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ANALYSIS OF MINERAL COMPOUNDS IN DRY DOG FOODS AND THEIR COMPLIANCE WITH NUTRITIONAL GUIDELINES

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ABSTRACT

The aim of this study was to estimate complete extruded dry food for adult dogs, with a particular focus on: mineral profiles and ratios and the division into breed size. Dog foods were subjected to chemical analyzes to determine the content of macroelements and microelements. Additionally, the presence of heavy metals was verified and mineral ratios were estimated. The material for the research consisted of 15 randomly selected industrial household maintenance foods for adult dogs (five for large breed dogs, five for small breed dogs and five for all breeds dogs). All the analyzed feeds met the FEDIAF minimum recommended levels of microelements and macroelements, although the potassium level in 33% of the analyzed feeds was below the recommended minimum. 20% of the tested feeds exceeded the permissible quantitative ratio of calcium to phosphorus. In none of the tested feeds no heavy metals (Ni, Cd, Pb) were found. When choosing a feed, always pay attention to the label and carefully analyze the component of the product.

Key words: dry extruded dog food, complete feed, macroelements, trace elements, heavy metals, breed size

INTRODUCTION

Nowadays, dogs are usually equally treated with other family members. According to The European Pet Food Industry (FEDIAF) Annual report [FEDIAF 2020a] – dogs are the most popular domestic animals in the European Union. There are 7.7 million of them in Poland, and 87.5 million in the entire Europe. As reported by FCI, the approximate total number of dogs (pure-breed or not) around the world is about 147 million. The owners take care of dogs' psychological comfort and use sophisticated diets. Due to the growing owners' awareness, the pet food industry is changing dynamically. Pet foods are manufactured with a myriad of ingredients. These ingredients are often of new origin, mimicking human nutritional trends. In the nutrition of dogs are mainly used dry foods and their industry is still growing – annual growth rate of the pet food industry (average value over the past 3 years) is 2,6% [FEDIAF 2020a]. Currently, dog food is adjusted to the dog' age, lifestyle, physical activity and breed size [Di Donfrancesco et al. 2014]. Despite this, it is common that the animal' diet is not properly balanced. Despite the current dietary guidelines, feed often do not meet minimum recommended nutrient levels or exceed the permitted maximum levels of nutrients, macro- and microelements [Davies et al. 2017]. Owners usually make the mistake of choosing food that is not adjusted to the age and size of the dog properly. For example, a common problem is giving adult dogs of small breeds a puppy food, although dogs of these breeds mature faster than large breeds dogs [Posada et al. 2014].

Few authors of scientific papers deal with the topic of food products' safety for pet animals, assessed from the perspective of their owners [de Nadai Fernandes et al. 2018]. According to legal regulations, a product marked as a complete/ maintenance food is balanced in such way that it can be the only source of food for the animal, without leading to nutrient deficiencies [EC 2009]. Many dogs are fed the same food for too long. As a consequence of humanizing domestic animals, dogs' owners emphasize the importance of choosing food from a trustworthy food producer. This is why it is necessary to evaluate the quality of pet food [Farcas et al. 2013, Kanakubo et al. 2015]. An important role in the development of the animal pro-

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duction technology is played by the nutrition regime and type of feed and additives used [Kiczorowska et al. 2015]. Currently, there are many studies conducted to verify the safety of dog food and comparing the results of the analyzes with the nutritional guides or the producer' declaration.

FEDIAF has established nutrition guidelines based on National Research Council and scientific research. In addition to the basic composition, FEDIAF also contains requirements for microelements and macroelements that are necessary for the proper functioning of the organism. Not only their respective levels, but also the ratios between minerals are important, especially the ratio of calcium to phosphorus [Davies et al. 2017]. Apart from the improper balance of feeds in terms of the content and ratios of minerals, heavy metals present in the raw materials for feed production are also a significant threat [Duran et al. 2010]. Even in trace amounts, heavy metals can cause serious problems for all organisms, and their toxicity is related to their accumulation in tissues and depends on the frequency of exposure, the amount absorbed and the absorption channel [Jaishankar et al. 2014, Abd-Elhakim et al. 2016, Squadrone et al. 2017].

Therefore, this paper suggests that it is necessary to take steps to reveal inaccuracies in the composition of products declared on the label and compare it with the actual list of ingredients, including the lack of nutrient balance verified by laboratory analyzes. Thus, the aim of this study was to estimate complete extruded dry food for adult dogs, with a particular focus on: mineral profiles and ratios and the division into breed size.

MATERIAL AND METHODS

Samples

The material for the study included 15 randomly selected extruded maintenance food for adult dogs: five for small breed dogs (S1-S5); five for large breed dogs (L1-L5); five for dogs of all breeds (A1-A5). Samples of feed were ground in a laboratory mill type KNIFETEC 1095 (Foss Tecator, Sweden), placed in sterile containers and marked with the symbols A1-A5; L1-L5; S1-S5.

