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Physical parameters of femur, humerus, ulna and radius under the nutritional influence of grass pea (Lathyrus sativus) seeds in the finishing pig diets

Wpływ nasion lędźwianu siewnego *(Lathyrus sativus)* w żywieniu tuczników na parametry fizyczne kości udowej, ramiennej, łokciowej i promieniowej

The studies on the composition of grass pea *(Lathyrus sativus)* seeds revealed that they may supplement protein fodder in animal nutrition (10-12). These seeds contain about 280-310 g of protein in 1 kg dry matter at about 6 g lysine and 3 g methionine and cystine in 100 g of protein (10-12). In the seeds of grass pea, there exist anti-nutritive factors, such as protease inhibitors, neurotoxins, osteotoxins and phytates of not known effects on the growth and development of young animals. Therefore, the consumption of raw grass pea seeds may result in the occurrence of characteristic disease, described as lathyrism in its osseous and nervous forms. The osseous form is conditioned by the presence in the raw seeds of grass pea, of osteotoxin, which inhibits the processes of normal growth and mineralization of bones, manifested mainly as the deformations of limb bones. In order to restrain the negative effects of these compounds, the seeds of leguminous plants are treated with such technological measures as toasting, extrusion and expanding or else, supplemented with various additions, which improve the utilization of the ingredients of such feeds owing to the elimination or inactivation of anti-nutritive factors (10-12).

The lack of the studies on growth and mineralization of pig bones as well as the change of their physical and geometrical characteristics at the simultaneous existence of limb bones diseases of this species contributed to starting this investigation aiming at determining physical characteristics of resistance parameters in pig limbs bones under the conditions of standard feeding as well as the application of extruded and raw additions of grass pea seeds in the diet.

MATERIAL AND METHODS

The studies were conducted on 96 fattened pigs, which were crossbreeds of Polish Large White x Polish Landrace (PLW x PL) of initial body weight of 70 kg. The pigs were divided into four groups according to Table 1. The pigs were housed in pens with slatted concrete floors (four gilts or four barrows per pen). Feed and water were available *ad libitum*. The composition of the finisher diets is presented in Table 1. Chemical composition, including DM, crude protein, crude fibre, ether extract and minerals (Ca and P total) and amino acid composition was determined according to routine laboratory procedures (1).

The experiment lasted 8 weeks after which the pigs were killed and their limb bones were isolated. The bones were tested with INSTRON 4302 apparatus by the method described before and geometrically measured (8, 13, 14). The bones of each experimental and control group were characterized according to the following resistance features:

a) the value of breaking force (N), measured from the value determined as the so-called breaking point, at which disintegration of bone structure occurs,

b) the value of maximum elastic strength (N), calculated from the so-called resilience points, determined by the deflexion of a tangent from the line representing the dependence between the strength and deformation,

c) the stiffness value, calculated from the section of the line representing the dependence between the force and deformation (DF/DL), where increasing force values (DF) are proportional to increasing deformations (DL).

The following geometrical parameters of the bones were also described (8): the secondary moment of the cross-sectional inertia in relation to the horizontal axis (Ix), cross-sectional area A (mm^2), the volume of bone between supports (vol.), mean relative wall thickness (MRWT), the length of bone (mm), the weight of bone (g).

RESULTS AND DISCUSSION

The received results of testing four bones have been presented in Figures 1-4 as well as Tables 2-9.

Femur revealed the highest value of breaking force in the group of pigs fed on extruded grass pea supplemented with 0.1% lysine, and the lowest in the group of pigs fed on extruded grass pea exclusively (Fig. 1). Also the value of maximum elastic force of femur was the highest in the group of pigs fed on extruded grass pea with the addition of lysine, and the lowest in the pigs fed on extruded grass pea exclusively (Fig. 2).

The stiffness value of femur was the highest in the control group comparing with the other experimental groups. Statistically significant differences were found out between the values of the control group and the value of the pigs fed on the supplement of extruded grass pea and the group fed on the addition of raw grass pea with the group fed on extruded grass pea and also between the group fed on the supplement of extruded grass pea and extruded grass pea combined with lysine (Tab. 2). Femur reached its highest weight as compared with the other bones. Within femur, the highest weight was observed in the group of pigs fed on extruded grass pea, and in the other groups such values were significantly lower and similar to one another (Tab. 8).

