Game (MG), Naked Neck (NN), New Hampshire (NH), Orloff Mille Fleur (OMF), Pantsirevka Black (PB), Pavlov Spangled (PS), Pavlov White (PW), Pervomai (Pm), Plymouth Rock Barred (PRB), Poland White-crested Black (PWB), Poltava Clay (PC), Pushkin (Pu), Red White-tailed Dwarf (RWD), Rhode Island Red (RIR), Russian Crested (RC), Russian White (RW), Silkie White (SW), Sussex Light (SL), Tsarskoye Selo (Ts), Ukrainian Muffed (or Ushanka; UM), Uzbek Game (or Kulangi; UG), White Cornish × (Brahma Light × Sussex Light) (crossbred; WC × [BL × SL]), Yurlov Crower (YC), Zagorsk Salmon (ZS) (Table 1). All birds came from, and maintained at, the same Russian Research Institute of Farm Animal Genetics and Breeding (RRIFAGB) experimental farm, i.e. the Bioresource Collection (known as the Genetic Collection of Rare and Endangered Chicken Breeds), a subsidiary of the RRIFAGB Center for Collective Use. The evaluation age of birds was 52 weeks (or 1 year). The ratio of females to males in each breed flock was 8♀:1♂. The minimum number of females in each breed was 100. The collected traits encompassed measurements of PA (using a goniometer; Fig. 1) and BW in both males and females at 52-week age. Also, EN from the onset of egg production to 52 weeks of age and mean EW at 52-week age, as well as the integrative index of EMY, which estimates the total mass of eggs laid for the study period (i.e. EN multiplied EW), were used as indicators of egg performance. Another integrative index, previously proposed by us (Vakhrameev *et al.*, 2022) and used in this work, was the specific PA, i.e. the ratio of the angle to body weight of birds (PA/BW).