Chemical analyzes

The phosphorus content was determined by the Egner-Riehm colorimetric method with ammonium molybdate, at a wavelength of 660 nm, in a Specol 221 apparatus. A mass spectrometer (iCE 3000 series, Thermo Fisher Scientific) was used to determine the content of calcium, potassium, magnesium, iron, zinc, manganese, copper, cobalt, chromium, molybdenum, nickel, cadmium and lead. The material for the analysis of macroelements concentrations was mineralized in concentrated sulfuric acid (VI) and chloric acid (VII). The results are expressed as grams per 100 g DM. The material for the analysis of microelements concentrations was mineralized in a mixture of nitric (V) and chloric acid (VII). The results of macroelements are expressed as g per 100 g DM. The results of trace elements are expressed as mg per 100 g DM. The levels of all nutrients were compared with recommendations from FEDIAF [2020b] considering an energy intake of 110 kcal/kg body weight $(BW)^{0.75}$ for dogs with moderate activity (1–3 hours per day). All chemical determinations were performed in triplicate and presented as mean values.

Statistical analysis

The obtained results were statistically evaluated, and the average of individual features were calculated. Significant differences were calculated by one-way analysis of variance using the Duncan multiple range test using Statistica 13.1 [StatSoft Inc. 2016].

RESULTS AND DISCUSSION

Microelements and macroelements

Except for the major nutrient requirements, companion animals have requirements for elements that must be provided in their food for a healthy, balanced diet. Minerals play an extremely important role in the body by regulating the processes taking place in it. Both the deficiency and the excess of macro- and microelements can lead to specific disorders of the body' functioning and disease states. In order to thoroughly analyze the feeds studied, and at a later stage to calculate the ratios between the elements, the presence and amount of five macronutrients was analyzed (Table 1).

Calcium participates in the process of blood clotting and conduction of nerve impulses. Plays an important role in bone formation and development. Both deficiency and excess of Ca can lead to disorders in skeletal development [Dobenecker et al. 2006, Mack et al. 2015, Böswald et al. 2019]. Calcium deficiency can lead to pathological fractures. An excess of this macronutrient in the diet of growing large breed dogs causes osteochondrosis and may inhibit growth. An excessive amount of calcium in the dog' diet can lead to a relative zinc deficiency by ruling out competing at the sites of absorption or acting as intestinal ligands. First symptoms can be seen after about 3–4 months, and clinical signs are growth retardation, anorexia, conjunctivitis, dull coat and flaky skin [Cline 2012]. The minimum recommended level (MRL) of calcium in the feed, is 0.5 g per 100 g of dry matter (DM), while the nutritional limit (NL), 2.5 g per 100 g DM. All the feeds tested had calcium levels within the normal range. The highest average, 1.77 g per 100 g DM, was discovered in group of foods for large breed dogs, where the range was 1.11–2.37 g per 100 g DM. In this

Table 1. Macroelements (g per 100 g DM) in tested dog foods

Tabela 1. Zawartość makroelementów w badanych karmach (g na 100 g s.m.)

Item – Wyszczególnienie	Ca	P	K	Na	Mg
Breed size[1] – Wielkość rasy[1]					
A-1	1.17	1.36	0.48	0.23	0.11
A-2	1.39	1.12	0.73	0.47	0.10
A-3	1.96	0.97	0.59	0.45	0.18
A-4	1.76	0.96	0.81	0.45	0.12
A-5	2.43	1.26	0.69	0.31	0.13
Mean[2] – Średnia[2]	1.74b	1.13a	0.66a	0.38a	0.13a
L-1	2.04	0.74	0.52	0.82	0.13
L-2	2.37	1.10	0.39	0.18	0.13
L-3	1.83	1.10	0.30	0.25	0.09
L-4	1.49	0.99	0.60	0.34	0.09
L-5	1.11	1.06	0.41	0.20	0.14
Mean[2] – Średnia[2]	1.77b	1.00a	0.44a	0.36a	0.12a
S-1	1.58	0.85	0.70	0.28	0.13
S-2	1.00	0.85	0.36	0.20	0.15
S-3	1.43	1.03	0.65	0.40	0.10
S-4	1.64	1.15	0.62	0.44	0.12
S-5	1.40	1.33	0.69	0.30	0.09
Mean[2] – Średnia[2]	1.41a	1.04a	0.61a	0.32a	0.12a
MRL*	0.50	0.40	0.50	0.10	0.07
NL*	2.50	1.60	–	–	–

*FEDIAF [2020b]; A-1 to A-5 = all breeds; L-1 to L-5 = large breeds; S-1 to S-5 = small breeds; DM = dry matter; MRL = minimum recommended level; NL = maximum level (nutritional limit).

[1]Means denoted by different letters differ statistically ($P < 0.05$) (for all columns separately); [2]means denoted by different letters differ statistically ($P < 0.05$) (for all columns separately).

*FEDIAF [2020b]; A-1 do A-5 = wszystkie rasy; L-1 do L-5 = duże rasy; S-1 do S-5 = małe rasy; DM = sucha masa; MRL = minimalny zalecany poziom; NL = maksymalny poziom (limit żywieniowy).

