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THE QUALITY OF DUCK MEAT FROM THE PERSPECTIVE OF PHYSICAL MEASUREMENTS AND EXPERT JUDGMENT*

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Abstract

The aim of this study was to evaluate the relationships between some physicochemical properties and organoleptic assessments of duck meat quality and expert assessment of the general appearance of raw breast and leg muscles. Body, carcass, breast and leg muscle weight were analysed. For both breast and leg muscles the following parameters were recorded: water holding capacity, thermal drip, colour lightness L*, electrical conductivity after 15 minutes and 24 hours *post mortem*, as well as four traits subject to expert organoleptic evaluation (general appearance, colour, odour and fatness). The dependence was evaluated using the Pearson's correlation and multiple regression equations (the general appearance was treated as a dependent variable). Three sets of variables were considered as factors influencing the general appearance of the raw breast and leg muscles. First, the influence of jointly selected performance traits and physicochemical properties of meat was analysed. Next, the impact of only the second-mentioned group of discriminants was considered, and then the dependence on other organoleptic attributes. It was shown that for both muscle groups, the following have a significant effect on the general appearance: muscle weight (breast muscle P<0.0001, leg muscle P<0.0001) in the first set, electrical conductivity 15 minutes after slaughter (breast muscle P = 0.023, leg muscle P = 0.042) in the second, and colour (both muscle groups P<0.0001) in the third. Muscle weight, electrical conductivity 15 minutes *post mortem* and visually assessed colour can be used to make a preliminary assessment of the technological and culinary quality of duck meat. Moreover, measurement with a conductometer is an economical and fast method, possible to carry out in a slaughterhouse.

Key words: duck meat, physicochemical properties, organoleptic assessment

For the production of duck meat in Poland, commercial hybrids are used, mainly Pekin ducks (*Anas platyrhynchos*). In recent years, birds with the genotype of fast-growing broilers GL-50xGL-30 (French origin) and A-55xF-11 (Polish origin) dominated, which were kept for standard 6–7 weeks (Witak, 2008; Michalczuk et al., 2016; Kokoszyński et al., 2019 a). However, for some time there has been an increased interest in carcasses of ducks kept longer (up to 11 weeks). This is in line with the general trend on the poultry meat market to obtain this raw material from less intensive production: medium-growing and slow-growing (Baeza, 2006; Castellini et al., 2008). Meat from alternative systems is characterized by a lower water content, a higher water holding capacity and less leakage during heat treatment (Fletcher, 2002; Baeza et al., 2021). It is used especially for the preparation of meat products according to the old, traditional recipes (pâtés, rolls, sausages in a jar, smoked meats), which have many supporters (Paustian et al., 2016). Changes in consumer expectations of duck meat inspire the introduction of new commercial hybrids (e.g. A-55xGL-30) and the search for optimal rearing periods.

The quality of meat according to modern criteria is a dynamic trait, changing depending on the raw material, market requirements and trends in human nutrition. Understanding the criteria applied by the consumer when choosing food products, including raw meat and processed meat, makes it easier for producers and traders to make decisions. Under conditions of competition and surplus supply, knowledge of the factors determining the choice of meat at the point of purchase is particularly important (Resurreccion, 2004; Paustian et al., 2016).

The quality of raw meat can be assessed using instrumental and sensory methods. Instrumental measurements, mainly concerning physicochemical traits, are fast and ensure higher repeatability of the results, which

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makes them highly objective (Warner et al., 2021). The second group includes both sensory analyses and consumer organoleptic evaluation. Research on consumer behaviour in the meat market has shown that visual assessment of the product at the time of purchasing decisions is of great importance. The most important traits here are colour, odour, fatness, and general appearance (Fletcher, 2002; Baeza et al., 2021).