Table 1. Number of birds and other characteristics of the chicken breeds studied

Breed/population	No. of hens	No. of cocks	PA		BW		EN	EW	EMY	PA/BW		IPI	Breed category number
			hens	cocks	hens	cocks				hens	cocks		
Amrock	16	4	76.64 ± 1.76	78.40 ± 2.66	2.17 ± 0.11	2.61 ± 0.10	162.5 ± 2.5	59.50 ± 0.50	9668.75	35.32	30.04	4.46	2
Aurora Blue	16	4	74.42 ± 1.15	70.40 ± 2.48	2.07 ± 0.07	2.68 ± 0.10	165.0 ± 5.0	57.00 ± 1.00	9405.00	35.95	26.27	4.54	2
Australorp Black	7	2	88.70 ± 1.40	92.80 ± 5.40	2.81 ± 0.07	3.57 ± 0.09	157.5 ± 2.5	59.00 ± 1.00	9292.50	31.57	25.99	3.31	2
Australorp Black Speckled	16	4	79.10 ± 1.20	79.70 ± 1.70	2.78 ± 0.08	3.18 ± 0.14	157.5 ± 2.5	59.00 ± 1.00	9292.50	28.45	25.06	3.34	2
Bantam Mille Fleur	16	4	73.18 ± 1.31	77.75 ± 4.40	0.88 ± 0.03	1.16 ± 0.03	123.5 ± 3.5	47.00 ± 1.00	5804.50	83.16	67.03	6.6	1
Brahma Buff	16	4	70.27 ± 1.34	67.00 ± 2.77	2.21 ± 0.12	2.73 ± 0.11	128.0 ± 3.0	56.00 ± 1.00	7168.00	31.80	24.54	3.24	1
Brahma Light	16	4	71.50 ± 1.14	76.60 ± 3.23	2.18 ± 0.07	2.85 ± 0.11	131.5 ± 1.5	58.00 ± 1.00	7627.00	32.80	26.88	3.5	1
Cochin Bantam	16	4	62.73 ± 0.90	61.60 ± 0.81	0.76 ± 0.02	0.98 ± 0.04	133.0 ± 3.0	57.50 ± 0.50	7647.50	82.54	62.86	10.06	1
Faverolles Salmon	16	4	75.90 ± 1.00	76.70 ± 2.70	2.34 ± 0.11	2.94 ± 0.13	132.5 ± 2.5	57.00 ± 1.00	7552.50	32.44	26.09	3.23	2
Frizzle	16	4	71.70 ± 1.90	73.15 ± 3.57	1.85 ± 0.03	2.74 ± 0.02	127.5 ± 2.5	59.00 ± 1.00	7522.50	38.76	26.70	4.07	1
Hamburg Silver Spangled Dwarf	16	4	75.70 ± 1.10	73.60 ± 1.50	1.16 ± 0.04	1.46 ± 0.08	122.0 ± 2.0	48.50 ± 0.50	5917.00	65.26	50.41	5.1	1
Leghorn Light Brown	16	3	75.90 ± 1.10	76.70 ± 1.90	2.02 ± 0.05	2.79 ± 0.16	166.0 ± 4.0	58.00 ± 0.25	9628.00	37.57	27.49	4.77	4
Leningrad Golden-and-grey	16	4	84.70 ± 1.10	77.20 ± 1.80	2.33 ± 0.07	3.13 ± 0.12	182.5 ± 2.5	59.00 ± 1.00	10 767.50	36.35	24.66	4.62	3
Leningrad Mille Fleur	17	4	77.20 ± 1.60	79.60 ± 3.60	2.25 ± 0.06	3.20 ± 0.14	185.0 ± 5.0	61.50 ± 0.50	11 377.50	34.31	24.88	5.06	3
Minorca Black	16	3	79.00 ± 1.10	83.70 ± 0.70	2.57 ± 0.14	2.56 ± 0.15	165.0 ± 5.0	55.50 ± 1.50	9157.50	30.74	32.70	3.56	4
Moscow Game	16	4	76.30 ± 0.90	74.80 ± 2.70	2.94 ± 0.09	3.89 ± 0.17	135 ± 5.0	59.50 ± 1.50	8032.50	25.95	19.23	2.73	1
Naked Neck	16	4	72.00 ± 2.10	77.20 ± 1.90	1.96 ± 0.12	2.78 ± 0.07	127.5 ± 2.5	57.50 ± 0.50	7331.25	36.73	27.77	5.13	2
New Hampshire	16	3	82.70 ± 1.10	80.00 ± 5.00	2.38 ± 0.06	3.24 ± 0.24	205.0 ± 5.0	59.50 ± 0.50	12 197.50	34.75	24.69	3.74	3
Orloff Mille Fleur	16	4	75.60 ± 0.80	76.70 ± 1.80	2.45 ± 0.11	3.40 ± 0.18	132.5 ± 2.5	56.00 ± 1.00	7420.00	30.86	22.56	3.03	1
Pantsirevka Black	14	3	78.80 ± 1.60	80.30 ± 2.80	2.44 ± 0.13	3.01 ± 0.08	165.0 ± 5.0	61.50 ± 0.50	10 147.50	32.30	26.68	4.16	3
Pavlov Spangled	16	4	73.80 ± 1.60	77.80 ± 2.00	1.52 ± 0.07	1.96 ± 0.08	127.5 ± 2.5	52.00 ± 1.00	6630.00	48.55	39.69	4.36	1
Pavlov White	13	2	76.50 ± 1.80	78.20 ± 1.90	1.67 ± 0.05	2.15 ± 0.09	120.5 ± 2.5	48.00 ± 1.00	5784.00	45.81	36.37	3.46	1
Pervomai	16	4	75.40 ± 2.10	79.00 ± 2.00	2.72 ± 0.14	3.29 ± 0.22	152.0 ± 3.0	58.50 ± 0.50	8892.00	27.72	24.01	3.27	2
Plymouth Rock Barred	16	3	77.55 ± 1.16	77.30 ± 0.70	2.46 ± 0.09	3.50 ± 0.07	162.5 ± 2.5	61.50 ± 0.50	9993.75	31.52	22.09	4.06	2
Poland White-crested Black	15	3	71.50 ± 1.50	72.00 ± 1.80	1.60 ± 0.08	2.07 ± 0.05	123.0 ± 3.0	55.00 ± 1.00	6765.00	44.69	34.78	4.23	1
Poltava Clay	14	3	76.09 ± 1.48	79.80 ± 3.40	2.30 ± 0.06	3.69 ± 0.35	142.5 ± 2.5	60.00 ± 1.00	8550.00	33.08	21.63	3.72	2
Pushkin	16	4	81.20 ± 1.50	83.70 ± 3.10	2.50 ± 0.08	3.44 ± 0.11	215.0 ± 5.0	61.50 ± 0.50	13 222.50	32.48	24.33	5.29	3
Red White-tailed Dwarf	15	3	71.25 ± 2.60	64.00 ± 3.70	1.09 ± 0.07	1.36 ± 0.05	162.5 ± 2.5	57.50 ± 0.50	9343.75	65.37	47.06	8.57	2
Rhode Island Red	26	6	86.18 ± 2.08	78.00 ± 1.97	2.35 ± 0.09	2.99 ± 0.09	175.0 ± 5.0	59.50 ± 0.50	10 412.50	36.67	26.09	4.43	3
Russian Crested	16	3	77.90 ± 2.70	84.80 ± 2.80	2.15 ± 0.07	3.04 ± 0.09	151.5 ± 3.5	58.50 ± 1.50	8862.75	36.23	27.89	4.12	1
Russian White	25	5	78.55 ± 2.28	79.60 ± 1.44	1.95 ± 0.07	2.37 ± 0.08	205.0 ± 5.0	55.50 ± 0.50	11 377.50	40.28	33.59	5.83	4