[1]Średnie oznaczone różnymi literami różnią się statystycznie ($P < 0,05$) (dla wszystkich kolumn oddzielnie); [2]średnie oznaczone różnymi literami różnią się statystycznie ($P < 0,05$) (dla wszystkich kolumn osobno).

group in one of the analyzed feeds, the calcium level was 79% above than MRL, and 5.2% lower than NL. It should be emphasized that the role of calcium in the diet of large breeds is particularly important and they should be provided with an appropriate level of Ca in the diet. Significantly the lowest level of calcium was found in group of foods for small breed dogs, where the average was 1.41 g per 100 g DM, with the range from 1.00 to 1.64 g per 100 g DM. The results of a larger spread were obtained in the research by Goi et al. [2019], where the range of calcium was from 0.43 to 3.77 g per 100 g DM. These studies show that some of the foods did not meet both MRL and NL, which seems to be worrying. Feeding the dog an unbalanced diet in terms of calcium content may contribute to the abnormalities mentioned above.

After Ca, P is the second most prevalent mineral in mammals, including. Phosphorus is a component of compounds necessary for the processes of energy metabolism, along with calcium participates in the process of bone tissue formation. Its deficiency may reduce the function of the heart muscle and the breakdown of erythrocytes, while its excess inhibits calcium absorption [Fuller et al. 1978]. High levels of phosphorus in the dog' diet contribute to the development of experimental chronic kidney disease in the dog. In dogs with kidney disease, serum phosphate levels increase due to decreased renal excretion of phosphate, followed by the release of bone phosphate. High levels of serum phosphate lead to a reduction in calcium levels and the induction of secondary hyperparathyroidism [Lopez-Hilker et al. 1990]. MRL of phosphorus in the feed, is 0.4 g per 100 g of DM, while NL – 1.6 g per 100 g DM. All the feeds tested had phosphorus levels within the normal range. In our study the phosphorus level did not differ significantly between the dog' foods due to the size of the breed. In A-1 feed, the phosphorus level was 70.6% above MRL, and 15% lower than NL.

Potassium plays an important role in conducting nerve impulses and regulating the action potential of cell membranes. Its deficiency may lower blood pressure and cardiac output. The excess of potassium usually results from kidney dysfunction [Kogika and de Morais 2017]. The most prominent clinical symptoms of dietary potassium deficiency (hypokalemia) result from its effects on the functioning of the heart muscle, skeletal muscles and the kidneys. Hypokalemia also affects the acid-base balance. Dietary potassium deficiency can lead to cardiac arrhythmias and generalized muscle weakness which is often manifested by stiff gait [Phillips and Polzin 1998]. MRL of potassium is 0.5 g per 100 g of dry matter. The FEDIAF [2020b] nutritional guidelines do not provide NL of potassium, magnesium and sodium. In our study the potassium level did not differ significantly between the dog' foods. In group of foods for large breed dogs the average was 0.44 g per 100g DM, while the range was from 0.30 to 0.60 g per 100 g DM. Among the foods for dogs of all breeds the average was 0.66 g per 100 g DM, while the range was from 0.48 to 0.81 g per 100 g DM. In the group of foods for dogs of small breeds the average was 0.61 g per 100 g DM, and the range was 0.36–0.70 g per 100 g DM. In A-4 feed, the potassium level was 38.3% above MRL.

Great attention should be paid to sodium, which is excreted in the urine, among other things, during physical activity. Sodium regulates the acid-base balance and participates in the conduction of nerve impulses. Its deficiency promotes dehydration and ataxia, and leads to increased heart rate [Ueda et al. 2015]. Excess can cause vomiting. According to Boemke et al. [1990], a sodium content greater than 2% in dry matter may contribute to a negative potassium balance. Increasing dietary sodium intake is believed to increase the risk of hypertension in dogs and cats, and the current recommendation for animals with hypertension is to avoid high dietary salt intake. Increased sodium in the diet increases urine output and may reduce the risk of calcium oxalate urinary stones due to a reduction in relative solute supersaturation. However, in animals with kidney disease, caution should be exercised with increasing sodium intake as this may have a negative effect on the kidneys regardless of the effect on blood pressure [Chandler 2008]. Despite the lack of established maximum recommended values, FEDIAF [2020b] provides, that scientific data show that Na levels up to 1.5 % DM is safe for healthy dogs. All feeds tested had a higher sodium level than MRL of 0.1 g per 100 g dry matter. In our study the sodium level did not differ significantly between the dog' foods. In group of foods for large breed dogs the average was 0.36 g per 100 g DM, while the range was from 0.18 to 0.82 g per 100 g DM. Among the foods for dogs of all breeds the average was 0.38 g per 100 g DM, while the range was from 0.23 to 0.47 g per 100 g DM. In the group of foods for dogs of small breeds the average was 0.32 g per 100 g DM, and the range was 0.20–0.44 g per 100 g DM. In L-1 feed, the sodium level was 87.8% above MRL.

