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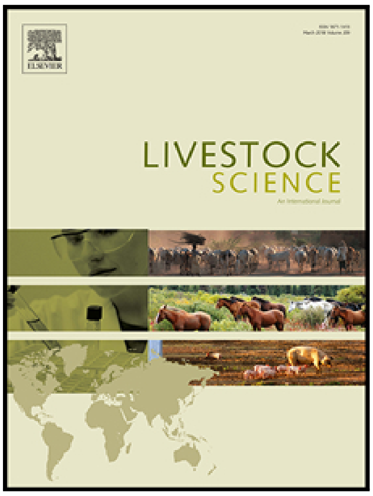

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| Genetics, Animal Genetic Resources and Breeding

Selection-driven chicken phenome and phenomenon of pectoral angle variation across different chicken phenotypes

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Highlights

- Selection-driven chicken phenome embraces varied phenotypes including pectoral angle.
- We studied PA variation across divergently selected chicken breeds.
- Patterns of PA relationship with performance traits were analysed.
- We propose a promising PA-based auxiliary index for using in layer selection.

Abstract

An appreciation of the synergy between genome and phenome of poultry breed is essential for a complete understanding of their biology. Phenotypic traits are shaped under the influence of artificial, production-oriented, selection that often acts contrary to that which would occur during natural selection. In this comparative study, we analysed the phenotypic diversity of 39 chicken breeds and populations that make up a significant part of the world gene pool. Grouping patterns of breeds found within the traditional, phenotypic models of their classification/clustering required in-depth analysis using sophisticated mathematical approaches. As a result of studying performance and conformation phenotypes, a phenomenon of previously underestimated variability in pectoral angle (PA) was revealed. Moreover, patterns of PA relationship with productive traits were analysed. We propose using PA measurement as a promising new auxiliary index for selecting hens and roosters of breeding flocks in egg production improvement programs.

Keywords: phenome, phenotypic traits, pectoral angle, egg production, chicken breeds, gene pool

Introduction

The world poultry gene pool has been formed as a result of long-term processes of domestication and breeding for phenotypic traits. These include economically important traits that make up phenome – the sum total of all phenotypes expressed in a given species (Rexroad et al., 2019). This led to the creation of numerous breeds, often synthetic by origin, that represent valuable genetic resources for the development of contemporary poultry farming, thereby facilitating further selection (Romanov, Bondarenko, 1994a; Romanov et al., 1994; Weigend et al., 2004a; Tagirov et al., 2006; Paronyan, 2016). Poultry breeds and varieties can carry certain mutations that shape a breed (e.g., Moiseyeva et al., 2009a; Corti et al., 2010) or cause abnormal developmental deviations (Bondarenko et al., 1995, 1996); they are characterised by important traits of performance and resistance to diseases (e.g., Dementeva et al., 2017, 2018).

A prominent geneticist Aleksandr S. Serebrovsky (Moiseyeva et al., 2012a,b, 2013; Romanov et al., 2012) drew attention to the importance of studying the gene pools of animals including poultry and, along with Sergey G. Petrov (Moiseyeva et al., 2000) and others, performed studies on the phenogeography of domestic chicken (*Gallus gallus*) populations. Thereafter, collection flocks of poultry breeds were developed (e.g., Bondarenko et al., 1986), one of which was created at the Research Institute of Farm Animal Genetics and Breeding (RIFAGB) (Paronyan et al., 2014; Dementeva et al., 2017, 2018; Dementieva et al., 2018; Romanov et al., 2021). The preservation of gene pools continues to be an urgent problem (Romanov et al., 1994; Wężyk et al., 1994; Wezyk et al., 1994, 1996; Romanov et al., 1995, 1999). Various approaches and methods have been used to assess the degree of diversity and structure of gene pool breeds and populations. Phenetic and phenogeographic studies can provide important primary information about known bird diversity, as has been shown for various gene pool breeds and populations, not only of chickens, but also geese and ducks (Romanov, 1992, 1993, 1994, 1995a,b). In contemporary breeding practices, molecular markers are widely used by geneticists for these purposes, e.g., RAPD, microsatellites, SNPs, etc. (Weigend, Romanov, 1999, 2002; Romanov et al., 1999; Romanov, Weigend, 2001; Weigend et al., 2004b; Dehghanzadeh et al., 2009; Dementeva et al., 2017; Lee et al., 2017; Dementieva et al., 2018).

Phenomics, an emerging area, covers the combined study of the phenome and big data associated with it, including the development of phenome databases, and genome-phenome correlations (e.g., Furbank et al., 2011; Rexroad et al., 2019; Amar et al., 2021; Matalonga et al., 2021; Silva et al., 2021). To some extent, this echoes the earlier discipline of phenetics (Romanov, 1992, 1993, 1994, 1995a,b), but phenomics is a more comprehensive concept and a newer, high throughput research field embodied in new projects such as the Agricultural Genome to Phenome Initiative (AG2PI, 2021). Less attention has been paid to the in-depth study of phenotypic traits in poultry, although their comparative characteristics can provide interesting and important information on the gene pool of various breeds (Larkina et al., 2021; Romanov et al., 2021).

The domestic gene pool of chickens is represented by the older and world–renowned breeds, e.g., the Orloff (Somes, 1988; Moiseyeva et al., 2016), Pavlov (Moiseyeva et al., 2009a; Corti et al., 2010), Yurlov Crower (YC) (Moiseyeva et al., 2007a, 2009b, 2011), Poltava Clay (PC) (Romanov, Bondarenko, 1994b; Moiseyeva et al., 2006, 2007b; Kulibaba et al., 2015) and others, as well as relatively younger breeds, e.g., Russian White (RWG) (Dementeva et al., 2017, 2018; Abdelmanova et al., 2021). Many of these breeds are synthetic, developed using different selection paths, and maintained in the RIFAGB bioresource collection (Paronyan et al., 2014), including the

Orloff Mille Fleur (OMF), two varieties of the restored Pavlov breed (Pavlov Spangled, PS; Pavlov White, PW), YC, PC, and others. They are targeted by conservation, breeding and selection efforts. The collection also contains imported foreign breeds that have specific, sometimes unusual, phenotypic and genetic characteristics, such as the French breed of Faverolles Salmon (FS) and the Chinese breed of Silkie White (SW) (Somes, 1988; Moiseyeva et al., 2009a; Corti et al., 2010). Various breeds and populations of the RIFAGB collection flock include poultry of all utility (purpose) and performance types according to the traditional classification model (TCM) that subdivides the entire chicken breed suite into egg-type breeds (ETB), meat-type breeds (MTB), dual purpose (egg-meat, EMB; and meat-egg breeds, MEB), game breeds (GB) and fancy breeds (FB) (Tables 1 and S1; Bogolyubsky, 1991). All these serve as a valuable resource for genetic and biological research (Paronyan, 2016).

In a previous study (Larkina et al., 2021), we examined models of evolutionarily determined subdivision of the world gene pool of chicken breeds as driven by artificial selection for performance (utility) and other phenotypic traits. The phenotypic clustering model (PCM) postulated by us enabled us to cluster, with sufficient plausibility, the existing RIFAGB collection chicken populations. PCM revealed certain differences from TCM. This facilitated amendment of the earlier concept of four evolutionary lineages in domestic chicken breeding postulated by Moiseyeva et al. (2003) and specified the attribution of the RIFAGB collection populations to one or another category of breeds (Tables S2 and S3). At the same time, we tested a number of phenotypic (exterior) and genotypic parameters that could be used when evaluating individuals in terms of their subsequent selection for increased egg or meat performance. As a result of this investigation (Larkina et al., 2021), it was not possible to identify any phenotypic (conformational) or genotypic indicator that would be directly related to the performance of a breeding flock. In this regard, we feel that it would be worthwhile to take a closer look at certain exterior features of breeder females and males, and their possible relationship with productivity traits.