Silkie White	16	3	75.55 ± 2.51	70.20 ± 2.33	0.86 ± 0.03	1.16 ± 0.07	81.5 ± 1.5	39.00 ± 1.00	3178.50	87.85	60.52	3.7	1
Sussex Light	16	4	82.67 ± 2.11	79.00 ± 5.29	2.54 ± 0.10	2.83 ± 0.15	157.5 ± 2.5	60.00 ± 1.00	9450.00	32.55	27.92	3.72	2
Tsarskoye Selo	16	4	83.10 ± 1.30	79.00 ± 1.80	2.38 ± 0.04	3.47 ± 0.09	147.5 ± 2.5	60.50 ± 1.50	8923.75	34.92	22.77	3.75	2
Ukrainian Muffed	15	3	78.80 ± 1.80	77.80 ± 1.40	2.48 ± 0.10	3.83 ± 0.22	102.5 ± 2.5	60.00 ± 1.00	6150.00	31.77	20.31	2.92	1
Uzbek Game	16	3	78.30 ± 1.40	81.70 ± 6.40	2.68 ± 0.10	3.18 ± 0.14	137.5 ± 2.5	57.00 ± 1.00	7837.50	29.22	25.69	2.48	1
White Cornish × (Brahma Light × Susse × Light)	12	2	124.50 ± 2.50	180.00 ± 0.01	5.63 ± 0.19	6.63 ± 0.42	157.5 ± 2.5	59.50 ± 0.50	9371.25	22.11	27.15	1.66	2
Yurlov Crower	16	4	78.40 ± 3.60	87.50 ± 4.50	2.87 ± 0.10	3.62 ± 0.19	137.5 ± 2.5	61.00 ± 1.00	8387.50	27.32	24.17	2.92	2
Zagorsk Salmon	15	2	83.80 ± 1.80	83.00 ± 2.30	2.61 ± 0.10	3.34 ± 0.10	170.0 ± 10.0	58.50 ± 0.50	9945.00	32.11	24.85	3.81	3

PA, pectoral angle; BW, body weight; EN, egg number; EW, egg weight; EMY, egg mass yield; IPI, Narushin's integral performance index (Vakhrameev *et al.*, 2023).

Figure 1. Procedure of a correct PA measurement using a goniometer.

To better match the conducted correlation analysis with the stated goals of the study, all the breeds examined were divided into the following four main categories (production types): non-productive, MEB, EMB and ETB. In addition, we performed the principal component analysis (PCA) for these breed categories and, in parallel, for 39 breeds using interbreed Euclid distances based on their respective mean values of PA/BW and IPI. The latter was a new index lately developed by Vakhrameev *et al.* (2023) to assess the key performance traits in chickens. This index was named here after the study's author Valeriy G. Narushin, who first suggested it, and was calculated using the following respective formula:

$$\mathrm{IPI} = \frac{\mathrm{EMY}}{\mathrm{BW}}$$

where IPI is Narushin's integral performance index, EMY is egg mass yield and BW is a mean female body weight.

PCA plots were generated using the Phantasus web tool (Zenkova *et al.*, 2018), while Neighbor Joining (Saitou and Nei, 1987) trees were retrieved using the online T-REX program (Boc *et al.*, 2012).