Magnesium, which is a cofactor of many enzymes, is involved in various metabolic processes, conduction of nerve impulses and regulates the metabolism of bone tissue. Chronic magnesium deficiency and its intracellular losses are associated with hypertension in many species. Compared to other breed types, blood pressure is often much higher in brachycephalic breed dogs, which belong to small breed dogs. This means that these breeds are particularly sensitive to dietary magnesium deficiency [Stahlmann et al. 2000]. The excess of magnesium is excreted from the body in the urine and feces. As magnesium is mainly excreted in the urine, excessive Mg supplementation is avoided, especially in dogs with renal insufficiency [Bateman 2006]. MRL of magnesium is 0.07 g per 100 g DM, while the NL is not specified [FEDIAF 2020b]. All the foods contained more magnesium than MRL. In our study the magnesium level did not differ significantly between the dog' foods. In group of foods for large breed dogs the average was 0.12 g per 100 g DM, while the range was from 0.09 to 0.14 g per 100 g DM. Among the foods for dogs of all breeds the average was 0.13 g per 100 g DM, while the range was from 0.10 to 0.18 g per 100 g DM. In the group of foods for dogs of small breeds the average was 0.12 g per 100 g DM, and the range was 0.09–0.15 g per 100 g DM. In A-3 feed, the magnesium level was 61.2% above MRL. While healthy dogs appear to be able to adapt to varying amounts of Na in their diets through the 'renin-angiotensin-aldosterone mechanism', information is lacking on the effects of excess and deficiency of Na on dog nutrition. Nevertheless, the effect of high Na content in pet foods is controversial, especially for those with hypertension. Moreover, it could also be mentioned that an excess of Na, in addition to heart disease, chronic kidney disease, damage to the gastric mucosa and gastric cancer, can also disturb Ca homeostasis [Sakhaee et al. 1993].

Copper is essential for the production of melanin, which determines the color of skin and hair [Fieten et al. 2012]. It is also a component of enzymes involved in metabolic changes. Long-term copper deficiency leads to loss of coat color. The consequences of excess copper in the diet can be especially severe for Bedlington Terriers, which suffer from liver disease caused by a malfunction of the enzyme responsible for the proper metabolism of copper [Hyun and Filippich 2004]. MRL is 0.72 mg per 100 g DM, the legal limit (LL) is 2.8 mg per 100 g DM (Table 2). Significantly the highest level of copper was discovered in group of foods for small breed dogs, where the average was 1.74 mg per 100 g DM, while the range was from 1.12 to 3.62 mg per 100 g DM. Among the foods for dogs of all breeds the average was 1.23 mg per 100 g DM, while the range was from 1.00 to 1.73 mg per 100 g DM. In the group of foods for dogs of large breeds the average was 1.29 mg per 100 g DM, and the range was 0.86–1.77 mg per 100 g DM. Only in S-5 feed, the copper level was 29.3% above LL. Some of the dog foods tested by Davies et al. [2017] were overloaded with Cu. Maximum level of copper in their research was 4.66 mg/100 g DM compared to MRL, 2.80 mg per 100 g DM.

Iron is a component of hemoglobin and myoglobin, the role of which is to transport and store oxygen in the body. Excess iron in the diet of dogs can lead to mild damage to the digestive tract. Iron deficiency causes anemia, pale mucous membranes, and diarrhea [Harvey 1998]. MRL is 3.6 mg per 100 g DM, and the LL is

Table 2. Microelements (mg per 100 g DM) in tested dog foods

Tabela 2. Zawartość mikroelementów w badanych karmach (mg na 100 g s.m.)

Item – Wyszczególnienie	Cu	Fe	Mn	Zn	Co	Cr	Mo	Ni	Cd	Pb
Breed size[1] – Wielkość rasy[1]										
A-1	1.22	10.36	2.92	6.52	0.004	0.056	0.009	nd	nd	nd
A-2	1.17	28.30	2.84	11.44	0.004	0.007	0.007	nd	nd	nd
A-3	1.00	6.30	2.34	11.27	0.005	0.005	0.007	nd	nd	nd
A-4	1.03	16.96	1.34	10.97	0.007	0.007	0.008	nd	nd	nd
A-5	1.73	25.79c	2.01	12.51	0.008	0.009	0.007	nd	nd	nd
Mean[2] – Średnia[2]	1.23a	17.54	2.29a	10.54c	0.006a	0.017b	0.008a	nd	nd	nd
L-1	1.51	12.90	1.35	12.40	0.009	0.004	0.006	nd	nd	nd
L-2	1.20	16.20	3.17	7.96	0.009	0.004	0.005	nd	nd	nd
L-3	1.77	17.92	3.42	6.86	0.010	0.005	0.005	nd	nd	nd
L-4	1.08	14.37	2.02	9.79	0.010	0.004	0.006	nd	nd	nd
L-5	0.86	16.07	3.48	6.63	0.005	0.003	0.005	nd	nd	nd
Mean[2] – Średnia[2]	1.29a	15.49b	2.69b	8.73a	0.008a	0.004a	0.006a	nd	nd	nd
S-1	1.47	7.54	0.87	9.73	0.010	0.004	0.005	nd	nd	nd
S-2	1.23	17.95	4.63	8.91	0.010	0.004	0.005	nd	nd	nd
S-3	1.12	12.06	2.05	9.94	0.011	0.003	0.004	nd	nd	nd
S-4	1.24	6.83	2.80	9.83	0.012	0.001	0.005	nd	nd	nd
S-5	3.62	12.09	4.00	8.36	0.014	0.004	0.004	nd	nd	nd
Mean[2] – Średnia[2]	1.74b	11.30a	2.87b	9.35b	0.012a	0.003a	0.005a	nd	nd	nd
MRL*	0.72	3.60	0.58	7.20	–	–	–	–	–	–
LL*	2.80	68.18	17.00	22.70	–	–	–	–	–	–