This assessment is largely subjective, as it results from the different sensitivity and specific habits of consumers (Okruszek et al., 2006; Castellini et al., 2008; Font-i-Furnols and Guerrero, 2014; Ismoyowati and Sumarmono, 2019). Most consumers consider colour to be a decisive factor in purchasing meat, identifying it with freshness (Troy and Kerry, 2010). The colour intensivity depends mainly on the physical structure of the muscle, and on the concentration and chemical form of the basic heme pigment, which is myoglobin, and is closely related to the content of intramuscular fat (Lacin et al., 2008; Kowalska et al., 2020). Depending on age and origin, the breast muscles of ducks contain from 63% to 84% red fibres and 16% to 37% white fibres, while in turkeys and chickens almost the entire breast muscle consists of white fibres (Mancini and Hunt, 2005; Wołoszyn et al., 2009). Predominant among the red breast muscle fibres of ducks are α red fibres (αR or IIA), which contain a large amount of myoglobin. Therefore, in the case of duck meat, a dark red colour is desirable. Understanding the main factors influencing the appearance and colour of duck meat is crucial for the ability to supply desired products of consistent high quality (Fletcher, 2002; Lacin et al., 2008).

Like the colour, the odour of fresh meat also depends on the amount of fat and its composition. In general, the smell is induced by low-molecular-weight volatile compounds (hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids, and esters) derived from lipid degradation (Florowski et al., 2002; Czerny et al., 2008). Changes in the microflora are also important, as these directly shape the olfactory experience. It has been shown (Wołoszyn et al., 2006) that duck meat has a favourable fatty acid composition, and the ratio of polyunsaturated fatty acids to saturated fatty acids in duck breast muscles is from 0.63 to 0.84. As a result, oxidative and putrefying processes can take place more slowly, which helps to maintain the desired flavour of the meat.

In addition to a variety of measurement methods, many criteria are known for assessing the quality of raw meat. Most of them are based on the determination of selected physicochemical parameters, which are most often analysed at two time points: immediately after the cessation of vital processes, which in the case of poultry means 15 minutes after slaughter; and after 24 hours, taking into account *post mortem* changes occurring in the meat. Traits such as water holding capacity and thermal drip are determined by the properties of proteins, in particular the content of sarcoplasmic proteins, and contribute to the culinary quality of meat (Smith et al., 1992; Sandercock et al., 2009). Some of the electrical properties of the animals' muscles, such as water holding capacity and conductivity, which change *post mortem*, are also used to assess meat quality. Use is made of the phenomenon of the dependence of conductivity on the rate of glycolysis and changes in the concentration of ions in the intercellular space of tissues, and changes in electrical conductivity over time may result from changes in the location of water in muscle capillaries (Hamm, 1986). This parameter is a good determinant for diagnosing meat quality deviations, indicating the presence of much more "free" water in the raw material, and drip during post-slaughter storage (Graczyk et al., 2016; Kokoszyński et al., 2017, 2019 a, b).

The physicochemical properties of raw meat constitute a complex that determines the behaviour of the raw material during storage, processing and consumption. Ultimately, it determines the quality and organoleptic parameters of the product, as well as the general appearance of the meat (Wołoszyn et al., 2009; Baeza et al., 2021). Early classification of meat, indicating the best possibilities of its further use, will allow the processing plant to obtain uniform products and direct high-quality raw material to the consumer market (Florowski et al., 2002; Czyżak-Runowska et al., 2010; Warner et al., 2021).

In the context of the development and evaluation of the quality of raw meat as described above, it seems that an integral element of the evaluation of the quality of raw meat is the visual evaluation of its general appearance in connection with physical measurements and organoleptic evaluations of other characteristics, and the issue of the complementarity of particular approaches is obvious.

The aim of the study was to indicate the parameters that enable a quick assessment of the quality of duck meat in terms of its general appearance, with the use of physical measurements and organoleptic assessment. There is a need to search for methods that are non-invasive and can be effectively applied to the qualitative prequalification of meat.