The secondary moment of inertia of femur (Ix) was also the highest in the group of pigs fed the supplement of extruded grass pea, similarly as the volume of bone between supports (vol.) and cross-sectional area (A), which did not differ among one another in the other groups (Tabs 3 and 4). Between the values of secondary moment of inertia (Ix), statistically significant differences corresponded to these of stiffness. With the bone volume (vol.) however, statistically significant differences existed only between the control group and the groups of pigs fed on the supplement of extruded grass pea and the group fed on the supplement of raw grass pea.

The breaking force of humerus was lower than the force for femur and ulna, with the highest value in the pigs fed on the supplement of raw grass pea, and the lowest in the group of pigs fed on the addition of extruded grass pea combined with

Tab. 1. Composition and nutritive value of experimental diets for finishing pigs

Item	Feeding groups			
	I control	II raw grass pea	III extruded grass pea	IV extruded grass pea + lysine
Barley	45.0	40.5	40.5	40.4
Rye	20.0	20.0	20.0	20.0
Rapeseed meal "OO"	10.5	5.0	5.0	5.0
Grass pea	-	10.0	10.0	10.0
Meat-bone meal	3.0	3.0	3.0	3.0
Wheat bran	20.0	20.0	20.0	20.0
Fodder chalk	0.5	0.5	0.5	0.5
Mineral-vitamins premix*	1.0	1.0	1.0	1.0
Lysine			-	0.1
Content in 1 kg of diets:				
Metabolizable energy, MJ	11.87	11.89	11.89	11.89
Crude protein, % of DM	16.15	16.19	16.21	16.23
Ether extract, % of DM	2.36	2.32	2.43	2.33
Crude fibre, % of DM	3.47	3.82	3.74	3.78
Lysine g	6.9	7.1	7.1	8.1
Methionine + cystine g	5.7	5.5	5.5	5.5
Ca g	6.4	6.3	6.3	6.3
P total g	5.3	5.1	5.1	5.1

Explanation: Mineral-vitamin premix - Ekomiks PT-2 super (PPHU Ekoplon S.A., Kielce)

Tab. 2. The changes in stiffness determined as relation of breaking force gain (F) expressed in newtons (N) and strain gain (L) in mm in pigs under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	1783^{a}	179	1177^{a}	100	1496^{a}	57	54^{a}	4.5
II raw grass pea	1782^{a}	136	1191^{a}	110	1461^{a}	103	50^{a}	3.8
III extruded grass pea	1647^{ab}	213	1317^{ab}	172	1804^{b}	174	81^{cb}	12.2
IV extruded grass pea + 0.1 % lysine	1571^{c}	274	775^{c}	27	1730^{cb}	52	72^{cd}	7.3

a, b, c, d - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 3. The value of the secondary moment of inertia of bone cross-section (Ix) of pig limbs under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	2820^{a}	327	3874^{a}	821	1270^{a}	241	32.7^{ab}	4.8
II raw grass pea	2815^{a}	156	3530^{a}	401	1176^{a}	206	26.5^{a}	5.7
III extruded grass pea	4519^{b}	633	3794^{a}	621	2459^{b}	699	42.2^{b}	7.3
IV extruded grass pea + 0.1 % lysine	2984^{a}	278	3050^{b}	373	1808^{ab}	288	32.5^{ab}	2.1

a, b - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 4. The value of cross-sectional areas (A) of pig limb bones under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	110.3^{a}	5.6	126.5^{a}	15.1	95.3^{a}	4.7	19.4^{a}	1.4
II raw grass pea	113.1^{a}	2.8	123.2^{a}	6.8	92.7^{a}	8.8	15.6^{b}	1.2
III extruded grass pea	153.7^{b}	13.5	142.7^{a}	17.3	97.4^{a}	12.3	16.9^{bc}	1.3
IV extruded pea + 0.1 % lysine	116.6^{a}	7.4	130.1^{a}	6.9	85.7^{a}	4.4	16.1^{bc}	1.4