*FEDIAF [2020b]; A-1 to A-5 = all breeds; L-1 to L-5 = large breeds; S-1 to S-5 = small breeds; DM = dry matter; MRL = minimum recommended level; LL = maximum level (legal limit).

[1]Means denoted by different letters differ statistically (P < 0.05) (for all columns separately); [2]means denoted by different letters differ statistically (P < 0.05) (for all columns separately).

*FEDIAF [2020b]; A-1 do A-5 = wszystkie rasy; L-1 do L-5 = duże rasy; S-1 do S-5 = małe rasy; DM = sucha masa; MRL = minimalny zalecany poziom; LL = maksymalny poziom (dozwolony limit prawny).

[1]Średnie oznaczone różnymi literami różnią się statystycznie (P < 0,05) (dla wszystkich kolumn oddzielnie); [2]średnie oznaczone różnymi literami różnią się statystycznie (P < 0,05) (dla wszystkich kolumn osobno).

68.18 mg per 100 g DM. All of the feeds tested contained iron levels in line with the standards. Significantly the highest level of iron was discovered in group of foods for dogs of all breeds, where the average was 17.54 mg per 100 g DM, while the range was from 6.30 to 28.30 mg per 100 g DM. Among the foods for large breed dogs the average was 15.49 mg per 100 g DM, while the range was from 12.90 to 17.92 mg per 100 g DM. In the group of foods for dogs of small breeds the average was 11.30 mg per 100 g DM, and the range was 6.83–17.95 mg per 100 g DM. In A-2 feed, the iron level was 87.7% above MRL, and 58.5% lower than LL.

Manganese acts as an activator of many enzymes, the consequences of its deficiency in animals are lameness and enlargement of the joints. Juveniles may experience delayed growth and shortened limbs [Hurley and Keen 1987]. MRL is 0.58 mg per 100 g DM, and LL is 17 mg per 100 g DM. All tested feeds were characterized by the level of manganese in accordance with the applicable standards. Significantly the highest level of manganese was discovered in group of foods for small breed dogs, where the average was 2.87 mg per 100 g DM, while the range was from 0.87 to 4.63 mg per 100 g DM. Among the foods for dogs of all breeds the average was 2.29 mg per 100 g DM, while the range was from 1.34 to 2.92 mg per 100 g DM. In the group of foods for dogs of large breeds the average was 2.69 mg per 100 g DM, and the range was 1.35–3.48 mg per 100 g DM. In S-2 feed, the manganese level was 70.6% above MRL, and 15% lower than LL.

Zinc is essential for the proper functioning of the skin and for wound healing. It plays an important role in the construction and functioning of biological membranes. Its deficiency may cause skin changes. High levels can have a positive effect in improving the condition of the hair coat [Marsh et al. 2000]. MRL of zinc is 7.2 mg per 100 g DM, and LL is 22.7 mg per 100 g DM. Of the foods tested, 20% had a lower zinc level than MRL. Zinc deficiency is well known in dog nutrition and, among others, may reduce Zn serum concentration, affect animals' growth, cause skin lesions, behavioral problems and compromises immune function. In pet food it is common practice to supplement diets with a Zn level above minimum requirement to prevent symptoms of deficiency [Pereira et al. 2020]. Low levels of zinc, which is one of the detoxifying agents of cadmium, lead and mercury, promote the absorption of these toxic metals from food. The imbalance in the diet in terms of Zn level also results in the appearance of skin inflammations and abnormal hair growth [Sousa et al. 1988]. No pet food exceeded the maximum content. Zinc and manganese contribute to the proper functioning of the enzymatic antioxidant system. Both of these trace elements thus prevent an excessive increase in the content of reactive oxygen species. Significantly the highest level of zinc was discovered in group of foods dogs of all breeds, where the average was 10.54 mg per 100 g DM, while the range was from 6.52 to 12.51 mg per 100 g DM. Among the foods for large breed dogs the average was 8.73 mg per 100 g DM, while the range was from 6.63 to 12.40 mg per 100 g DM. In the group of foods for dogs of small breeds the average was 9.35 mg per 100 g DM, and the range was 8.36–9.94 mg per 100 g DM. In A-5 feed, the zinc level was 42.5% above MRL, and 44.9% lower than LL.