Material and methods

A total of 390 crossbred individuals (F2 of Pekin A-55 and GL-30) were included in the study. All individuals were housed in one flock (under the same environmental conditions) at the same time. Birds were fed *ad libitum* from 0 to 6 weeks of age on an initial diet followed by a grower diet from 6 to 11 weeks of age. During the second period, birds were kept in individual cages. At 11 weeks of age (before slaughter), the body weight was measured (using the AXIS B15S electronic scale, with an accuracy of 5 grams) in live birds after 12 hours without access to feed and with constant access to water. Slaughter and post-slaughter treatment were carried out in the same standard technological conditions. After decapitation, bleeding, plucking, evisceration and cleaning, the carcasses were immersed in baths with

water and ice for about 45 minutes, until a temperature of 9°C was reached inside the breast muscles (*m. pectoralis superficialis* and *m. pectoralis profundus*). Then the carcasses were hung on drip stands (15 minutes) and cooled in a cold store at a temperature of 4°C and a humidity of 60–65%. At 24 hours after slaughter, the carcasses were weighed to obtain the weight of the carcass with the neck but without giblets, and a simplified dissection was carried out according to the methodology given by Ziołecki and Doruchowski (1989).

The electrical conductivity was measured directly in 15 minutes (before the carcasses are immersed in water) and 24 hours *post mortem* using a Matthäus LF-STAR conductometer. The stylet electrodes were driven directly through the skin into the superficial pectoral muscle and the thigh.

During dissection, the following were distinguished: breast muscles [BM] (superficial and *profundus*) and leg muscles [LM] (thigh and drumstick). The carcasses and muscles were weighed using RADWAG WPT 5C electronic scales with an accuracy of ±0.2 grams.

The lightness (L* value) of colour (CIE, 1986) of the surface of the breast muscles and legs adjacent to the skeleton was measured on the prepared muscles at three points. The mean of the measurements on individual muscles was taken as the result of the determination. A Minolta Chroma Meter C580 electronic trichromatic colorimeter was used (light source D65, observer 10°, measuring head opening 8 mm, calibration with a white standard: L* – 99.18. In this system, L* denotes lightness, which is a spatial vector.

The water holding capacity of the meat was determined using the Grau and Hamm (1952) method, modified by Pohja and Niinivaara (1957), and the thermal drip according to the method of Pikul (1993). The water content was tested in accordance with PN-ISO 1442: 2000.

In instrumental measurements, values were determined for the following characteristics: body weight (BW), carcass weight (CW), weight of the breast muscles and legs (BMW, LMW), and for both of the above-mentioned muscle groups on the right side of the carcass: electrical conductivity (EC) 15 minutes and 24 hours after slaughter (EC15BM, EC15LM, EC24BM, EC24LM), thermal drip (TDBM, TDLM), colour lightness L* (L* BM, L* LM), and on the left side of the carcass: water holding capacity (WHCBM, WHCLM) and water content (WCBM, WCLM).

In addition to the above-mentioned instrumental measurements, selected quality traits of the duck meat were assessed organoleptically (i.e. with the use of the senses). The muscles extracted on the left side of the carcass were placed in plastic, disposable containers and covered with lids. Separately the breast muscles (*m. superficialis* and *profundus*) and the muscles of the whole leg. All samples for evaluation were coded individually. This assessment was carried out by five trained experts (ISO 8586:2014-03) with many years of experience in conducting sensory evaluations of meat and poultry products. The assessment was carried out in a specialized room (ISO 8589: 2007), without the possibility of eye contact. The samples for evaluation were given in random order. A hedonic 4-point scale was used, with scores ranging from 2 to 5, where 2 was the lowest quality level, and 5 was the desired very good level. A score with an accuracy of 0.5 points was assigned for each tested determinant (Baryłko-Pikielna and Matuszewska, 2009).

The organoleptically assessed characteristics were colour (CRBM, CRLM), odour (ORBM, ORLM), fatness (FBM, FLM), and general appearance (GABM, GALM) of the raw breast muscles and legs. A basic statistical description of the traits is given in Table 1.