Mathematical and statistical analyses and approximations were performed using MS Excel applications as well as the advanced analytics software package STATISTICA 5.5 (StatSoft, Inc./TIBCO, Palo Alto, CA, USA). In particular, statistical calculations were carried out according to the conventional formulae of statistical analysis including computation of mean values, standard deviation (SD) and correlation coefficient. In addition to basic statistics such as mean, SD, etc., correlation analysis was employed using STATISTICA 5.5.

Results

To generalize the analysis of egg performance and conformation scores for females and males corresponding to different types of production and purpose of use, the 39 breeds studied were grouped into four categories: three productive, ETB, EMB and MEB, which were created for utility purposes, and one broad category of 'non-productive breeds'. The latter embraced the breed types of FB and GB that are clearly not meant for poultry meat and/or egg production.

As shown in Fig. 2, the correlation dependence of egg performance on the PA value in females had a slight tendency to increase as it approached ETB selected and used purely for egg production. However, there was an inverse relationship among males. A closer correlation relationship was observed between egg productivity and BW values in both hens and roosters within non-productive and ETB (Fig. 3), although this did not seem to be the case within MEB and ETB. This fact justified the acceptability of using the proposed integrative PA/BW index (Vakhrameev *et al.*, 2022) in the correlation analysis relative to EMY values, the results of which are adduced in Fig. 4. Of note, the correlation values based on PA (Fig. 2) and PA/BW (Fig. 4) when approaching toward ETB were higher in females than in males, with inverse sexual differences in the correlation based on BW (Fig. 3). GCM1 test results, along with related graphs, are presented in Supplementary Material S1. The correlation between egg productivity and PA values fully corresponded to the trend we previously observed for PCM (Vakhrameev *et al.*, 2022).

To assess and analyse the validity of the correlations that served as the basis for plotting graphical dependencies (Figs 2–4), the appropriate correlation coefficients and, accordingly, their significance values were computed and are presented in Table 2.

To verify the above breed distinction models according to the categories (production types), we obtained the PCA plots showing a distinct separation of these categories. This confirmed that the correlation dependences and indices we inferred here for the main egg and meat performance traits were valid and generally reliable. When retrieving clustering patterns for 39 single breeds using PA/BW values in females (Supplementary Fig. S2a, b), these formed a boomerang-like curve. Its right end was composed of five mostly non-productive bantam (dwarf) breeds (SW, BMF, CB, HSSD and RWD) followed by three non-productive FBs (PS, PW and PWB). Further, ETBs (RW, LLB) and EMBs (RIR, LGG, NH and LMF) were localized, being overlapped and intermingled with some MEBs. At the very left end of this boomerang-like curve, there was one MTB (of crossbred chickens) followed by several MEBs (YC, Pm, ABS, PRB, AoB, FS, SL and PC).

Use of the Narushin's IPI indicator resulted in distinguishing the four breed categories (Fig. 5) similarly to the PA/BW-based pattern (Fig. 6a), although the separation of the egg type and egg-meat type was not so obvious. The respective PCA plot (Supplementary Fig. S2c) also showed a boomerang-like curve with a similar arrangement of the 39 breeds at two ends of this curve as was seen in Supplementary Fig. S2a. The Neighbor Joining tree (Supplementary Fig. S2d) had a similar two-branch topology, with each of two major branches having the same breed sets. Thus, the proposed correlation-derived model for distinguishing the four breed categories relative to their production types and based on PA and PA-derived indices was to a larger extent verified by the PCA and Neighbor Joining clustering analyses.

Discussion

The development of the pectoral muscles of a bird is essential for its viability both in the wild and in conditions of keeping on productive farms. The pectoral muscles provide the work of the wings. With wings, the bird carries out flights and maintains