Although FEDIAF nutritional guidelines do not specify MRLs or LLs of chromium, cobalt and molybdenum, their trace amounts were found during own analyzes. However, Kim et al. [2018] research shows that in dog food these elements may be present in greater amounts. In their studies, the concentrations of chromium and molybdenum in all dog foods were at levels that would be considered higher than the average daily human consumption. However, based on further findings, it appears safe to consume these amounts of minerals in dry dog food.

However, the level of the element in the diet is not the only factor, as the bioavailability and metabolism of minerals are also important. Many factors affect the absorption and use of the mineral by the animal's body. Intestinal absorption of trace elements such as Zn and Cu can be reduced if the diet is relatively high in fiber or anti-nutritional substances (phytates). Also, a high level of Ca may inhibit the absorption of Fe and Zn in the gastrointestinal tract. Therefore, bioavailability of trace elements determines the effectiveness [Grases et al. 2001]. Kastenmayer et al. [2002] showed that apparent absorption of Ca, Fe and Zn, but not Cu, from commercial dry dog food by adult dogs is low. The low absorption should be taken in account when recommendations for requirements of these elements are established.

Relations between the elements

The absorption of minerals depends not only on their amount, but also on the proportion of the provided food. Some components of the diet reduce the bioavailability of elements, an excess of one mineral may impede the absorption of another.

The metabolism and bioavailability of minerals are complex. A high dietary fiber or phytate content may reduce the intestinal absorption of micronutrients such as zinc or copper. Moreover, high levels of calcium in the diet may inhibit the absorption of iron and zinc in the gastrointestinal tract. In animals with subclinical diseases such as early stage kidney disease, differences in hormone status or vitamin status can significantly affect mineral uptake from the gut [Pereira et al. 2018].

The nutritional guidelines have only established MRL (1:1) and MNL (2:1) for the Ca:P ratio [FEDIAF 2020b], which is shown in Table 3. The highest average ratio of calcium to phosphorus, 1.83:1, was in the group of foods for large breed dogs, where the range was 1.04–2.76:1. In group of foods for dogs of all breeds the average was 1:58:1, and the range was 0.86–2.02:1. The lowest average, 1.38:1, was in group of foods for small breed dogs, while the range was from 1.05:1 to 1.86:1. Own analyzes showed that 20% of feeds (A-3; L-1; L-2) exceeded the permitted maximum value. Long-term feeding of feeds that are poorly balanced in terms of Ca and P content may lead to depletion of the body' calcium reserves and disturbance of the mineral stability of bone structures, and then to the syndrome of secondary nutritional hyperparathyroidism [Tal et al. 2018]. One feed (A-1) had a Ca:P ratio less than the recommended minimum, 0.86:1. The results from our analyzes were closer to the FEDIAF [2020b] standards than, for example, in the analyzes by Davies et al. [2017], where some of the feeds had a Ca:P ratio less than 0.25:1, and some more than 2.5:1.

Recommended ratios between other elements are not determined by the nutritional guidelines. That is why the mineral ratios (Table 3) were calculated on the basis of the FEDIAF [2020b] recommended minimum content of a given element in dog food. The ratio of calcium to magnesium (Ca:Mg) has gained a lot of attention in recent years. It increases the risk of metabolic, inflammatory and cardiovascular disorders. When the calcium concentration is high, the absorption of magnesium can be significantly reduced [Dai et al. 2007]. The correct ratio of calcium to magnesium should be at least 7.17:1. The highest average ratio, 15.74:1, was in the group of foods for large breed dogs, where the range was 8.00–21.25:1. In group of foods for dogs of all breeds the average was 13.74:1, and the range was 10.64–18.78:1. The lowest average, 12.26:1, was in group of foods for small breed dogs, while the range was from 6.82:1 to 14.98:1. Among the analyzed foods 93% met the recommended minimum. Only S-2 food had a lower ratio. The L-3 food had the highest ratio of calcium to magnesium. A high ratio may indicate abnormal calcium metabolism, causing excessive calcium deposition in the soft tissues. This leads to constant muscle tension and contraction. For example, if the muscles surrounding the bladder are in a tense state due to a disturbed ratio of these minerals, the bladder capacity will be reduced, which may consequently increase the frequency of urination due to the limited bladder size. The action of magnesium in the body is suppressed by excess calcium, which may contribute to calcium deposition in the urinary tract and gallbladder. Highest ratio of calcium to magnesium may has a certain relationship with the incidence rate of urolithiasis in dog [Yangfeng and Zhang 2016].