The issue of the relationship between the observable characteristics of a bird (i.e., its phenome; Rexroad et al., 2019) and its performance is not new. Examination of the exterior of animals in order to determine their breeding value is always an important part of livestock breeding and selection. Examination of the external characteristics provides a general overview of assessing the appearance of a bird. The external characteristics include general conformation, outline and posture of the body and limbs, as well as features of external shape, and the development and structure of separate body elements, i.e., build, plumage, body weight (BW), skin colour, and other specifics of skin and feather covering. Performance traits and features of the exterior and conformation characteristic of birds of various poultry species, breeds and strains are inherited, but are subject to alteration under the influence of selection, feeding, growing conditions of young stock, and other factors (Landauer, 1941; Arzhankova, Ivanova, 2012). In this regard, a key significance of the external assessment is the most accurate understanding of the predisposition of a bird/breed to manifesting expected phenotypic traits. The latter include performance use, constitutional strength, health and fitness of an organism to specific environment conditions, and the overall utility type of an animal for which it is bred, raised and exploited. Thus, by examining the exterior, it is possible to judge, within certain limits, the performance potential of an animal/breed and important breed characteristics. These are correlated with the biological sustainability and adaptability to the environment in which the breed exists, produces and reproduces full-fledged offspring (Borisenko, 1966). Only birds purposefully assessed/selected and harmoniously conforming to each other and the environment are expected to be the most viable and productive.

Furthermore, in terms of the ETB exterior features that can be linked to a higher egg productivity, one should note that the head shape in these breeds is less massive than in MTB, the neck is longer and thinner, while they have a more pronounced comb, indicating a higher hormonal background (Su et al., 2014). Also, ETB have a more developed lower and posterior part of the trunk, where the reproductive organs and the digestive tract are located (Williams, Sharp, 1978), with a characteristic convex breast (Tyasi et al., 2020). In addition, ETB tend to have a more developed tail, especially in roosters, as well as longer legs (He et al., 2019; Valentim et al., 2019). In addition, the following are most often used in ETB as exterior indicators: head shape, comb shape, length and breadth of the neck and back, abdomen volume, shape and plumage of the tail.

Determining the development of muscles in the breast area is of great importance both for breeding and for assessing marketable qualities of meat-type poultry, i.e., broilers, turkeys, geese and ducks (Kochish et al., 2004). These indicators also include breast angle, or pectoral angle (PA), which began to be used in the 1940s as an indicator of meat quality and a characteristic of the pectoral muscle development (Poley et al., 1940; Dolecek et al., 1941; Asmundson, Lerner, 1951). To date, PA continues to be used only in poultry meat production (e.g., Kochish et al., 2004; Miguel et al., 2008; Hou et al., 2013; Li et al., 2015; Mikryukova, 2020), as well as for assessing certain physiological characteristics in some other bird species (Millán et al., 2003; Mougeot et al., 2004; Villanúa et al., 2007; Irvine et al., 2007).

In the present study, we set a goal of assessing phenotypic traits and possible relationships between them, including indicators of egg production and BW, as well as various body measurements. The objects of the study were various chicken breeds and populations from the RIFAGB bioresource collection (Paronyan et al., 2014), phenomes of which have been created and shaped under selection for different breeding characteristics. Furthermore, since conformational indicators, including PA, may have a certain potential for a deeper analysis and subsequent selection, we have searched here for correlations between these indicators and the egg productivity in breed flocks of different performance, utility and phenotypes. Herewith, additional information has been obtained regarding PA as an indicator for discriminating the entire spectrum of chicken breeds and populations studied.

Materials and methods

Ethics statement

All experiments were conducted with an ethical approval of the RIFAGB – Branch of the L. K. Ernst Federal Research Center for Animal Husbandry (Protocol No. 2020-4 dated 3 March 2020). All procedures involving chickens implied no physical harm.

Characteristics of phenotypic features in the studied chicken breeds

To assess the phenotypic diversity, the core of the RIFAGB bioresource collection (Paronyan et al., 2014) was examined including 39 chicken breeds and populations, including synthetic ones, that are kept in floor pens, at a sex ratio of one male to eight females, and fed the complete compound feed PK1-1 (Gatchina Feed Mill). The same environmental conditions were used to maintain all chicken breed flocks. According to TCM, these breeds represent different types of productivity and utility of poultry breeds, i.e., ETB, MTB, dual purpose (EMB and MEB), GB and FB (Bogolyubsky, 1991; Larkina et al., 2021) (Tables 1 and S1). Some of them carry notable mutations at certain chicken genes, e.g., *GHR* in RWD (Burnside et al., 1992) and *Na* in NN (Desta et al., 2021).

Sampling of phenotypic traits

Values of morphometric parameters, including BW and 13 body measurements of 330-day-old hens and roosters, as well as egg number (EN) at 52 weeks of life and EW were collected in the studied breeds and populations in 2016 for all genotypes (Vakhrameev, 2021; Tables 1, S2 and S3). A descriptive and comparative assessment of the variation in these phenotypic traits was carried out using Microsoft Excel. Also, an integral indicator of egg mass yield (EMY) was used as an index of egg productivity, which estimated the total mean weight of eggs per population laid during the study period and, accordingly, was calculated as the product of EW and EN. Usage of the EMY index rather than EN is known to provide better comparisons of flocks and strains of birds in terms of layer production (TNAU, 2020).

The following individual body measurements were sampled with a compass and a tape measure: body length (cm), body slanting length (cm), body and neck length (cm), keel length (cm), chest girth (cm), chest depth (cm), PA (°), distance between shoulder joints (cm), distance between hip joints (cm), femur length (cm), tibia length (cm), shank length (cm), and shank girth (cm). The techniques of taking these measurements, including PA, and their values in various breeds, have been most fully described in our monograph “Exterior Assessment of Chickens” (Vakhrameev et al., 2021). In particular, PA (in degrees) was measured with a special device called a protractor or goniometer (Kochish et al., 2004). This tool was applied perpendicular to the pectoral muscle at a distance of 1 cm from the edge of the sternum keel (Fig. 1; Erigina et al., 2015; Mikryukova, 2020).

When looking for the relationship between the obtained phenotypic parameters and performance data, we proceeded from the grouping of 39 breeds and chicken populations in accordance with TCM and PCM. For a more generalised comparison, we also combined data for those types of breeding flocks that were not subject to targeted selection for increased egg or meat production. These included chickens of FB, GB and Bantam type breeds (BTB).

Mathematical and statistical analyzes

Basic statistical parameters (mean, standard deviation, significance, and correlation coefficients) and graphical dependences for the experimental data obtained as a result of analytical measurements were calculated using standard MS Excel applications.

Mathematical approximation of graphical dependencies was performed using standard MS Excel applications as well as an advanced analytics software package STATISTICA 5.5 (StatSoft, Inc./TIBCO, Palo Alto, CA, USA).

Results and discussion

Overall characteristics of the main phenotypic (performance) traits. As a result of this study, the values of phenotypic traits were obtained for adult birds of both sexes (Tables 1, S2 and S3). Essential variation was observed for BW, 13 main body measurements, 52-week EN, and EW. Overall, the mean BW of females was 2.23 ± 0.80 kg, and that of males 2.89 ± 0.98 kg; the mean EN was 149.55 ± 27.67 eggs, and the mean EW was 57.14 ± 4.60 g (Tables 1, S2 and S3; see also Supporting Info (SI) S1–S4). The greatest linear correlation was found between EN and EW, i.e., at $r = 0.57$ ($p < 0.001$; SI S1). BW correlated significantly with EN, the Pearson correlation coefficient between EN and female BW being 0.31 ($p < 0.001$; SI S2) and that between EN and a sum of male and female BW 0.30 ($p < 0.001$; SI S3), while there was no significant correlation between EN and male BW 0.28 ($p > 0.05$; SI S3). Linear correlation plots for pairs of compared traits EN – EW, EN – female BW, and EN – summed male and female BW are shown in Figs. S1a,b,c. Significant correlation was also observed between EW and BW (0.55–0.62; $p < 0.001$; SI S4).