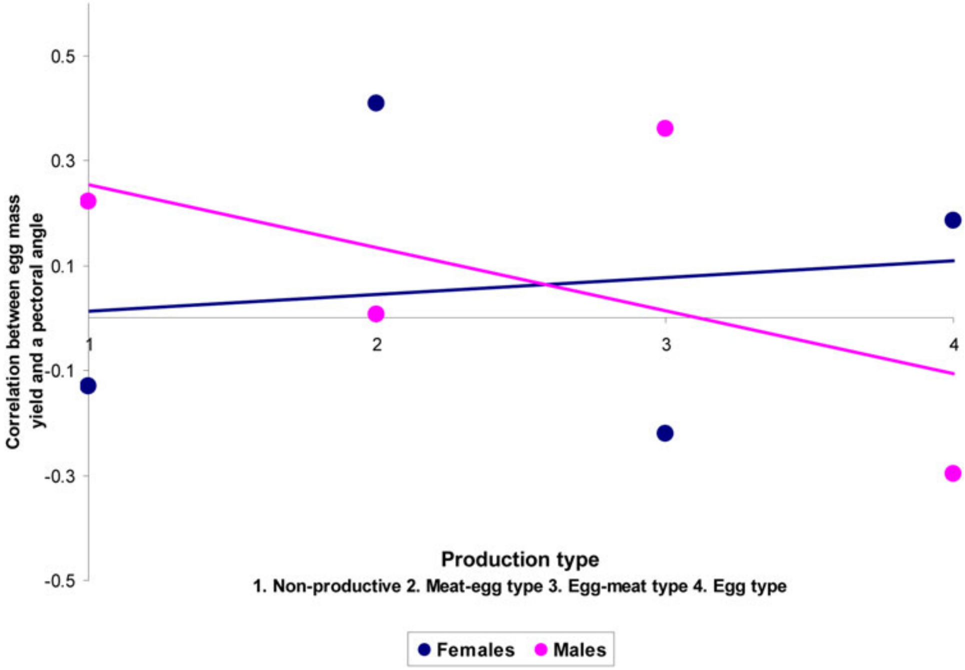

Figure 2. Correlation (EMY = f(PA)) between egg productivity of the breeding flocks and PA values in hens and roosters when grouping the studied breeds according to the traditional classification model. Values at the y-axis conform to coefficients of correlation.

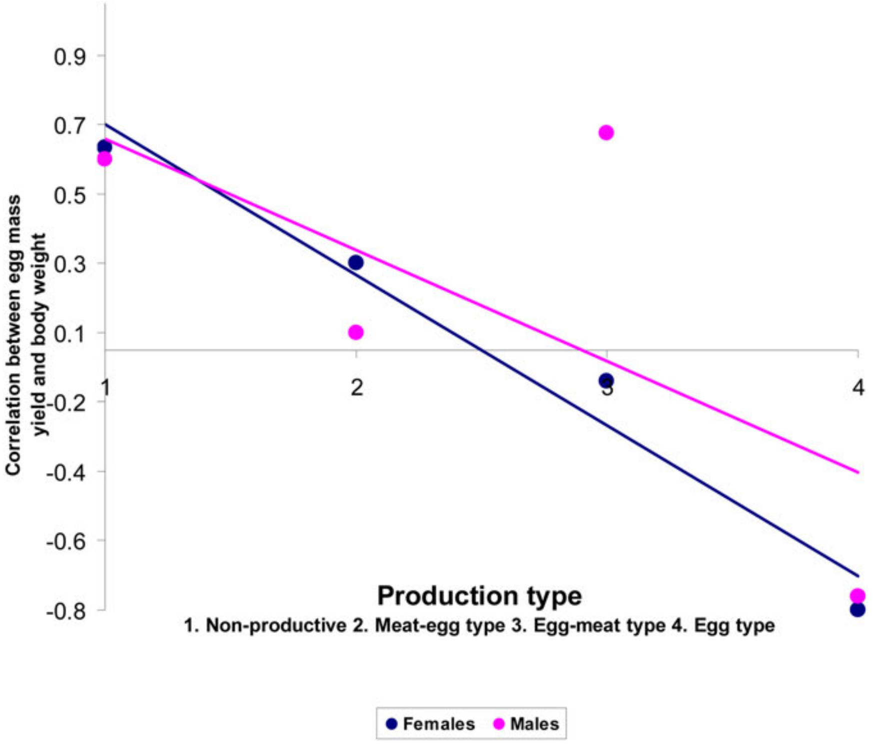

Figure 3. Correlation (EMY = *f*(BW)) between egg productivity of the breeding flocks and body weight of hens and roosters when grouping the studied breeds according to the traditional classification model.

balance. In many birds, wings serve as a defence-attack tool, especially in waterfowl. Thus, we hypothesize that the level of development of the pectoral muscles can serve as an indicator of the viability and general tonus of the bird, which is directly related to reproductive functions, primarily egg production.