The ratio of calcium to potassium (Ca:K) should be not less than 1:1. All analyzed feeds met the recommended minimum. A-2 had the lowest ratio, while L-3

Table 3. Relations between elements in tested dog foods calculated according to MRL

Tabela 3. Stosunki minerałów w analizowanych karmach na podstawie MRL

Item – Wyszczególnienie	Ca:P	Ca:Mg	Ca:K	Na:K	Na:Mg	Zn:Cu	Fe:Cu
Breed size – Wielkość rasy							
A-1	0.86:1	10.64:1	2.46:1	0.48:1	2.05:1	5.34:1	8.49:1
A-2	1.24:1	13.26:1	1.89:1	0.64:1	4.47:1	9.77:1	24.16:1
A-3	2.02:1	10.92:1	3.32:1	0.76:1	2.50:1	11.25:1	6.29:1
A-4	1.84:1	15.12:1	2.16:1	0.55:1	3.85:1	10.64:1	16.45:1
A-5	1.93:1	18.78:1	3.53:1	0.45:1	2.41:1	7.23:1	14.91:1
Mean – Średnia	1.58:1	13.74:1	2.67:1	0.58:1	3.06:1	8.85:1	14.06:1
L-1	2.76:1	15.27:1	3.95:1	1.59:1	6.14:1	8.19:1	8.52:1
L-2	2.15:1	18.34:1	6.04:1	0.46:1	1.40:1	6.63:1	13.49:1
L-3	1.66:1	21.25:1	6.15:1	0.83:1	2.88:1	3.87:1	10.10:1
L-4	1.52:1	15.82:1	2.49:1	0.57:1	3.62:1	9.07:1	13.32:1
L-5	1.04:1	8.00:1	2.73:1	0.50:1	1.47:1	7.71:1	18.67:1
Mean – Średnia	1.83:1	15.74:1	4.27:1	0.79:1	3.10:1	7.09:1	12.82:1
S-1	1.86:1	11.84:1	2.26:1	0.40:1	2.07:1	6.63:1	5.14:1
S-2	1.17:1	6.82:1	2.75:1	0.55:1	1.37:1	7.25:1	14.60:1
S-3	1.39:1	13.67:1	2.19:1	0.61:1	3.80:1	8.91:1	10.82:1
S-4	1.43:1	13.99:1	2.63:1	0.71:1	3.76:1	7.92:1	5.51:1
S-5	1.05:1	14.98:1	2.03:1	0.43:1	3.20:1	2.31:1	3.34:1
Mean – Średnia	1.38:1	12.26:1	2.37:1	0.54:1	2.84:1	6.60:1	7.88:1
MRL*	1:1	7.17:1	1:1	0.2:1	1.43:1	10:1	5:1

*FEDIAF [2020b]; A-1 to A-5 = all breeds; L-1 to L-5 = large breeds; S-1 to S-5 = small breeds; DM = dry matter; MRL = minimum recommended level.

*FEDIAF [2020b]; A-1 do A-5 = wszystkie rasy; L-1 do L-5 = duże rasy; S-1 do S-5 = małe rasy; DM = sucha masa; MRL = minimalny zalecany poziom.

had the highest one. The highest average ratio, 4.27:1, was found in the group of foods for large breed dogs, where the range was 2.49–6.15:1. In group of foods for dogs of all breeds the average was 2.67:1, and the range was 1.89–3.53:1. The lowest average, 2.37:1, was in group of foods for small breed dogs, while the range was from 2.03:1 to 2.75:1. The appropriate level of potassium is necessary to sensitize tissues to the effects of thyroid hormones. In adults, too low a potassium level in the diet leads to a reduction in blood pressure and cardiac output [Abbrecht 1972]. The excess of potassium usually results from kidney dysfunction. A high calcium to potassium ratio may indicate hypothyroidism and/or a decreased cellular response to thyroxine. Long-term food intake with a high ratio of calcium to potassium may manifest itself, inter alia, in chronic fatigue, depression, tendency to overweight.

The minimum sodium to potassium (Na:K) ratio should be greater than 0.2:1. All analyzed feeds met the standards. The lowest ratio was observed in S-1, while the highest in L-1. The highest average ratio, 0.79:1, was in the group of foods for large breed dogs, where the range was 0.46–1.59:1. In group of foods for dogs of all breeds the average was 0.58:1, and the range was 0.45–0.76:1. The lowest average, 0.54:1, was in group of foods for small breed dogs, while the range was from 0.40:1 to 0.71:1. The right ratio of sodium to potassium is essential to maintain the body's water and electrolyte balance. Sodium is the main cation in the extracellular fluid and one of the basic minerals [Pak 2000]. Its deficiency may lead to, among others, increased heart rate, dehydration, increased thirst, ataxia and lethargy [Ueda et al. 2015]. The correct concentration of sodium and potassium in the plasma is maintained by balanced intake and excretion.

The ratio of sodium to magnesium (Na:Mg) should be no less than 1.43:1. Among the analyzed foods, 13% were below that level. The feed ratio was the lowest for S-2, and the highest for L-1. The highest average ratio, 3.10:1, was in the group of foods for large breed dogs, where the range was 1.40–6.14:1. In group of foods for dogs of all breeds the average was 3.06:1, and the range was 2.05–4.47:1. The lowest average, 2.84:1, was in group of foods for small breed dogs, while the range was from 1.37:1 to 3.80:1. Magnesium affects the activity of the adrenal cortex, and the decreased activity of the adrenal glands increases magnesium retention. Its deficiency in young dogs can lead to paralysis of the hind limbs, while long-term calcium deficiency in the diet of dogs can lead to hyperparathyroidism. Skeletal defects, such as pathological fractures, are also a consequence of hypocalcemia. Skeletal abnormalities are observed in young dogs, particularly large and giant breeds [Nap et al. 1993]. Low calcium to magnesium ratio may be associated with decreased adrenal function, which may be manifested by low blood pressure, constipation, dry epidermis.