a, b, c - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 5. The value of mean relative wall thickness (MRWT) of pig limb bones under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	19.6^{a}	0.32	17.9^{a}	0.41	18.0^{a}	0.38	16.8^{a}	0.79
II raw grass pea	19.9^{a}	0.19	17.5^{a}	0.14	17.6^{a}	0.19	15.0^{b}	0.31
III extruded grass pea	20.7^{b}	0.13	18.6^{b}	0.21	19.0^{b}	0.18	16.6^{a}	0.31
IV extruded grass pea + 0.1 % lysine	19.3^{a}	0.12	17.3^{a}	0.36	17.4^{a}	0.27	15.1^{b}	0.42

a, b - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 6. The value of bone volume between supports of pig limb bones under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	0.49^{a}	0.05	0.41^{a}	0.04	0.80^{a}	0.12	0.85^{ab}	0.1
II raw grass pea	0.46^{a}	0.02	0.37^{a}	0.01	0.76^{a}	0.06	0.92^{b}	0.08
III extruded grass pea	0.46^{a}	0.05	0.44^{a}	0.04	0.49^{b}	0.06	0.74^{a}	0.06
IV extruded grass pea + 0.1 % lysine	0.43^{a}	0.02	0.37^{a}	0.06	0.43^{b}	0.09	0.77^{a}	0.02

a, b - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 7. The value of bone length in pig limbs under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	19.6^{a}	0.32	17.9^{a}	0.41	18.0^{a}	0.38	16.8^{a}	0.79
II raw grass pea	19.9^{a}	0.19	17.5^{a}	0.14	17.6^{a}	0.19	15.0^{b}	0.31
III extruded grass pea	20.7^{b}	0.13	18.6^{b}	0.21	19.0^{b}	0.18	16.6^{a}	0.31
IV extruded grass pea + 0.1 % lysine	19.3^{a}	0.12	17.3^{a}	0.36	17.4^{a}	0.27	15.1^{b}	0.42

a, b - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 8. The value of bone weight of pig limbs under the influence of control and experimental nutrition

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
I control group	262^{a}	9.9	240^{ab}	10	160^{a}	8.8	18.6^{a}	1.3
II raw grass pea	262^{a}	8.1	228^{a}	9.3	144^{b}	8.8	20.8^{a}	0.8
III extruded grass pea	302^{b}	9.9	270^{b}	5.9	184^{c}	9.7	19.4^{a}	1.7
IV extruded grass pea + 0.1 % lysine	264^{a}	6.5	228^{a}	5.9	160^{a}	3.7	20.5^{a}	1.2

a, b, c - the different letters - statistically ($p \leq 0.05$) significant differences between groups

Tab. 9. The values of mean relative wall thickness (MRWT) for four different limb bones of the pig

Groups	Femur		Humerus		Ulna		Radius	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
MRWT	0.47^{a}	0.02	0.40^{a}	0.02	0.70^{c}	0.05	0.84^{b}	0.05

a, b, c - the different letters - statistically ($p \leq 0.05$) significant differences between bones