It is noteworthy that the graphs in Figs. S1a,b,c showed some common patterns in the distribution of breeds and populations. In particular, there was an isolated single position of some populations, e.g., MTB chickens (population that consisted of three-way crossbreds based on WC, i.e., WC × (BL × SL), and bred *inter se*), RWD (a parental strain from a commercial broiler cross), SW, and CB that belong to BTB. On the other hand, formation of fairly stable groupings of closely localised populations can be noted, e.g., LLB, MB and Aurora Blue (AB); Poland White-crested Black (PWB) and two varieties of the newly restored Pavlov breed (PS and PW; Paronyan et al., 2014); Leningrad Golden-and-grey (LGG) and Leningrad Mille Fleur (LMF); Plymouth Rock Barred (PRB) and Pantsirevka Black (PB); RC and Pervomai (Pm); etc. The further characterization of the breeds and populations by phenotypic traits observed using more sophisticated mathematical approaches are discussed in more detail in the section below.

Body measurements with a focus on pectoral angle. We explored the data of conformation indicators (i.e., body measurements) for females and males, corresponding to different types of utility and performance when grouping the studied breeds and populations according to PCM, as presented in Tables S2 and S3, respectively. Since the population WC × (BL × SL) used as an MTB representative in our investigation was an obvious outlier and stood out in terms of the characterised phenotypic traits, we further looked for possible interbreed differences in body measurements for the rest breed groups (i.e., other than MTB). Additionally, we combined FB, BTB and GB into a larger group of non-productive breeds, i.e., non-selected for egg or meat productivity, to see how phenomic features driven by selection could correlate with performance traits.

As shown by the analysis of correlations between egg productivity assessed by EMY, on the one hand, and the exterior traits, on the other, in females of ETB and EMB types, the closest relationship was observed for PA ($r = 0.974$ and 0.909, respectively; $p < 0.01$). Because of that, we decided to focus on this featured indicator in further analysis, and the respective results of the correlation relationship were presented in the form of graphical dependencies (Fig. 2). Herein, we found out some decreasing tendency in the correlation coefficient for females of the MEB type ($r = 0.303$; $p < 0.3$) and breeds that have never been selected for the purpose of increased egg production ($r = –0.406$; $p < 0.25$). This suggested to take a closer look at the indicator of PA, and a similar tendency was observed in males using the same subdivision into productive types.

Since this conformational indicator was developed to assess the meat quality of poultry (Asmundson, Lerner, 1951), we considered it necessary to assess the relationship between PA and BW, both hens and roosters. The results of the assessment are presented in Fig. 3.

To assess the closeness of this relationship and its possible mathematical recalculation for the PA value depending on BW, the obtained linear dependences were approximated by the following formulae:

$$PA_F = 5.272 BW_F + 65.805, \tag{1}$$

$r = 0.612$,

$p < 0.01$;

$$PA_M = 4.633 BW_M + 64.589, \tag{2}$$

$r = 0.608$,

$p < 0.01$;

where the respective subscript 'F' or 'M' was assigned to the characteristics of females and males.

The mathematical model that includes the dependencies (1) and (2) quite accurately describes the relationship between PA and BW of birds within the framework of studying various breeds. Herewith, the correlation estimates were practically the same for both females and males, suggesting that the resulting equations reflect a plausible approximate estimation of these parameters in a breed.

As evidenced by the obtained relationships (1) and (2), these two parameters, PA and BW, are rather closely interrelated with each other, and therefore, the dependencies shown in Fig. 2 could only be explained by the fact that individuals in breeds under egg production-oriented selection are heavier than others. Although the data in Tables S2 and S3 do not confirm this trend, we decided to reduce the influence of the bird's BW to zero, for which we introduced the specific PA indicator (i.e., PA/BW) into the analysis, for which the angle values were divided by the bird's BW.

A similar analysis showed the same trend (Fig. 4) that was obtained for PA alone (Fig. 2), although the values of the correlation coefficients decreased slightly.

Undoubtedly, the specific index PA/BW proposed by us deserved a further closer study, and therefore, we tried to assess variation of egg productivity indicator, EMY, within each of the analysed groups, depending on PA/BW value (Fig. 5).

Next, we also evaluated which indicator of egg production, i.e., mean EN or EW, is more influenced by the PA/BW value. The results by group are presented in Fig. 6.

Additionally, the intra-breed correlation between PA and BW was assessed in our study. The correlation coefficient for males was 0.1–0.2 higher than that for females, i.e., this correlation was at the level of 0.25–0.3 for hens and 0.3–0.4 for roosters. In productive breeds, the correlation was higher than in non- productive ones. In some productive breeds, a very high correlation was found. Particularly, in ZS chickens (43 head in 2017), the correlation between BW and PA was 0.624 (Vakhrameev, Makarova, 2021).

Discussion

Correlation between performance traits

It is well known that EN is negatively, and EW is positively, correlated with BW. However, it should be borne in mind that, as a rule, these correlation estimates are strongly influenced by the estimated population as well as the method used (Szwaczkowski, 2003). Thus, when comparing EN and BW in different populations of layers, the correlation coefficient can vary, e.g., from −0.10 to 0.01 (Anene et al., 2020) to 0.12 (Islam et al., 2013), although these values were insignificant in the given examples. In our study, we found a significant correlation between these indicators at the level of ~0.30 (SI S2 and S3). At the same time, the correlation between BW and EW, according to other authors, can vary from 0.23–0.33 (Haq et al., 2011) to 0.28–0.36 (Anene et al., 2020) and up to 0.67 (Islam et al., 2013). In our current investigation, these indicators correlated within 0.55–0.62 (SI S4). The variation in the correlation between EN and EW can range from –0.03 (an insignificant value; Anene et al., 2020) to 0.42 (Islam et al., 2013), while we observed the correlation of these indicators equal to 0.57 among 39 most diverse chicken breeds and populations (SI S1).

Pectoral angle in breeding and selection

For the most part, in this study, we were interested in examining PA, which is an ambiguous phenotypic indicator. In poultry meat production, PA as measured (in degrees) with a protractor/goniometer is used for assessing the extent of pectoral muscle development in young poultry at slaughter age. This body measurement characterises meat productivity (Mikryukova, 2020), with the heritability coefficient for PA being high ($\boldsymbol{h_a^2}$ = 0.45–0.47; Le Bihan-Duval et al., 1997; Szwaczkowski, 2003). However, there are few analytical articles among current publications regarding various chicken exterior measurements, and we have not come across detailed studies on the PA indicator. Recently, studies on body measurements in poultry were carried out at the Poultry Research and Technological Institute, Sergiyev Posad, Moscow Oblast (Egorova, 2016, 2017, 2018; Egorova et al., 2018; Grishina, Zharkova, 2020), but there were no published data on PA.

It is clear that, in meat poultry production, the level of development of the pectoral muscles is almost the main significant trait for selection. In this regard, there was an interesting example of the breeding of Brwinów synthetic strain of meat-type chickens in Poland obtained as a result of crossing WC that had dominant and recessive white colour with White Leghorns and Rhode Island Reds and further selection for conformation, especially for PA (Somes, 1988). At the same time, it is difficult to deny that the development of the pectoral muscles is an indicator of not only meat content, but also the health of a bird. For instance, due to some diseases the birds can “dry up” and such sick individuals are called “rusks” in veterinary practice. When touching the keel of a bird with completely absent pectoral muscles, it is relatively easy to appreciate this term (Vakhrameev, 2021).

