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REVIEW PAPER

Optimization of dogs' nutrition – an overview of current research*

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Abstract

Trends in companion animal nutrition often reflect trends in human nutrition. Some keepers use a raw food (primary) diet for their animals, believing that it may provide better health benefits for their animals. Others, basing their diet on products of plant origin, will feed dogs a vegetarian or vegan diet. Recently, products containing protein from insects have become increasingly popular on the food market. Dog nutrition is very often related to the owner's lifestyle, which leads to nutritional mistakes that, if repeated over a long period of time, may cause behavioral disorders or diseases. Knowledge of the specificity of the digestive tract, digestive behavior and energy needs of a dog allows us to optimize the nutrition of this species. Current knowledge about the nutritional requirements of dogs is the result of decades of research, and dog nutrition should be based on it. Due to the constantly growing interest in dog nutrition among guardians, as well as the growing empathy towards companion animals, owners want to feed them well so that their animals live longer in the best possible condition. The article presents the nutritional requirements of dogs based on the recommendations of the National Research Council (NRC) and The European Pet Food Industry Federation (FEDIAF), and provides an up-to-date review of research on the optimal nutrition of dogs, especially in particularly demanding physiological or health phases/periods of their lives, with particular attention to indicators, such as age, castration, obesity, pregnancy and lactation, or behavior.

Keywords: dogs, nutrition, age, behavior, physical condition

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INTRODUCTION

The domestic dog is an animal of a very diverse species, with a body weight ranging from 4 kg to 80 kg. The birth weight of puppies depends on the breed and ranges between 120 g and 550 g. During the first 5 months, puppies gain on average 2-4 g kg^{-1} BW (body weight) for a day of expected adult body weight (Makwana et al. 2021). Small breed dogs are puppies for a shorter period of time than medium, large or giant breed dogs due to their physical maturity being reached more quickly (Villarreal et al. 2020). They usually reach their target size at 9 to 12 months, and large and giant ones only at 18-24 months. Due to differences in growth rates depending on the dog's size, commercial production companies try to tailor food for small, medium, large and giant breeds. Foods for small and medium-sized dogs are richer in energy and protein, while foods for large and giant breeds are lower in calories, but still rich enough in protein to enable proper growth and development (Case et al. 2010, Greco 2014). Other groups of dogs, such as sports dogs, working dogs, geriatric dogs, pregnant or lactating bitches, require an individual balanced diet in terms of the demand for selected nutrients, including minerals and vitamins (Laflamme 2005, Metzger 2005, Foster 2011, Laflamme 2012, Wakshlag et al. 2014, Bosch et al. 2021, Ridgway 2021, Zoran 2021).

FACTORS INFLUENCING THE AMOUNT OF NUTRIENTS NEEDED BY DOGS

Genetic conditions

The type of food is determined by the structure of the digestive system. The characteristic structure of the digestive tract indicates that the dog has been a carnivorous animal since the beginning of time: wide mouth, long tongue and 42 massive cutting and gripping teeth. Mucins in saliva, antibacterial lysozymes, and the low pH of gastric juice with a high concentration of hydrochloric acid facilitate the digestive process. Carnivorous animals have a single-chamber stomach, into which food enters through a muscular, flexible oesophagus adapted to swallow large bites. They also have short loops of the small intestine with a retrograde cecum, contrary to omnivores and herbivores (Smeets-Peeters et al. 1998). These animals are sensitive to the deficiency of exogenous amino acids and vitamins, including A, D, E and K. Arginine and/or taurine deficiency may be particularly dangerous. For dogs to enjoy long-term health, skillfully balancing their diet is very important. Not all human dietary trends can be incorporated into a dog's diet. A dog, compared to a human, has an entirely different demand for individual nutrients. The biggest challenge is to meet the demand for protein

and exogenous amino acids. Therefore, vegetarian or vegan diets, although becoming more and more popular among people, is highly debatable in the case of dogs due to the difficulty in providing an adequate pool of exogenic amino acids, which are missing in products of plant origin. Proper feeding hygiene for dogs also means meeting their nutritional, and behavioral needs, i.e. chewing, biting and licking, which should be an integral part of every dog's diet (Sandri et al. 2016).

Age

In animal nutrition, it is particularly important to optimize the coverage of protein needs and energy. Nutritional requirements change with age (Table 1), and therefore the energy needs of dogs vary depending on the age of the dog (Abood et al. 2021). The theory is that a dog should be fed puppy

Table 1

Nutritional recommendations regarding the daily energy requirement MER in dogs depending on age (FEDIAF 2019)