Table 1. Means and standard deviations of the recorded traits

Trait	Mean	Standard deviation
Body weight (g)	3122.00	290.64
Carcass weight (g)	2340.94	225.64
Breast muscle weight (g)	333.20	44.24
Leg muscle weight (g)	239.35	29.08
Electrical conductivity 15 minutes after slaughter, breast muscles (mS/cm)	6.28	1.53
Electrical conductivity 15 minutes after slaughter, leg muscles (mS/cm)	4.59	1.19
Electrical conductivity 24 hours after slaughter, breast muscles (mS/cm)	7.27	1.67
Electrical conductivity 24 hours after slaughter, leg muscles (mS/cm)	4.74	1.16
Water holding capacity, breast muscles (mg%)	33.17	3.55
Water holding capacity, leg muscles (mg%)	33.30	3.44
Thermal drip, breast muscles (%)	16.68	2.72
Thermal drip, leg muscles (%)	16.21	3.03
Lightness, breast muscles	44.38	3.82
Lightness, leg muscles	51.24	2.91
Water content, breast muscles (%)	74.87	1.02
Water content, leg muscles (%)	73.09	1.51
Colour, breast muscles (pts)	4.62	0.13
Colour, leg muscles (pts)	4.28	0.31
Odour, breast muscles (pts)	4.63	0.10
Odour, leg muscles (pts)	4.48	0.19
Fatness, breast muscles (pts)	4.62	0.15
Fatness, leg muscles (pts)	4.34	0.28
General appearance, breast muscles (pts)	4.30	0.61
General appearance, leg muscles (pts)	4.26	0.43

The relationships between the general appearance of raw breast and leg muscles and the production characteristics of ducks (body weight, carcass weight, muscle weight) and the physical parameters of the both muscles (electrical conductivity 15 minutes and 24 hours after slaughter, water holding capacity, lightness L*, thermal drip, water content) were investigated. Moreover, relations of the other organoleptic assessments concerning colour, odour and fatness and the general appearance were determined.

The dependences were evaluated by the use of Pearson's correlation and multiple regression equations of the form

$$y_i = b_1 x_{1i} + b_2 x_{2i} + \ldots + b_k x_{ki} + e_i$$

where: y_i stands for the general appearance of the i-th bird, b_1, b_2, ..., b_k are the regression coefficients, and x_{1i}, x_{2i}, ..., x_{ki} are the observations of the respective variables for the i-th duck. The value k denotes the number of variables affecting the general appearance.

These computations were performed using the Statistica ver. 10.0 software package.

Results

The Pearson's correlation coefficients are listed in Table 2. It may be noted that there are higher correlations for breast muscles than for leg muscles. For example, the values of electrical conductivity 15 minutes and 24 hours after slaughter are correlated with three productive traits in case of breast muscles, which is not the case for leg muscles.

Table 2. Pearson's correlations between analysed traits for breast muscles (upper triangle) and leg muscles (lower triangle)