In 2007, at the Department of Poultry, St. Petersburg State Agrarian University, a small research project was conducted to assess chicken body measurements using appropriate tools. Among them, the goniometer was characterised by the department staff as a barely useful tool because there was no clear relationship between PA and productive traits. However, it should be noted that only a small number of birds were sampled in that investigation. This might explain why no clear pattern in various breeds was found (Vakhrameev, 2021). At RIFAGB since 2018, when it was necessary to measure a larger number of birds, only basic measurements (seven in total) and BW were measured; indeed PA was not measured in that study (Vakhrameev, 2021; Vakhrameev, Makarova, 2021). This indicator was included in further studies when a complete set of information on the examined birds was collected (Makarova, Vakhrameev, 2020; Vakhrameev, Makarova, 2021). The correlation of PA with BW studied in our own investigations showed quite predictable results, with a slightly higher correlation coefficient in males than females. This is understandable since roosters grow disproportionately in the breast area, while hens do so in the abdominal area (Vakhrameev, 2021; Vakhrameev, Makarova, 2021).

Thus, it can be stated that PA has been under-studied in terms of the methodological aspects of evaluating the phenotype of layer birds (e.g., Nyalala et al., 2021). However, our analytical assessment of the conformational performance of hens and roosters of breeding flocks and their relationship with egg productivity shows that such an omission is unwise (as discussed in the section below).

Pectoral angle implications in egg-type chickens

There is some benefit in exploring several traits jointly in genetic evaluations. In particular, based on sex-limited characteristics of egg production, information about selected layers is available only after the entire period of their production test, while for selection candidate males it is generally impracticable to obtain directly. Thereby, layer breeding programs may need to account for, and use, indirect indicators from these selection candidates, such as conformation or PA (Besbes, Ducrocq, 2003).

In the general practice of layer breeding, PA, can be considered as an indirect indicator of development of egg producing hens. In other words, the underdevelopment of the pectoral muscles is inferior, but the overdeveloped pectoral muscles seem to detract from a part of the layer vitality. It is difficult to say how much specialists in layer breeding are guided by the PA value. Most often, scoring of hens is carried out by individual inspection of the abdomen, manual measuring of distance between the pubic bones, and subsequent scoring of a layer (Smith, 2015; Vakhrameev, 2021).

The results of our investigation, when grouping the studied breeds and populations (except one MTB population) into four major production-based groups, have shown the effectiveness of the PA trait, which suggests the possible selection of individuals of both sexes when breeding and/or culling in egg-type breeder flocks. Since our investigation was carried out on breeder flocks, we believe that the genetic contribution of males to productive traits is no less important than that of females (as also demonstrated in our previous study; Larkina et al., 2021). As evidenced by the data of the graphical dependencies in Fig. 2, the more the utility/purpose of breeder flocks approaches the egg type, the higher the relationship of PA with egg production.

Similar to MTB (Kochish et al., 2004; Miguel et al., 2008; Mikryukova, 2020), there is a closer correlation between the PA and BW values in both sexes in ETB and non-productive flocks (Fig. 3), which are described by linear dependences (Eqns1,2). In this regard, we suggest using a slightly modified specific indicator, the ratio of PA to BW (i.e., PA/BW). In our opinion, it might more adequately characterise an individual/strain in terms of its potential for the increased EMY. The graphical dependencies in Fig. 4 suggest the validity of this premise.

We obtained very similar data as in the graphs in Fig. 4 when analysing egg productivity (i.e., EMY, or the total weight of eggs laid during the estimated period) using the four types of breeding flocks we considered (Fig. 5). For the ETB and EMB types, there was a corresponding tendency to increase EMY with an increase in PA/BW. However, for the MEB type and especially for non-productive breeds, this tendency changed in the opposite direction. This reaffirms the notion that, in a flock where there has been no breeding for increased egg productivity, PA might not bear any positive information in terms of assessing an individual for its egg laying potential. Nonetheless, the PA usefulness could be more appropriate in flocks, like ETB, selected for egg productivity.

It should be noted that, in the case of chickens that are not classified as the ETB, EMB, MEB or MTB types, a strong selection bias towards ornamental or other special (fancy) traits could lead to an almost complete lack of attention to productive traits and associated body measurements, as suggested by the results of our study.

Our attempts to assess which particular indicator of egg production, EN or EW, depends to a greater extent on the PA/BW index (Fig. 6), demonstrated that in egg-oriented breeding flocks, the correlation with PA/BW is due precisely to the trend towards an increase in EN, not EW. Presumably, this observation can be explained by the fact that in this case the factor of a denser conformation with an overall small BW can play a role as some authors claim (OOO-VetCentr, 2021). This possible reason is also confirmed by other relevant studies, e.g., in managing indigenous chicken genetic resources (Dana et al., 2010) or breeding pheasants (Kırıkçı et al., 2004).

Phenomic studies in chickens

Based on the above studies, we feel that research on phenomics in chickens should be given more attention when implementing measures to preserve the gene pool of various breeds and strains (Romanov, Weigend, 2001; Weigend et al., 2004a). These should embrace those that have been created using different, often contrasting production-oriented, selection paths and include synthetic ones. Particularly, if there is a limited opportunity to apply high throughput molecular genetic methods, measurements of phenotypic traits become few that could be produced (Weigend et al., 2004a,b; Paronyan, 2016; Vakhrameev, 2021). At RIFAGB, a wealth of information has been accumulated regarding body measurements obtained in the bioresource collection in 2007 and 2017, as well as in the last three years, when searching for the indicators of growth rate in the first four months of chicken life (Vakhrameev, 2021). The time has come to analyze the generated phenotypic data and, if possible, associate it with certain indicators of productivity and genotypic variability as undertaken in our recent studies (Larkina et al., 2021; Romanov et al., 2021) and the current research herein presented.

The unconditional interest in phenomic studies and assessment of the conformation in chickens will serve as a good incentive for further work in this direction. In general, view of the state of the art is that, with the advent of powerful techniques in molecular genetics, genomics and computational biology, the possibilities have increased dramatically for elucidating the patterns associated with measurements of the external characteristics and phenomics of chickens as a whole. Undoubtedly, the use of methods for collecting extensive phenotypic data, as well as improved statistical and computational methodologies for the integration of various phenotypic traits (including emerging ones) will contribute to the expansion of selection-driven phenomics research in poultry and the development of new breeding strategies (Silva et al., 2021). Analysis of such phenotypic traits, as undertaken in this study, will facilitate their use as indicators of new traits relevant to the genetic improvement of poultry and livestock populations. This is especially pertinent considering modern and pressing phenotypes of economic and societal significance (Silva et al., 2021).

Conclusions

Within the framework of the pilot phenomic investigation on chickens in previous (Larkina et al., 2021) and current work, we have started the process of evaluating the phenotypic diversity in a wide range of commercial, local and fancy breeds selected for productive and non-productive traits. Many of these breeds are synthetic, and together they constitute a large sample of the global gene pool, the sustainable conservation of which ensures the food security of countries of the world (Zubets et al., 2007; Mel’nyk et al., 2009; Tereshchenko et al., 2015). As a result of our research, we propose a hypothesis that the greater the vector of selection pressure toward egg production among breeds varying from lower to high laying performance, the closer the relationship between their productivity and PA may be. Furthermore, we suggest the ratio of PA to BW as a promising new index for selecting females and males in breeding flocks in order to improve egg production. Models of relationships and clustering by phenotypic traits observed in different breeds and populations need further analysis using more sophisticated mathematical analytical tools. Phenotyping techniques, especially high-throughput ones, demonstrate new potential pathways for genomic dissection of complex traits and genomic improvement in poultry and livestock, with attention to previously known and new selected phenotypes (Silva et al., 2021). The present study exemplifies their potential application, given these promising findings.