It is important to characterize available genetic resources using conventional and new methods for their further breeding and effective utilization (e.g. Moiseyeva *et al.*, 1993; Moiseeva, 1995; Moiseyeva, 1996; Sulimova *et al.*, 2005). As is known from classical works on poultry breeding (e.g. Abplanalp *et al.*, 1960),

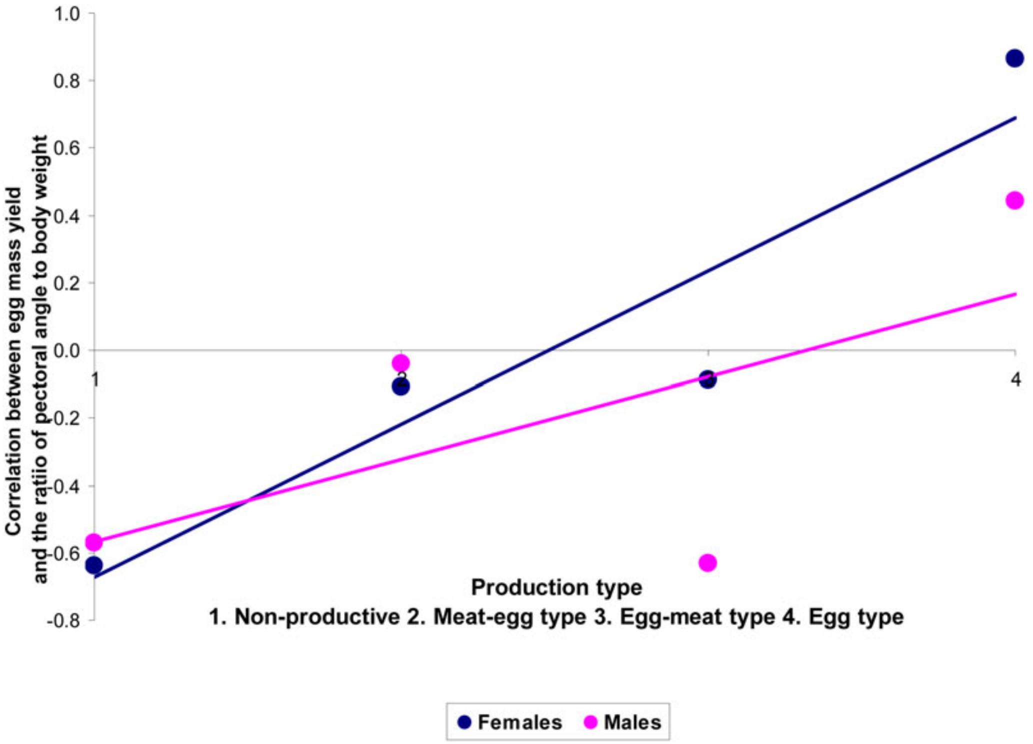

Figure 4. Correlation (EMY = *f*(PA/BW)) between egg productivity of the breeding flocks and value of the specific PA index in hens and roosters when grouping the studied breeds according to the traditional classification model.

Table 2. Values and significance of the correlation coefficients used for plotting the graphical dependencies between egg mass yield (EMY), pectoral angle (PA), body weight (BW) and the PA/BW ratio (as shown in Figs 2–4)

Breed category (production type)	Females	Males
Between EMY and PA (Fig. 2)		
1. Non-productive	−0.130	0.222
2. Meat-egg type	0.409	0.007
3. Egg-meat type	−0.220	0.361
4. Egg type	0.185	−0.297
Between EMY and BW (Fig. 3)		
1. Non-productive	0.584[a]	0.551[a]
2. Meat-egg type	0.250	0.049
3. Egg-meat type	−0.090	0.627[a]
4. Egg type	−0.750	−0.710
Between EMY and PA/BW (Fig. 4)		
1. Non-productive	−0.637[a]	−0.570
2. Meat-egg type	−0.109	−0.039
3. Egg-meat type	−0.086	−0.630[a]
4. Egg type	0.866[a]	0.441[a]

[a] $P < 0.05$; the values without any index are insignificant.

integrative selection indices have been recommended on the basis of statistics and genetics as a way to combine data on several measured phenotypic characteristics into a single selection criterion. In theory, it is anticipated that selection choices based on such integrative indices will result in the greatest genetic gains in terms of presumptive economic values under mass selection (Abplanalp *et al.*, 1960). However, even if the genetic parameters are precisely determined for a given population, it is possible that they will not apply perfectly to subsequent generations of that population/breed or to other populations/breeds that are similar to the population for which they are being used (Abplanalp *et al.*, 1960). Here, we proposed to revisit the conventional phenotypic trait, PA, and introduced two novel integrative indices, EMY and PA/BW, for testing their correlations on a large breed spectrum of the world chicken gene pool grouped by the four major types within two previous classification/clustering models (Larkina *et al.*, 2021a).