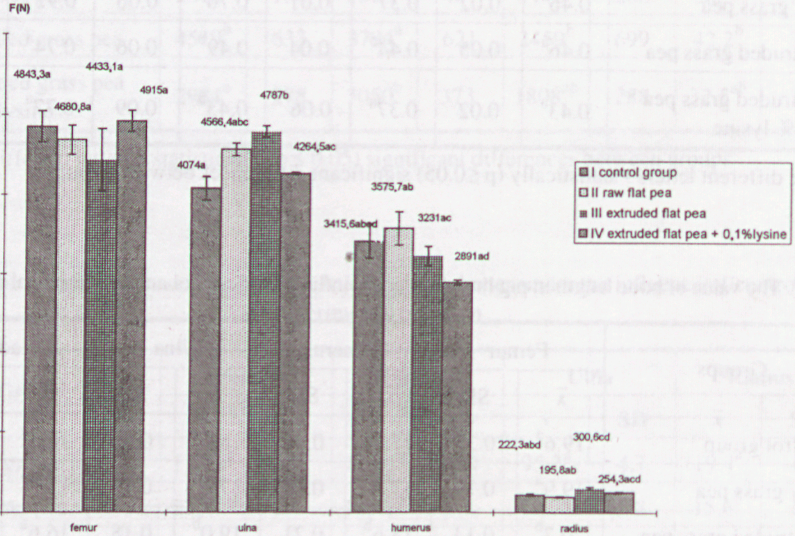

Fig. 1. The value of breaking force of pig limbs expressed in newtons (N) under the influence of control and experimental nutrition

lysine (Fig. 1). The statistically significant differences in the breaking force values of that bone were observed between the group fed on extruded grass pea and the group fed on the supplement of raw grass pea and also between the group fed on the additions of extruded grass pea combined with lysine (Fig. 1), as well as between the group fed on the supplement of raw grass pea and the group fed on the supplement of extruded grass pea combined with lysine. Similar dependencies were observed when studying maximum elastic strength, but significant differences occurred only in comparison with the group fed on the supplement of raw grass pea and the groups fed on the addition of extruded grass pea and extruded grass pea combined with lysine (Fig. 2).

The highest stiffness value was found in the group of pigs fed on the supplement of extruded grass pea at the lowest value in the groups fed on with the grass pea combined with lysine supplement, similarly to the results of testing cross-sectional area of the bone (Tab. 4, 7, 8). The weight revealed statistically significant differences between the control group and the one fed on supplement of extruded

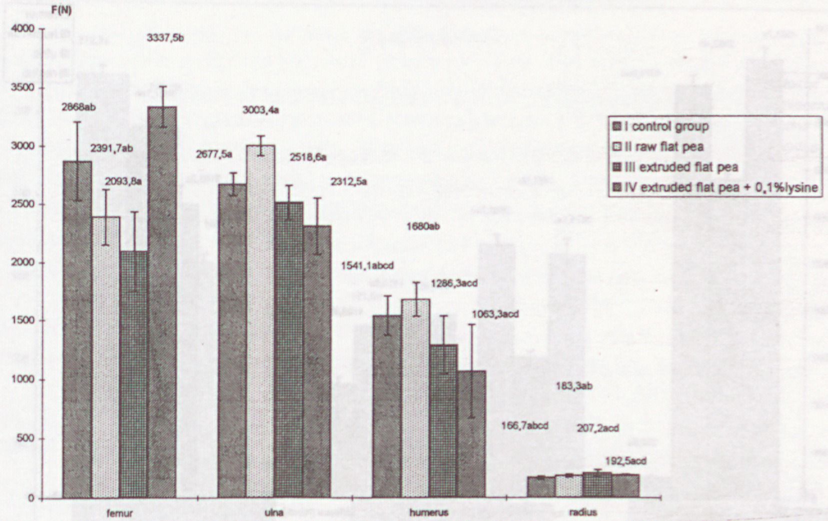

Fig. 2. The value of maximum elastic strength of pig limb bones expressed in newtons (N) under the influence of control and experimental nutrition

grass pea and the group fed on the supplement of extruded grass pea with the groups fed on the addition of raw grass pea and extruded grass pea combined with lysine (Tab. 8). As far as the length of the bones was concerned, statistically significant differences occurred between the group fed on the supplement of extruded grass pea and the groups fed on supplement of raw grass pea and extruded grass pea combined with lysine (Tab. 7).

The value of the breaking force of ulna was lower than the force for femur, yet it was higher than the value for humerus (Figs 1 and 3). The highest value of that force was observed in the group of pigs fed on the supplement of extruded grass pea, at statistically significant differences between the control group and the one fed on the addition of extruded grass pea. Statistically significant differences were observed also between the breaking force of the group fed on extruded grass pea and the group fed on the addition of extruded flat pea combined with lysine (Fig. 1).

Stiffness was the highest in the group fed on extruded flat pea and extruded grass pea combined with lysine at statistically significant differences between the volume of the control group and the group fed the supplement of extruded grass pea (Tab. 2).