Author Contributions

Conceptualization, V.G.N., M.N.R. and A.B.V.; methodology, V.G.N., M.N.R., A.B.V. and Y.S.S.; software, V.G.N. and M.N.R.; validation, A.B.V. and T.A.L.; formal analysis, V.G.N., M.N.R. and A.B.V.; investigation, G.K.P., A.V.M., A.B.V., T.A.L. and O.Y.B.; re-sources, O.I.S., A.B.V., A.V.M. and G.K.P.; data curation, O.I.S., A.B.V., N.V.D., M.V.P., G.K.P. and T.A.L.; writing—original draft preparation, V.G.N., A.B.V., M.N.R., Y.V.B. and A.P.D.; writing—review and editing, V.G.N., M.N.R. and D.K.G.; visualization, V.G.N., M.N.R. and A.B.V.; supervision, T.A.L.; project administration, T.A.L.; funding acquisition, T.A.L. All authors have read and agreed to the published version of the manuscript.

Data statement

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

Supplementary Materials

The following are available online at https://, Fig. S1: Microsoft Excel plots of the correlation dependences of 52-week egg production on egg weight (a), female body weight (b), and summed male and female body weights (c) among the 39 phenotyped chicken breeds/populations. Population codes are given according to Table S1. Egg weight and egg number appear highly correlated (a), unlike a much lower correlation in the case of body weight by egg number (b, c);

Table S1: Thirty-nine chicken breeds, strains and crosses used in the study and listed in accordance with TCM; Table S2: Phenotypic traits in females among the 39 studied chicken gene pool breeds/populations listed in accordance with PCM; Table S3: Phenotypic traits in males among the 39 studied chicken gene pool breeds/populations listed in accordance with PCM; Supporting Information (SI) S1: Statistics and correlations for egg weight and egg number; SI S2: Statistics and correlations for female body weight and egg number; SI S3: Statistics and correlations for male/female body weight and egg number; SI S4: Statistics and correlations for body weight and egg weight.

Declaration of Competing Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Fig. 1. Measurement of pectoral angle in birds of the studied breeds and populations using a goniometer.

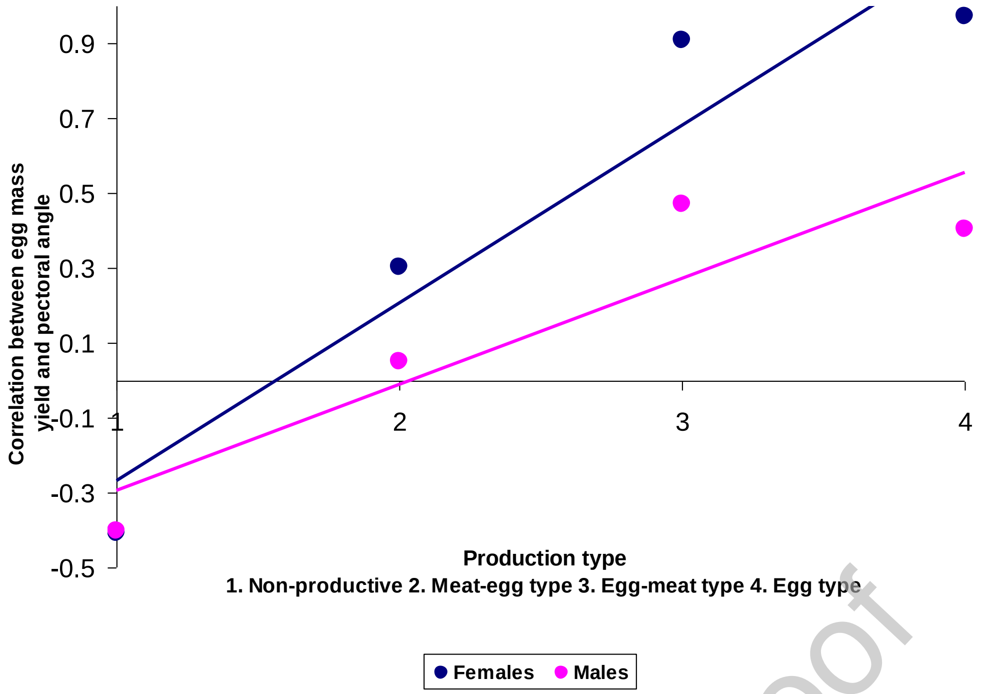


Fig. 2. Correlation relationship between the egg productivity of the breeding flock and pectoral angle in females and males when grouping the studied breeds and populations(except one MTB population as explained in the text) into four major production-based groups.

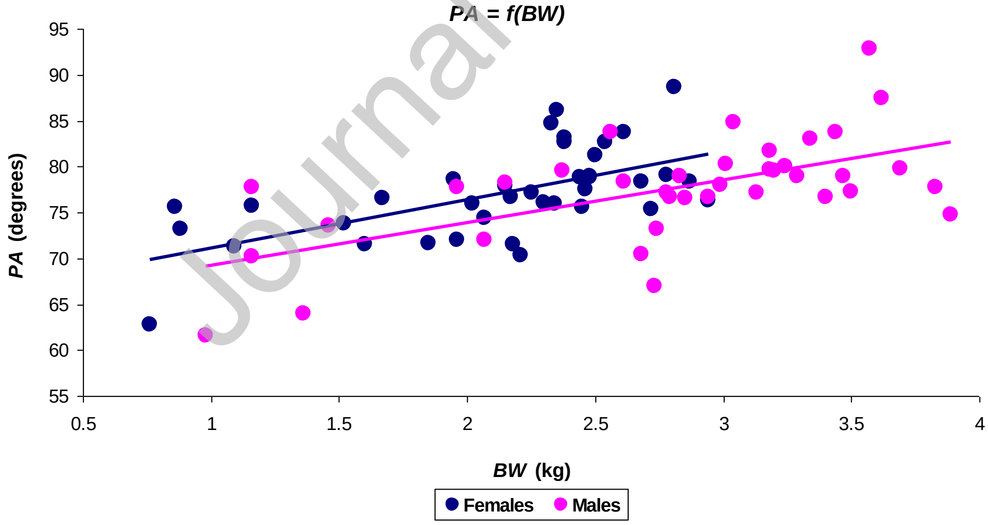


Fig. 3. Dependence of mean pectoral angle (PA) on mean body weight (BW) in 38 studied breeds and chicken populations (except one MTB population).