The direct approximation of EMY values by PA values did not result in a meaningful correlation dependence respective to the four breed types according to TCM (Fig. 2). However, the use of PA/BW instead of simple PA values led to much more comprehended and convincing correlation changes (Fig. 4). The latter were even more distinct than those obtained by Vakhrameev *et al.* (2022) for the same dependence within PCM. On the other hand, the GCM1-derived results were comparatively similar to the PCM-based correlation pattern (Vakhrameev *et al.*, 2022). Thus, taking into account the results obtained, a comparative assessment of the three models allows us to lean toward TCM in terms of correlation between two integrative indices, EMY and PA/BW.

Interestingly, we observe a higher correlation for ETB females than males when comparing EMY values *v.* PA (Fig. 2) and PA/BW (Fig. 4). This was due to a well-known fact that males and females exhibit sexual dimorphism for PA, with males having noticeably wider breast angles (Siegel, 1962a). It is noteworthy and should be taken into account that not all correlation coefficients were significant (Table 2). This is quite understandable, since we operated with averaged data for each breed type, of which there were not so many in the corresponding productivity categories. The latter fact was one of the criteria in the significance calculation. Nevertheless, even these data made it possible to track the trend of changes in the correlation coefficients for various relationships between performance parameters.

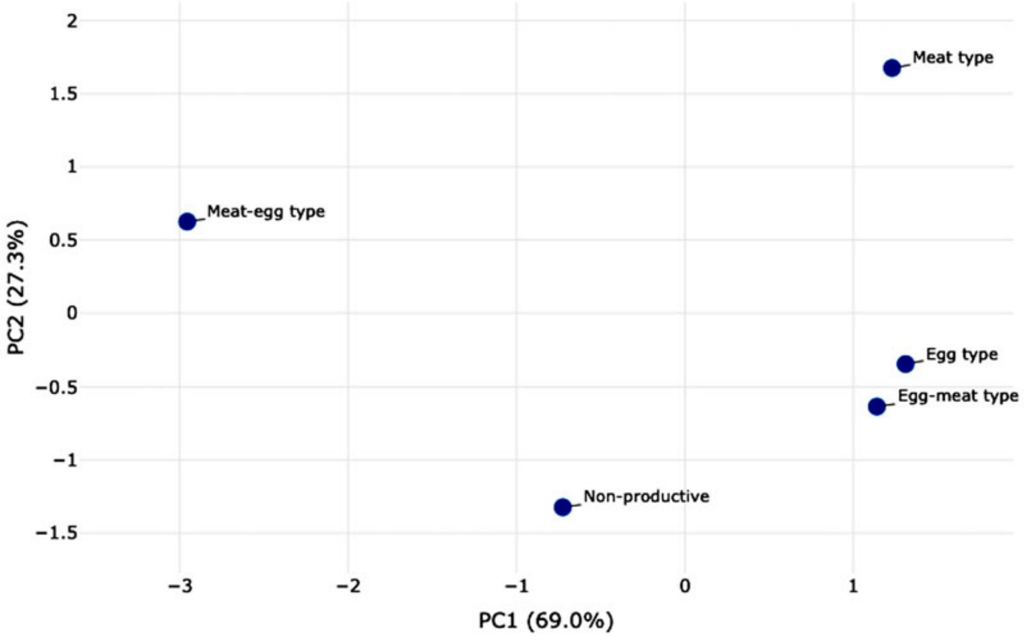

Figure 5. PCA plot for four breed categories using the IPI values in females. Plot composed in the plane of the first (*x*-axis, PC1) and second (*y*-axis, PC2) components.