L---B	BW	CW	BMW	EC15	EC24	WHC	TD	L*	WC	CR	OR	F	GA
BW		0.92*	0.67*	0.13*	0.12*	–0.01	–0.01	0.11*	–0.10	0.42*	0.38*	0.22*	0.58*
CW	0.92*		0.71*	0.12*	0.18*	–0.05	–0.04	0.04	–0.11*	0.44*	0.35*	0.17*	0.60*
LMW	0.71*	0.71*		0.05	0.19*	0.07	–0.01	0.01	0.02	0.48*	0.35*	0.12*	0.74*
EC15	–0.03	–0.02	0.09		0.25*	–0.17*	–0.09	0.16*	–0.16*	0.15*	0.16*	0.10	0.15*
EC24	–0.03	–0.01	0.02	0.44*		0.05	0.04	0.14*	0.03	0.08	0.11*	0.03	0.18*
WHC	0.07	0.02	–0.05	0.12*	–0.02		0.15*	0.07	0.29*	0.01	–0.02	–0.02	0.01
TD	0.00	–0.01	0.00	0.16*	–0.06	0.36*		0.06	0.17*	–0.00	–0.05	–0.00	0.04
L*	0.18*	0.12*	0.12*	0.02	–0.06	0.04	–0.00		0.10	–0.06	0.04	–0.03	–0.02
WC	–0.05	–0.06	0.05	0.16*	0.09	0.06	0.02	–0.09		–0.02	–0.05	–0.02	–0.03
CR	0.56*	0.52*	0.72*	0.07	0.01	–0.01	0.03	0.12*	0.02		0.53*	0.56*	0.60*
OR	0.41*	0.37*	0.54*	0.06	0.02	0.05	0.05	0.05	0.04	0.80*		0.67*	0.46*
F	0.31*	0.26*	0.44*	0.05	–0.01	0.00	0.04	0.09	0.03	0.75*	0.84*		0.30*
GA	0.57*	0.52*	0.79*	0.11*	0.01	–0.01	0.01	0.15*	0.04	0.86*	0.70*	0.68*	

Note on symbols: L – leg, B – breast, BW – body weight, CW – carcass weight, BMW – breast muscle weight, LMW – leg muscle weight, EC15 – electrical conductivity 15 minutes after slaughter, EC24 – electrical conductivity 24 hours after slaughter, WHC – water holding capacity, TD – thermal drip, L* – lightness, WC – water content, CR – colour, OR – odour, F – fatness, GA – general appearance; "*" denotes a significant (P<0.05) correlation coefficient.

Table 3. Multiple regression coefficients for productive traits and physicochemical properties of meat affecting the general appearance of breast muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
BW	0.0003	0.0002	0.1299
CW	0.0000	0.0003	0.7875
BMW	0.0086	0.0007	<0.0001
EC15	0.0405	0.0149	0.0068
EC24	0.0069	0.0136	0.6135
WHC	–0.0021	0.0064	0.7476
TD	0.0172	0.0079	0.0306
L*	–0.0106	0.0058	0.0676
WC	–0.0092	0.0222	0.6815

Note on symbols: BW – body weight, CW – carcass weight, BMW – breast muscle weight, EC15 – electrical conductivity 15 minutes after slaughter, EC24 – electrical conductivity 24 hours after slaughter, WHC – water holding capacity, TD – thermal drip, L* – lightness, WC – water content.

Table 4. Multiple regression coefficients for productive traits and physicochemical properties of meat affecting the general appearance of leg muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
BW	0.0004	0.0001	0.0019
CW	–0.0006	0.0002	0.0004
LMW	0.0120	0.0007	<0.0001
EC15	0.0179	0.0133	0.1786
EC24	–0.0069	0.0132	0.6040
WHC	0.0006	0.0043	0.8873
TD	–0.0003	0.0049	0.9522
L*	0.0062	0.0048	0.1988
WC	–0.0021	0.0093	0.8245

Note on symbols: BW – body weight, CW – carcass weight, LM – leg muscle weight, EC15 – electrical conductivity 15 minutes after slaughter, EC24 – electrical conductivity 24 hours after slaughter, WHC – water holding capacity, TD – thermal drip, L* – lightness, WC – water content.

As has already been mentioned, three sets of variables were considered as factors influencing the general appearance of the raw breast and leg muscles of ducks. Multiple regression coefficients for productive traits and physicochemical properties of the meat affecting the general appearance of breast and leg muscles are listed in Tables 3–4.

Multiple regression coefficients for the physicochemical properties of meat affecting the general appearance of breast and leg muscles are listed in Tables 5–6.

Multiple regression coefficients for the organoleptic properties of meat affecting the general appearance of breast and leg muscles are listed in Tables 7–8.