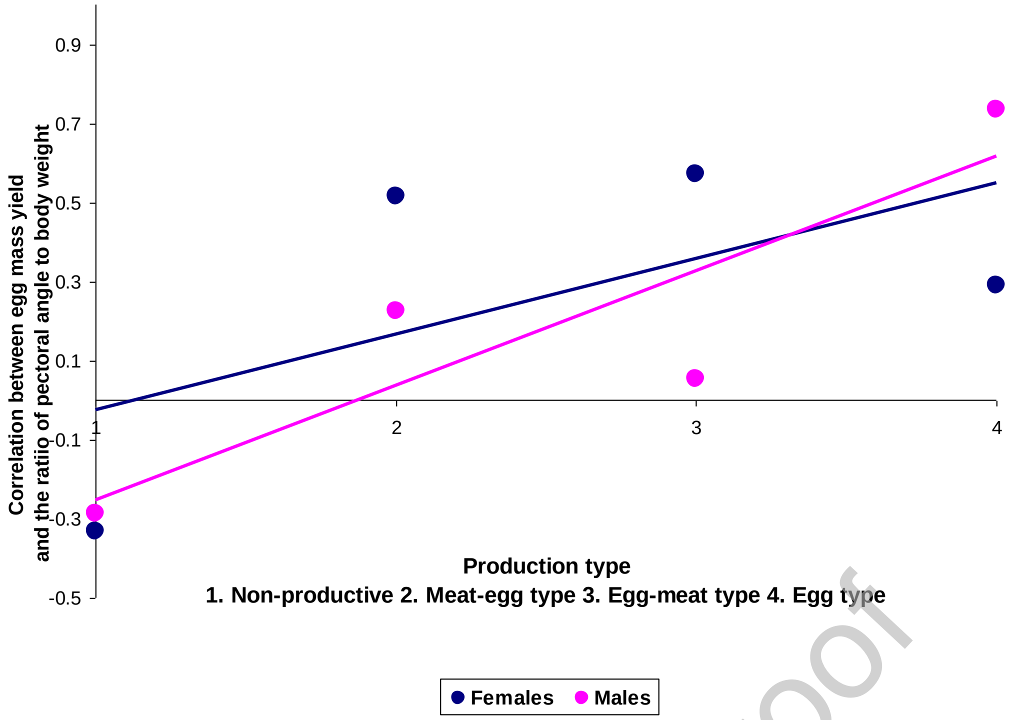
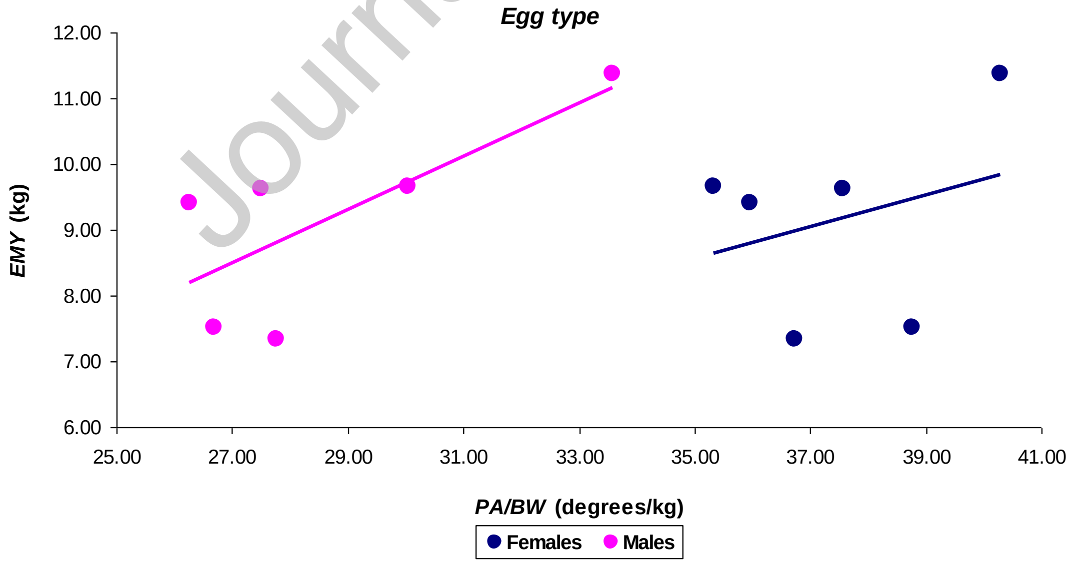
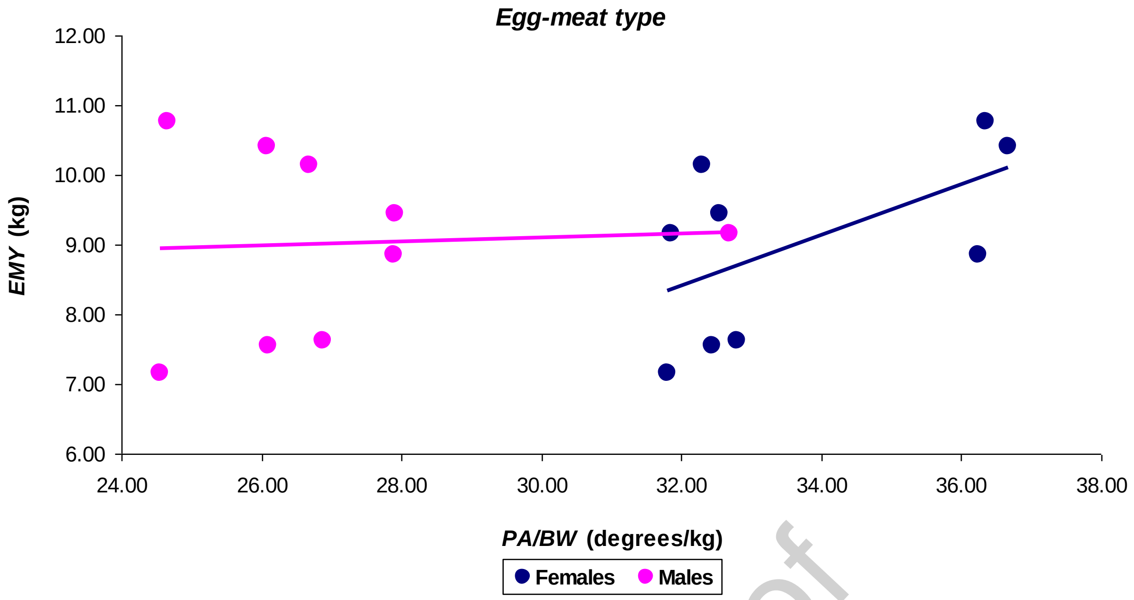


Fig. 4. Correlation relationship between the egg productivity of the breeding flock and the specific pectoral angle (PA/BW) in hens and roosters when grouping the studied breeds and populations (except one MTB population) into four major production-based groups.

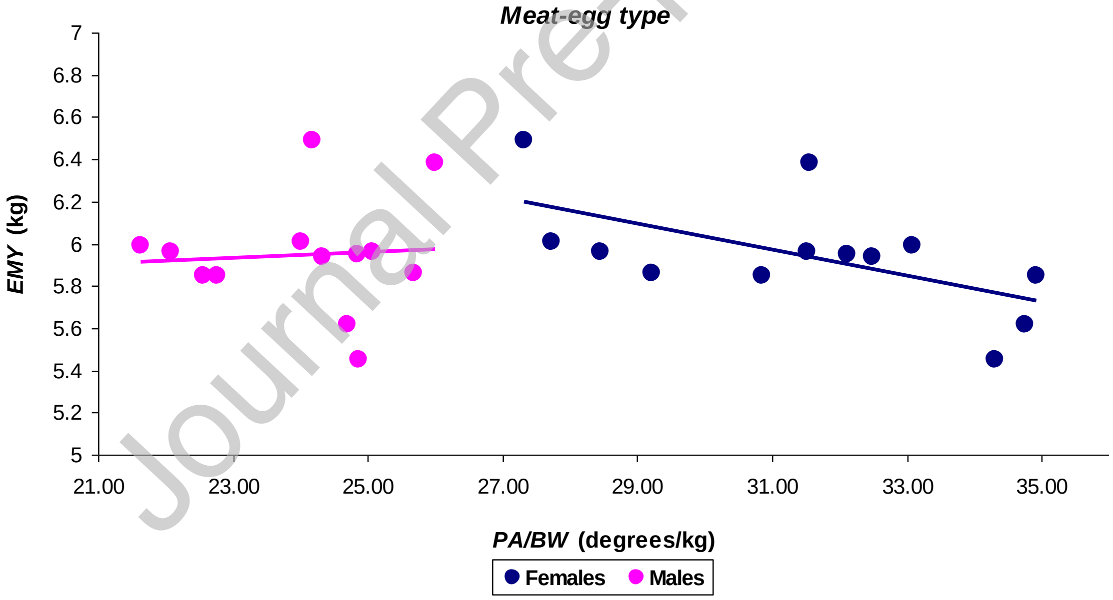
a



b


Egg-meat type
EMY (kg)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
24.00
26.00
28.00
30.00
32.00
34.00
36.00
38.00
PA/BW (degrees/kg)
● Females ● Males

c


Meat-egg type
EMY (kg)
7
6.8
6.6
6.4
6.2
6
5.8
5.6
5.4
5.2
5
21.00
23.00
25.00
27.00
29.00
31.00
33.00
35.00
PA/BW (degrees/kg)
● Females ● Males