Zinc and iron are antagonistic to copper. In the case of a high concentration of zinc ions, the absorption of copper ions may decrease. To avoid secondary deficiency, it is important to maintain the correct ratio between zinc and copper in the diet. According to the recommendations of FEDIAF [2020b], the ratio of zinc to copper (Zn:Cu) should be no less than 10:1. In all, 87% of the analyzed foods had a ratio below the norm. The lowest ratio was found for S-5, while the highest for A-3. The highest average, 8.85:1, was in the group of foods for all breeds dogs, where the range was 5.34–11.25:1. In group of foods for large breed dogs the average was 7.09:1, and the range was 3.87–9.07:1. The lowest average, 6.60:1, was in group of foods for small breed dogs, while the range was from 2.31:1 to 8.91:1. Zinc is essential for potassium retention in the body. A low zinc to copper ratio often indicates a tendency towards decreased thyroid activity as a result of potassium deficiency. Zinc and copper are closely related to hormones, and their levels in tissues may indirectly reflect the status of estrogen and progesterone in the body. An incorrect ratio of zinc and copper can lead to some emotional and physical changes. Zinc deficiency can cause skin lesions and slow down the growth rate of young dogs [Sanecki et al. 1982].

The correct ratio of iron to copper (Fe:Cu) should be at least 5:1. The highest average, 14.06:1, was in the group of foods for dogs of all breeds, where the range was 6.29–24.16:1. In group of foods for dogs of large breeds the average was 12.82:1, and the range was 8.52 to 18.67:1. The lowest average, 7.88:1, was in group of foods for small breed dogs, while the range was from 3.34:1 to 14.60:1. 93% of the analyzed foods met the recommended minimum. Only the S-5 food had a lower ratio. The feed A-2 had the highest ratio of iron to copper. An excess of iron in a dog's diet can lead to mild gastrointestinal damage. High levels of copper interfere with iron absorption, which reduces its use by the body. This leads to anemia and frequent diarrhea [Harvey 1998].

CONCLUSIONS

This study highlights non-compliance of popular pet foods with current EU guidelines. All foods meet the recommended minimum of macro- and microelements, but 33% feeds (A-1, L-2, L-3, L-5, S-2) had potassium level lower than MRL. What is more, the S-5 feed exceeded the acceptable copper level. The minimum recommended quantitative Ca to P ratio (1:1) for adult dogs was not met in the A-1 food. However, the maximum allowable (2:1) was exceeded by 20% of the tested foods (A-3, L-1, L-2). The quantitative relationship is also decisive for the other assessed minerals, because some of them show an antagonistic effect. Own analyzes and calculations showed the correctness of relations to the FEDIAF [2020b] calculations. No heavy metals (Ni, Cd, Pb) were found in any of the feeds tested. When choosing a food, always pay attention to the label and carefully analyze the component composition of the product. It is worth choosing feeds, the manufacturer of which declares the component composition according to the names of the raw materials, thanks to which you know exactly what species was used to produce the feed. Keep in mind that the dog is a relative carnivore and most of its diet should be meat products. It is necessary to select the appropriate food according to the animal's needs, its physiological condition, age and breed size. The domestic dog is a very diverse species: small breeds require different food than large breeds. The results obtained support the need for more frequent, regular, and more accurate analyzes of pet food. The presented study also showed that nutrient levels should only be verified on the basis of nutritional guidelines.

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ANALIZA SKŁADNIKÓW MINERALNYCH W SUCHEJ KARMIE DLA PSÓW I ICH ZGODNOŚĆ Z WYTYCZNYMI ŻYWIENIOWYMI

STRESZCZENIE

Celem pracy była ocena pełnoporcjowych suchych ekstrudowanych karm dla dorosłych psów, ze szczególnym uwzględnieniem: profili i wskaźników mineralnych oraz podziału na wielkość ras. Karmy były poddane analizom chemicznym w celu określenia zawartości makroelementów i mikroelementów. Dodatkowo zweryfikowano obecność metali ciężkich. Materiałem badawczym było 15 losowo wybranych komercyjnych karm dla psów dorosłych (pięć dla psów dużych ras, pięć dla psów małych ras i pięć dla wszystkich ras). Wszystkie analizowane karmy zawierały rekomendowane przez FEDIAF minimalne zalecane poziomy mikroelementów i makroelementów, chociaż poziom potasu w 33% karm był poniżej zalecanego minimum. W 20% testowanych karm przekroczono dopuszczalny stosunek ilościowy wapnia do fosforu. W żadnej z testowanych karm nie stwierdzono metali ciężkich (Ni, Cd, Pb). Wybierając karmę, należy zawsze zwracać uwagę na informacje na etykiecie i dokładnie przeanalizować skład produktu.

Słowa kluczowe: sucha ekstrudowana karma dla psów, pełnoporcjowa karma, makroelementy, pierwiastki śladowe, metale ciężkie, wielkość rasy

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