Table 5. Multiple regression coefficients for the physicochemical properties of meat affecting the general appearance of breast muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
EC15	0.0504	0.0220	0.0229
EC24	0.0557	0.0196	0.0047
WHC	0.0051	0.0094	0.5858
TD	0.0116	0.0118	0.3273
L*	–0.0106	0.0084	0.2108
WC	–0.0145	0.0326	0.6569

Note on symbols: EC15 – electrical conductivity 15 minutes after slaughter, EC24 – electrical conductivity 24 hours after slaughter, WHC – water holding capacity, TD – thermal drip, L* – lightness, WC – water content.

Table 6. Multiple regression coefficients for the physicochemical properties of meat affecting the general appearance of leg muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
EC15	0.0438	0.0215	0.0422
EC24	–0.0141	0.0216	0.5130
WHC	–0.0049	0.0069	0.4829
TD	0.0007	0.0080	0.9315
L*	0.0225	0.0077	0.0036
WC	0.0122	0.0150	0.4190

Note on symbols: EC15 – electrical conductivity 15 minutes after slaughter, EC24 – electrical conductivity 24 hours after slaughter, WHC – water holding capacity, TD – thermal drip, L* – lightness, WC – water content.

Table 7. Multiple regression coefficients for the organoleptic properties of meat affecting the general appearance of breast muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
CR	2.5364	0.2294	<0.0001
OR	1.9863	0.3583	<0.0001
F	–0.9142	0.2397	0.0002

Note on symbols: CR – colour, OR – odour, F – fatness.

Table 8. Multiple regression coefficients for the organoleptic properties of meat affecting the general appearance of leg muscles

Trait	Regression coefficient	Standard deviation of regression coefficient	P-value
CR	1.1325	0.0652	<0.0001
OR	–0.0497	0.1250	0.6910
F	0.1411	0.0769	0.0674

Note on symbols: CR – colour, OR – odour, F – fatness.

Breast muscle

In the analysis taking account of the selected production parameters of ducks and the physicochemical properties of their breast muscles (Table 3), it was found that among the traits in the first group, muscle weight significantly influenced the general appearance (P<0.0001). The influence of the other two production traits was negligible. It should be noted, however, that in this analysis the regression coefficient for carcass weight, although statistically insignificant, was nevertheless positive. The general appearance was also significantly dependent on the electrical conductivity 15 minutes *post mortem* (P = 0.007) and on thermal drip (P = 0.031).

On the other hand, in the analysis concerning only the influence of the physicochemical characteristics on the general appearance (Table 5), the electrical conductivity, both 15 minutes (P = 0.023) and 24 hours (P = 0.005) *post mortem*, proved to be statistically significant.

When another aspect of characteristics of the breast muscles was analysed (Table 7), the general appearance was found to be significantly dependent on all of the assessed differentiators, namely colour (P<0.0001), odour (P<0.0001) and fatness (P<0.0001).

Leg muscles

In the case of leg muscles (Table 4), it was shown that all of the analysed production traits had a significant impact on the general appearance: body weight (P = 0.002), carcass weight (P<0.0001) and muscle weight (P<0.0001). Regression coefficients for the remaining (physicochemical) traits were not significant. Noteworthy is the negative value of the regression coefficient for the carcass weight, which indicates a decrease in the value of the general appearance with an increase in carcass weight. Subsequent analyses, in which the least significant variables were rejected, confirmed the initial conclusion.

When the relationships between the general appearance of the leg muscles and the physiological properties were examined (Table 6), it was found that the electrical conductivity 15 minutes *post mortem* (P = 0.042) and the colour lightness L* (P = 0.004) had a significant influence.

Analysis of the last set of variables for this muscle group (Table 8) showed that colour (P<0.0001) and, to some extent, fatness (P = 0.067) had a significant influence on the general appearance. In contrast to the findings concerning the dependence of general appearance on organoleptic assessments for the breast muscles, odour was found to be a trait that had no effect on the general appearance (P = 0.691) of the leg muscles.