d

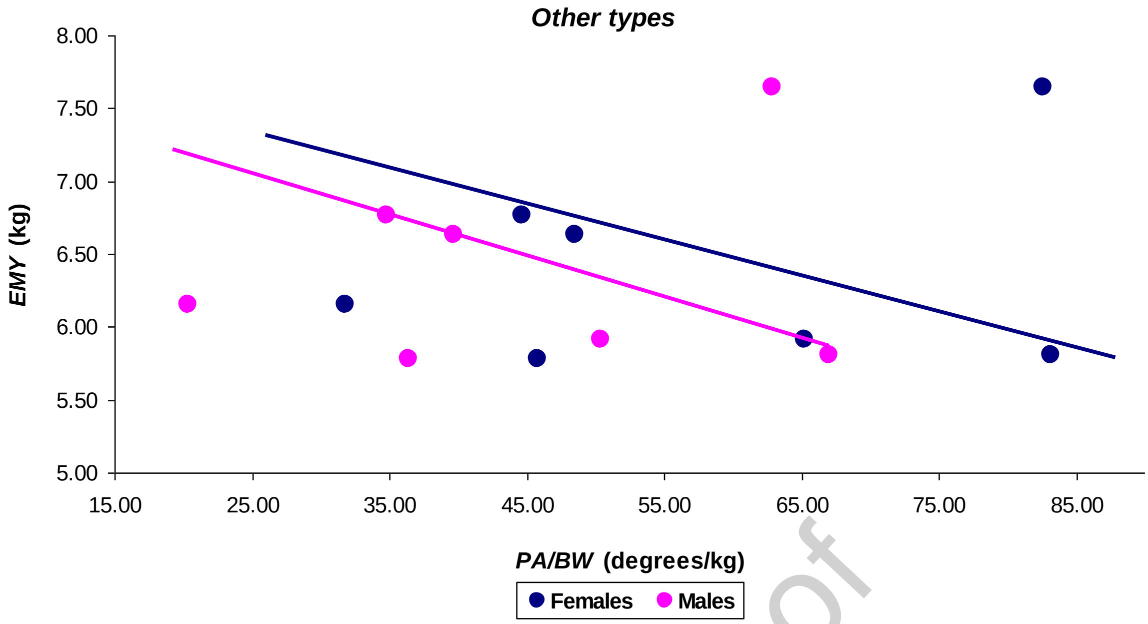
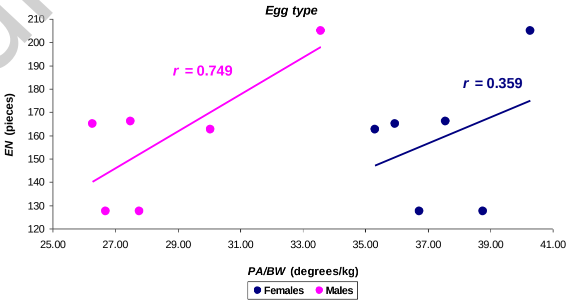
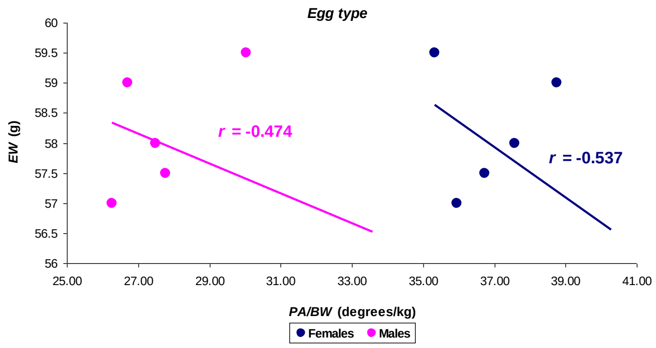


Fig. 5. Dependence of egg productivity assessed by egg mass yield (EMY) on the specific pectoral angle (PA/BW) for ETB (**a**); EMB (**b**); MEB (**c**); and other breed types non-selected for performance (**d**) when grouping the studied breeds and populations (except one MTB population) into four major production-based groups.

a

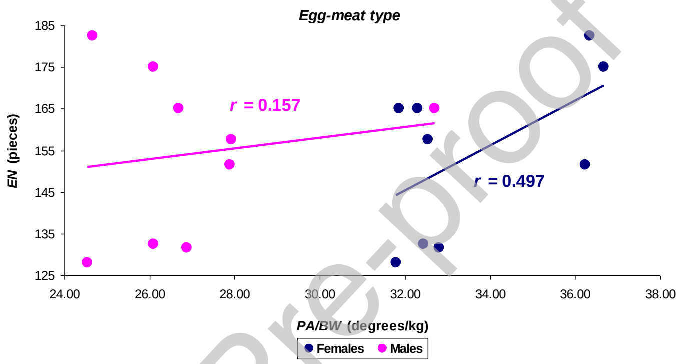
b

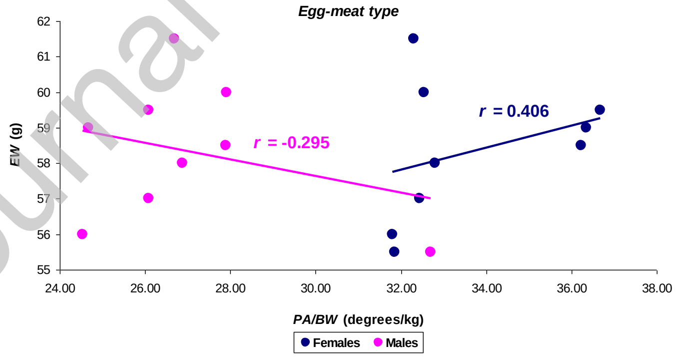



Egg type
60
59.5
59
58.5
58
57.5
57
56.5
56
EW (g)
r = -0.474
r = -0.537
25.00
27.00
29.00
31.00
33.00
35.00
37.00
39.00
41.00
PA/BW (degrees/kg)
● Females ● Males

c

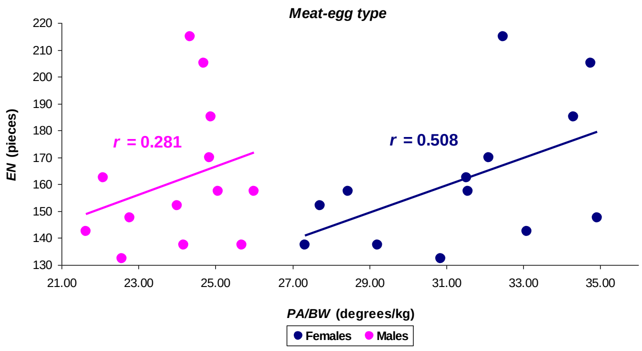
d

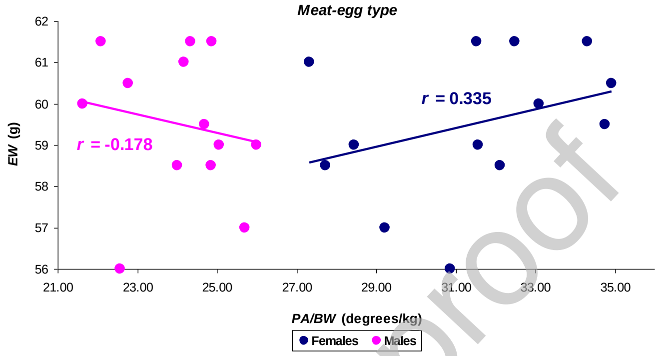

Egg-meat type
185
175
165
155
145
135
125
EN (pieces)
r = 0.157
r = 0.497
24.00
26.00
28.00
30.00
32.00
34.00
36.00
38.00
PA/BW (degrees/kg)
● Females ● Males