The highest values of weight and length were in the group of pigs fed on with the supplement of extruded grass pea (Tab. 7 and 8). The weight values differed significantly between the group fed on the supplement of raw grass pea and the group fed on the supplement of extruded grass pea (Tab. 8). The length of this bone was additionally significantly different between the group fed on the extruded grass pea supplement and the group fed on the addition of extruded grass pea and lysine

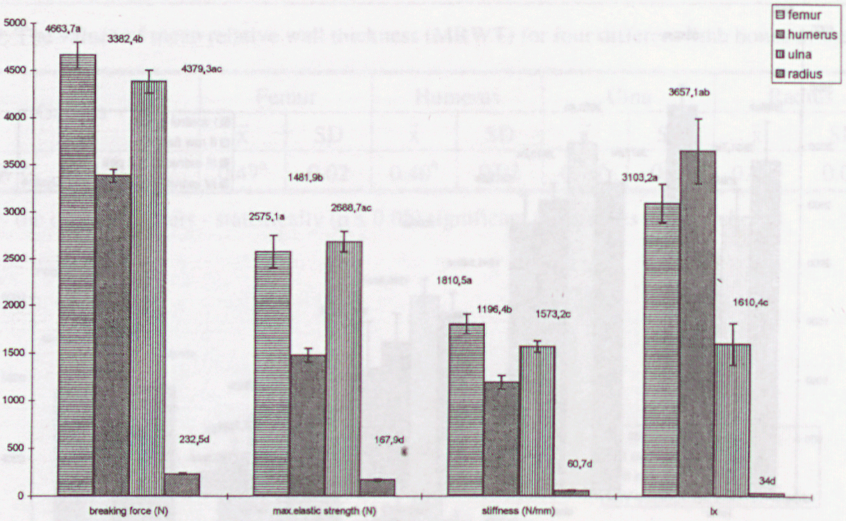

Fig. 3. The mean values of resistance and geometrical parametres obtained from four different limb bones of the pig

(Tab. 7). The highest mean relative wall thickness (MRWT) value was observed in the control group and the one fed on the supplement of raw grass pea, at statistically significant differences between the group fed on the addition of raw grass pea and grass pea combined with lysine (Tab. 5).

The lowest values of resistance and geometrical characteristics were observed in radius, grass pea the occurrence of statistically significant differences between the values of breaking force, maximum elastic force, stiffness and length only (Figs 1 and 2, Tabs 2-9).

Within the bones of pectoral limb, the highest values of the majority of studied features were characteristic of humerus, and the lowest of radius. The received results of the studies prove similar differentiation of the physical features of swine limb bones and of rats and poultry, however, these differences between individual bones within the same limb, e.g. pectoral, are most clearly seen in comparison with humerus and ulna and radius.

The received results of the studies confirm the effect of grass pea seeds on the physical and geometrical characteristics of bones. In breeding, there exist significant losses resulting from the disorders in mineralization processes of skeletal system in view of deficient nutrition and genetically conditioned diseases of poultry, swine, colts and other species (2, 3, 4, 5, 6,7, 9, 15, 16, 17).

Pigs are characterized by fast increase in body weight, and due to anatomical conditions, this species have weak limbs, which, compared with relatively high body weight and overpressure, may lead to the occurrence of such disorders as bones deformations, rachitis, osteomalacia, dischondroplasia and osseous breaks,