Discussion

In the case of poultry, including ducks, the most valuable elements of the carcass are the muscles, especially the breast muscles, and those that make up the thigh and drumstick. Therefore, efforts to breed ducks are focused on obtaining lines with a good growth rate, high rearing efficiency, and a high proportion of breast and leg muscles in the carcass (Baeza, 2006). The meat weight obtained from the duck carcass is an extremely important element not only for the production and economic efficiency of rearing (Solomon et al., 2006; Rayan et al., 2020), but also for the profitability of the processing plant (Huda et al., 2011; Biswas et al., 2019). As demonstrated by our research, muscle weight, considered with other selected physicochemical and organoleptic characteristics (Tables 3–4), also has a significant impact on the overall appearance of raw duck meat (BM + LM). This may explain the assessment of the culinary and technological quality of this raw material and determine the final price of the product (Fletcher, 2002; Huda et al., 2011). Obtaining the highest possible muscle weight is one of the basic objectives of breeding work carried out in flocks of slaughter ducks. It is associated with the obtaining of duck carcasses with high weight containing a proportionally large quantity of good-quality breast muscles (Baeza, 2006; Kokoszyński et al., 2019 a). To assess the general appearance of these muscles, it is mainly *pectoralis superficialis* that is exposed. This is a uniform flap (fillet) covered only with a thin flaccid connective tissue membrane with a small amount of external, intermuscular fat visible during evaluation (Smith et al., 1993). Therefore, in our analysis of the aforementioned breast muscle group (Table 3), the regression coefficient for the weight of the carcass, though statistically insignificant, was nevertheless positive. On the other hand, the leg muscles are a group consisting of many muscles, the most important of which are *m. biceps femoris* in the thigh and *m. tensor fasciae latae* in the drumstick. Individual muscles are surrounded by flabby connective tissue, the cells of which have a special ability to store fat, so that intermuscular fat fills the numerous spaces between the muscles. A light layer of soft texture forms on the surface being assessed, which negatively affects the overall appearance of the leg muscles. Since ducks have a natural tendency to accumulate fat in the form of subcutaneous fat, inter- and intramuscular fat, or adipose fat, a larger carcass weight can be expected to correspond to greater fatness, especially in the leg muscles (Baeza, 2006; Witak, 2008; Kokoszyński et al., 2019 a, b). Therefore, in the analysis of the general appearance of this group of muscles, a negative value of the regression coefficient for carcass weight was found (Table 4).

It has been proven in many studies that the value of electrical conductivity is closely related to changes in meat hydration during *post mortem* processes. However, the degree of correlation between the value of electrical conductivity and the technological and sensory characteristics of meat may depend on the time of measurement as well as the species of animal and the type of muscle (Saelin et al., 2017; Kokoszyński et al., 2019 a). Jukna et al. (2012) found that the water holding capacity, pH and hardness of mature meat correlated the best with the

electrical conductivity during the first 45 minutes after slaughter. Our research has shown that among the analysed physicochemical parameters, the electrical conductivity measured immediately after slaughter, i.e. in poultry 15 minutes *post mortem* (EC15), had a significant impact on the overall appearance of both muscle groups (BM – Tables 3 and 5 and LM – Table 6). In contrast, in the case of duck breast muscles, EC measurements at both time points (EC15 and EC24) can be used to estimate general appearance. Czyżak-Runowska et al. (2010) showed that the electrical conductivity measured after two time periods – 90 min (EC90') and 24 h (EC24h) after slaughter – in the longissimus muscle of the pig (*longissimus lumborum*) was correlated with thermal drip (r = 0.368 and r = 0.290, respectively), the ability to retain water (r = 0.361 and r = 0.344) and juiciness (r = –0.348 and r = –0.361). Higher values of the EC measurement were associated with higher thermal drip, lower water holding capacity, and a deterioration in juiciness. Together, these characteristics also affect the overall appearance of raw meat. Pale soft exudative meat is rated lower by consumers (Castellini et al., 2008; Font-i-Furnols and Guerrero, 2014). In our research, a relationship between the general appearance and thermal drip was demonstrated only for the breast muscles (Table 5), which may be a good indication for classifying this valuable raw material in the processing plant in order to minimize losses during heat treatment. Many authors point out that the electrical conductivity test makes it possible to assess the quality of meat without destroying the sample and in a short time, without the need to set up a specialized measuring station. This makes it possible to apply these analyses on an industrial scale (Florowski et al., 2002; Saelin et al., 2017).