Egg-meat type
62
61
60
59
58
57
56
55
EW (g)
r = 0.406
r = -0.295
24.00
26.00
28.00
30.00
32.00
34.00
36.00
38.00
PA/BW (degrees/kg)
● Females ● Males

e

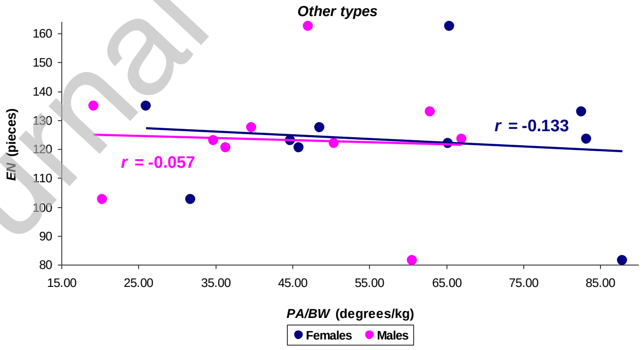
f


Meat-egg type
EN (pieces)
220
210
200
190
180
170
160
150
140
130
r = 0.281
r = 0.508
21.00
23.00
25.00
27.00
29.00
31.00
33.00
35.00
PA/BW (degrees/kg)
● Females ● Males


Meat-egg type
EW (g)
62
61
60
59
58
57
56
r = 0.335
r = -0.178
21.00
23.00
25.00
27.00
29.00
31.00
33.00
35.00
PA/BW (degrees/kg)
● Females ● Males

g

h


Other types
EN (pieces)
160
150
140
130
120
110
100
90
80
r = -0.133
r = -0.057
15.00
25.00
35.00
45.00
55.00
65.00
75.00
85.00
PA/BW (degrees/kg)
● Females ● Males

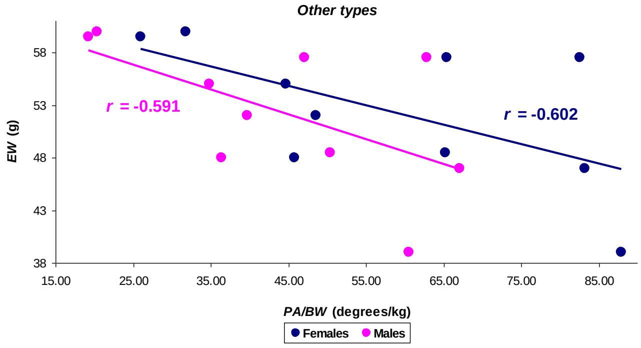

Other types
EW (g)
58
53
48
43
38
r = -0.591
r = -0.602
15.00
25.00
35.00
45.00
55.00
65.00
75.00
85.00
PA/BW (degrees/kg)
● Females ● Males

Fig. 6. Dependences of the mean number of eggs laid (EN) and their mean weight (EW) on the specific pectoral angle (PA/BW) for ETB (**a**, **b**); EMB (**c**, **d**); MEB (**e**, **f**); and other breed types non-selected for performance (**g**, **h**) when grouping the studied breeds and populations (except one MTB population) into four major production-based groups.

Table 1. Performance traits (mean ± standard deviation) in the 39 studied chicken breeds (populations) when grouped according to the traditional classification model (TCM; Larkina *et al.*, 2021; Romanov *et al.*, 2021)

Classification type	**Breed (population)**	**Code**	***n***	**Egg number**	**Egg weight, g**	**Body weight, kg**	
						females	**males**
Egg-type	Leghorn Light Brown (or Italian Partridge)	LLB	43	166.0±4.0	58.0±0.3	2.02±0.05	2.79±0.16
	Russian White	RWG	266	205.0±0.5	55.5±0.5	1.95±0.07	2.37±0.08
	Minorca Black	MB	135	165.0±5.0	55.5±1.5	2.48±0.13	2.56±0.15
Meat-type	White Cornish × (Brahma Light × Sussex Light)	WC × (BL × SL)	119	157.5±2.5	59.5±0.5	5.63±0.19	6.63±0.42
	Red White-tailed Dwarf	RWD	49	162.5±2.5	57.5±0.5	1.09±0.07	1.36±0.05
Dual purpose (egg-meat)	Zagorsk Salmon	ZS	108	170.0±10.0	58.5±0.5	2.61±0.10	3.34±0.10
	Pushkin	Pu	362	215.0±5.0	61.5±0.5	2.50±0.08	3.44±0.11

	Rhode Island Red	RIR	125	175.0±5.0	59.5±0.5	2.35±0.09	2.99±0.09
	Leningrad Mille Fleur	LMF	131	185.0±5.0	61.5±0.5	2.25±0.06	3.20±0.14
	Leningrad Golden-and-gray	LGG	240	182.5±2.5	59.0±1.0	2.33±0.07	3.13±0.12
	Pantsirevka Black	PB	165	165.0±5.0	61.5±0.5	2.44±0.13	3.01±0.08
Dual purpose (meat-egg)	Australorp Black Speckled	ABS	166	157.5±2.5	59.0±1.0	2.78±0.08	3.18±0.14
	Aurora Blue	AB	86	165.0±5.0	57.0±1.0	2.07±0.07	2.68±0.10
	Australorp Black	AoB	47	157.5±2.5	59.0±1.0	2.81±0.07	3.57±0.09
	Amrock	Ar	88	162.5±2.5	59.5±0.5	2.17±0.11	2.61±0.10
	Naked Neck	NN	109	127.5±2.5	57.5±0.5	1.96±0.12	2.78±0.07
	New Hampshire	NH	84	205.0±5.0	59.5±0.5	2.38±0.06	3.24±0.24
	Pervomai	Pm	114	152.0±3.0	58.5±0.5	2.72±0.14	3.29±0.22
	Plymouth Rock Barred	PRB	48	162.5±2.5	61.5±0.5	2.46±0.09	3.50±0.07
	Poltava Clay	PC	120	142.5±2.5	60.0±1.0	2.30±0.06	3.69±0.35

	Sussex Light	SL	103	157.5±2.5	60.0±1.0	2.54±0.10	2.83±0.15
	Faverolles Salmon	FS	98	132.5±2.5	57.0±1.0	2.34±0.11	2.94±0.13
	Tsarskoye Selo	Ts	322	147.5±2.5	60.5±1.5	2.38±0.04	3.47±0.09
	Yurlov Crower	YC	161	137.5±2.5	61.0±1.0	2.87±0.10	3.62±0.19
Game	Orloff Mille Fleur	OMF	84	132.5±2.5	56.0±1.0	2.45±0.11	3.40±0.18
	Moscow Game	MG	97	135.0±5.0	59.5±1.5	2.94±0.09	3.89±0.17
	Uzbek Game (Kulangi)	UG	93	102.5±2.5	60.0±1.0	2.48±0.10	3.83±0.22
Fancy	Russian Crested	RC	77	151.5±3.5	58.5±1.5	2.15±0.07	3.04±0.09
	Ukrainian Muffed	UM	103	137.5±2.5	57.0±1.0	2.68±0.10	3.18±0.14
	Bantam Mille Fleur	BMF	100	123.5±3.5	47.0±1.0	0.88±0.03	1.16±0.03
	Brahma Buff	BB	57	128.0±3.0	56.0±1.0	2.21±0.12	2.73±0.11
	Brahma Light	BL	62	131.5±1.5	58.0±1.0	2.18±0.07	2.85±0.11
	Hamburg Bantam Silver Spangled	HBSS	25	122.0±2.0	48.5±0.5	1.16±0.04	1.46±0.08

	Poland White-crested Black	PWB	63	123.0±3.0	55.0±1.0	1.60±0.08	2.07±0.05
	Silkie White	SW	91	81.5±1.5	39.0±1.0	0.86±0.03	1.16±0.07
	Cochin Bantam (Pekin Bantam)	CB	38	133.0±3.0	57.5±0.5	0.76±0.02	0.98±0.04
	Frizzle	F	87	127.5±2.5	59.0±1.0	1.85±0.03	2.74±0.02
	Pavlov Spangled	PS	107	127.5±2.5	52.0±1.0	1.52±0.07	1.96±0.08
	Pavlov White	PW	32	120.5±2.5	48.0±1.0	1.67±0.05	2.15±0.09
Average				**149.6±27.7**	**57.1±4.6**	**2.23±0.80**	**2.89±0.98**