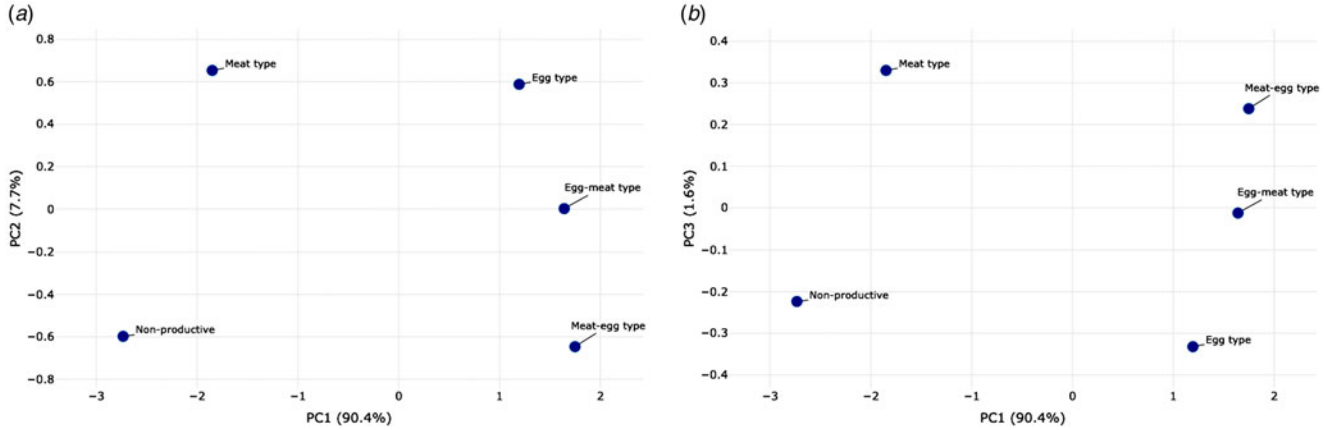

Figure 6. PCA plots for four breed categories using the mean PA/BW values in females. (*a*) Plot composed in the plane of the first (*x*-axis, PC1) and second (*y*-axis, PC2) components. (*b*) Plot drawn in the plane of the first (*x*-axis, PC1) and third (*y*-axis, PC3) components.

The PA heritability ranges from approximately 0.3 to 0.5 (Siegel, 1962a), which is considered to be moderate to high estimates (Siegel, 1963). This makes PA a reasonable target for direct and correlated selection response. In the case of correlated response, the related modification of an unselected trait occurs when artificial selection affects the targeted specific trait (Siegel, 1962b). This associated response may be a result of genetic effects (induced by pleiotropy and linkage), environmental factors or a mix of both (Siegel, 1963). In this respect, we suggest that such a correlated change in PA and/or PA-based integrative index could be expected in response to selection for egg performance traits, especially when using the EMY integrative index. There is another known correlated response example (Szwaczkowski, 2003) where selection for meat traits (including PA) results in a correlated decrease in egg production in MTB. At the same time, selection for egg traits correlates and inversely affects meat traits in ETB. This well-established correlation pattern was confirmed in our experiment (Fig. 3).

Our findings regarding PA, integrative indices and corresponding correlations established with respect to the main phenotypic (productive) traits on a wide sample of the global chicken gene pool will facilitate their worthy application in future research on poultry breeding, conservation and utilization of genetic resources, and phenomics (Bondarenko *et al.*, 1989; Romanov, 1994; Tixier-Boichard *et al.*, 1999; Tagirov *et al.*, 2006; Tereshchenko *et al.*, 2015; Khvostyk *et al.*, 2017; Silva *et al.*, 2021).

Conclusion

In the present study, we revisited and evaluated PA, the traditional anatomical phenotypic trait, and its specific integrative index PA/BW in terms of their applicability for exploring the respective correlations and distinguishing the main types of various divergently selected chicken breeds within two classification/clustering models, TCM and GCM1. An additional integrative egg performance index, EMY, was also shown to be useful for this purpose. Four breed types derived from TCM did not show significant correlations when the EMY values were directly approximated with the PA and BW values. However, substantial correlation values were obtained when PA/BW was used instead of just PA and BW. In comparison to roosters, we observed a greater connection between EMY and PA/BW in hens. This may be attributed to the well-known fact that roosters and hens show sexual dimorphism in PA, with roosters typically having wider PA than hens (Siegel, 1962a). The obtained results can be further used in poultry breeding, conservation-related research and phenome-associated studies.

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Competing interests. None.

Ethical standards. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the Russian Research Institute of Farm Animal Genetics and Breeding – Branch of the L. K. Ernst Federal Research Center for Animal Husbandry (Protocol No. 2020-4 dated 3 March 2020).

Data availability statement. The data presented in this study are available in this article and supplementary material.

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