In the analysis of the general appearance of meat, colour is a very important factor, in terms of both its instrumentally measured components and visual assessment. The measurement of the colour lightness L* in our research showed an influence of this parameter on general appearance only for the leg muscles (Table 6). This is related to the previously discussed fat gain in this part of the birds' muscles. Duck meat consumers expect a product with a uniform dark red colour, characteristic of dark meat (Smith et al., 1993; Michalczuk et al., 2016). In spectrophotometric assessment, the adipose tissue is characterized by higher colour lightness than the muscle tissue, especially in the presence of the intensely red tissue of the duck leg muscles, which contain nearly 100% more heme pigment than the breast muscles (Florowski et al., 2002). Therefore, the lightness measurements of the non-uniformly fat leg muscles are often varied, in contrast to the results obtained for the breast muscles. Meat with too light a colour and uneven saturation is perceived as a raw material with low technological value, and especially a lower ability to retain its own water and higher culinary losses and hardness (Fletcher, 2002; Kowalska et al., 2020). It is also characterized by a poorer general appearance (Mancini and Hunt, 2005; Wołoszyn et al., 2009; Gornowicz et al., 2015). This was also confirmed by visual assessments. Among others, Baeza (2006) showed that an increase in muscle lipid content increases lightness, and juice loss after cooking, with significantly high correlation coefficients (0.49, 0.47 and 0.54, respectively). Our research shows that among the parameters analysed organoleptically (Tables 7–8), only colour has a significant ($P<0.0001$) influence on the general appearance of both muscle groups. Similarly, other authors (Wołoszyn et al., 2009; Troy and Kerry, 2010; Michalczuk et al., 2016) have reported that the most important and easily grasped distinguishing trait of meat sensory quality is colour.

However, among the organoleptic parameters, the odour and fatness (Table 7) were also important in assessing the appearance of the most valuable component of the carcass – the breast muscles. These two traits are strongly correlated with each other. The human sense of smell needs an appropriate concentration of lipid derivatives to register the presence of the aroma (Czerny et al., 2008). Duck meat is characterized by a high content of fat rich in unsaturated fatty acids, which contributes significantly to the flavour (Biswas et al., 2019). However, the breast muscles are perceived as a refined, high-quality product, not too fatty, and with a delicate meaty aroma. Customers associate these traits with the freshness of meat, and they contribute to the overall impression made by the appearance of this product. This was also reflected in the results of our research.

Summarising the results obtained, it can be concluded that measurements of muscle weight, electrical conductivity and visual assessment performed by trained specialists, especially in terms of colour, can be used to assess the overall appearance of duck meat. These are rapid and non-invasive methods that can be used directly on the slaughter line. For this reason, they can be used for initial planning of the use of the available raw materials in a poultry processing plant.

Conclusions

1. The weight of muscles (both breast and leg muscles) is a factor determining their general visual appearance, and can therefore be an element of the qualitative classification of meat for the consumer market.

2. Determination of the electrical conductivity of duck meat (breast and leg muscles) 15 minutes *post mortem* (EC15) can be used as an indicator of the overall appearance of this raw material. Measurement with a conductometer is also an economical and fast method, possible to carry out in a slaughterhouse.

3. The colour of duck meat visually assessed by experts is a good criterion for a rapid quality assessment of this product in terms of its general appearance.

4. Muscle weight, electrical conductivity 15 minutes *post mortem* (EC15) and visually assessed colour can be used to make a preliminary assessment of the technological and culinary quality of duck meat.

Conflict of interest

The authors declare no conflicts of interest.

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