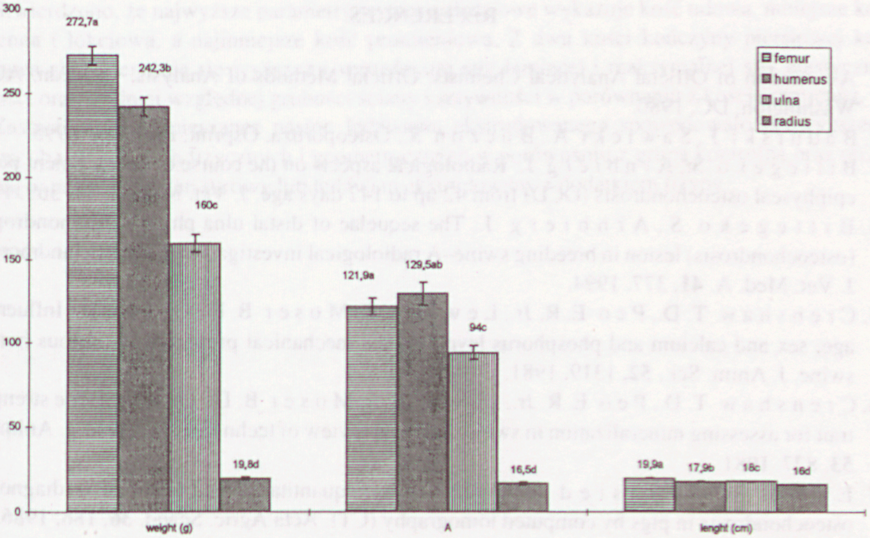

Fig. 4. The mean values of all data obtained from four different limb bones of the pig

which in pigs, usually concern femur, humerus and ulna and that results in high economical losses in breeding (2, 3, 4, 5, 6, 7, 9, 15, 16, 17). Such disorders, according to present views, depend on genetic predisposition, yet the releasing factors are rather the manner of feeding, the composition of the diet and the conditions of rearing.

The processes of growth and mineralization of pig bones and the whole skeleton are not well-known and there exists the necessity to conduct the studies on this species, as it may be the biological model most closely related to that of a human being. It should be also stressed that heterogenic organic transplantation from this species to people, including bones, have lately been proclaimed well-founded by means of the elimination of rejecting transplants.

CONCLUSIONS

1. The bones of pectoral and pelvic limbs in the pig differ in the values of breaking force, maximum elastic strength, stiffness and geometrical features.
2. The highest values of breaking force, maximum elastic strength and stiffness occur in femur, lower in ulna and humerus and the lowest in radius.
3. Out of the two bones of pectoral limb, ulna is characterized by higher values of breaking force, maximum elastic strength, length, mean relative wall thickness (MRWT) and stiffness as compared with humerus.
4. Supplementing the diet with extruded grass pea affects the above-mentioned values of the studied physical and geometrical features as compared with the other experimental groups.

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STRESZCZENIE

Badania przeprowadzono na 96 tucznikach, mieszańcach rasy pbz x wbp o początkowej masie ciała 70 kg, podzielonych na cztery grupy żywieniowe. Czynnikiem różnicującym grupy był 10% udział w mieszance nasion lędźwianu siewnego *(Lathyrus sativus)* w postaci surowej śruty lub poddanych procesowi ekstruzji. Zwierzęta żywiono sypkimi mieszankami pełnodawkowymi przy swobodnym dostępie do wody. Doświadczenie trwało 8 tygodni, po czym świnie ubito przy masie około 110 kg, izolowano kości kończyn i (przy użyciu aparatu INSTRON 4302) określono wartość siły łamiącej, maksymalnej siły elastycznej, sztywności oraz parametrów geometrycznych, takich jak: wtórny moment bezwładności przekroju poprzecznego, pole powierzchni przekroju poprzecznego, objętość kości poddawanej działaniom sił oraz średnią względną grubość ściany, a także długość i masę kości.

Stwierdzono, że najwyższe parametry wytrzymałościowe wykazuje kość udowa, mniejsze kość ramienna i łokciowa, a najmniejsze kość promieniowa. Z dwu kości kończyny piersiowej kość łokciowa charakteryzuje się wyższymi wartościami siły łamiącej i maksymalnej siły elastycznej, długości oraz średniej względnej grubości ściany i sztywności w porównaniu z kością ramienną.

Zastosowanie w mieszance nasion lędźwianu ekstrudowanego spowodowało podwyższenie wartości badanych cech fizycznych i geometrycznych w porównaniu z grupą kontrolną oraz otrzymującą w paszy lędźwian surowy lub lędźwian ekstrudowany z dodatkiem lizyny.