Age (year)	kcal ME *(kg $^{0.75}$)$^{-1}$	kJ ME *(kg $^{0.75}$)$^{-1}$
1–2	130 (125-140)	550 (523-585)
3–7	110 (95-130)	460 (398-545)
> 7	95 (80-120)	398 (335-500)

food from weaning until adulthood. Feeds for young animals are characterized by a higher energy concentration, a higher content of easily digestible protein and a higher supply of calcium in dry matter (Laflamme 2001). The energy value of food for adult dogs is approximately 300-400 kcal kg^{-1} BW, less than in puppy food (Delaney, Fascetti 2023). The minimum protein requirement for an adult dog according to the NRC (National Research Council 2006) is 45 g 1000 kcal^{-1}. Foods below 60 g 1000 kcal^{-1} are considered low-protein, and foods above 90 g 1000 kcal^{-1} are considered high-protein. Currently, nutritional guidelines provide information on the minimum levels of protein and amino acids, but maximum limits have not been set, so the maintenance food for adult dogs may vary significantly in protein levels. Most commercial foods usually provide much more protein than a healthy dog needs. The nutrition of adult dogs depends on many factors, including: physical activity, general condition, physiological status, or castration. With age, the demand for energy and protein per kilogram of metabolic body weight decreases due to a decrease in physical activity and a lower metabolic rate. Dogs over the age of seven may require 10-15% less energy than those aged three to seven (Bermingham et al. 2014). The minimum protein content in the diet of adult dogs according to the nutritional guidelines is 18% in dry matter (21% with lower energy intake), which is lower compared to the protein needs of puppies, which need approximately 25% of total protein in the diet for proper growth and development (FEDIAF 2021). Due to the increased incidence of chronic kidney disease, it is recommended to reduce the sup-

ply of phosphorus and, due to the higher risk of obesity, also to reduce energy intake (Metzger 2005, Lauten 2006). Therefore, it is necessary to properly balance the food depending on the energy needs of a given individual.

To correctly assess the energy demand of a given dog, taking into account its age, body weight, physiological condition and physical activity, the MER (Maintenance Energy Requirement) values, then the RER (Resting Energy Requirement) and DER (Daily Energy Requirement) values should be correctly estimated.

MER = dog body weight 0.75,

RER = MER x 70,

DER = RER x variable value depending on the age, size, physiological state, condition (BCS) and activity of a given dog (Burger 1994, Case et al. 2010, Pedrinelli et al. 2019).

Examples:

DER for a dog growing from 8 to 12 months of age = 2.5 x RER,

DER for a neutered adult dog = 1.8 x RER,

DER for an obese adult dog = 1 x RER,

DER for a pregnant bitch after the 6th week of pregnancy = 3x RER,

DER for a working dog = 2-8 x RER (depending on work intensity) – Freeman et al. (2011).

Compared to the requirements of adult dogs, puppies have an increased need for many nutrients that support organ development, muscle synthesis, and skeletal growth (Foster 2011, Hemmings 2018, Villarreal et al. 2019). The most important ones include protein, fats, calcium, phosphorus and vitamin D (McLeod 2008, Rossi et al. 2021). The carbohydrate needs of puppies, like those of other age groups, are not defined by restrictive standards (Rankovic et al. 2019, Gizzarelli et al. 2021). Puppies begin intense growth already during the weaning period (Table 2), and the growth rate depends on the breed. Growing puppies should be fed a diet specifically formulated

Table 2

Average energy requirement of dogs during the growth period

Development period	Energy demand	
Newborns or toddlers	25 kcal 100 g^{-1}	105 kJ 100 g^{-1}
Up to 50% of an adult dog's body weight	210 kcal * (kg $BW^{0.75}$)$^{-1}$	880 kJ * (kg $BW^{0.75}$)$^{-1}$
50 to 80% of an adult dog's body weight	175 kcal * (kg $BW^{0.75}$)$^{-1}$	730 kJ * (kg $BW^{0.75}$)$^{-1}$
80 to 100% of an adult dog's body weight (FEDIAF, 2021)	140 kcal * (kg $BW^{0.75}$)$^{-1}$	585 kJ * (kg $BW^{0.75}$)$^{-1}$

to meet their nutritional needs for proper development (American Kennel Association). The food for growing puppies is characterized by a high protein content in the range of 50-62.5 g for every 1000 kcal. The minimum fat requirement is 21.25 g 1000 $kcal^{-1}$ of metabolic energy ME, (FEDIAF 2021) – Table 3.

Table 3

Data for balancing the diet for puppies of selected dog breeds (FEDIAF 2021)

Data	DER (kcal)	Minimal demand				Recommended Ca:P (min./max)
		protein (g)	fat (g)	calcium (mg)	phosphorus (mg)	Recommended for a puppy
Miniature breed	283.5	14.17	6.02	500	560	1:1 or 1:1.8
						1:1,41
Small breed	537.36	26.87	11.4	1080	940	1:1 or 1:1.8
						1.04:1
Medium breed	754.21	37.71	16.03	1510	1320	1:1 or 1:1.8
						1.58:1
Large breed	1835.4	91.75	39	4580	5870	1:1 or 1:1.6
						1.28:1
Extra-large breed	2347.87	117.39	49.86	3210	4110	1:1 or 1:1.6
						1.13:1

The gastrointestinal tract of large and giant breed puppies accounts for only approximately 2.7% of their total body weight and its immaturity, combined with the high energy requirements of puppies, may pose a nutritional problem for breeders and caregivers (Hemmings 2018) The pre-weaning period has the highest mortality rate resulting from improper feeding or malnutrition of puppies (Chastant-Maillard et al. 2012, Mila et al. 2021). The most common cause is abnormal behavior of the mother resulting from a low level of maternal instinct or incorrect nutrition of the bitch during the third stage of pregnancy and during lactation. The amount of antibodies penetrating the placenta is very low (only 10-20%) – Case et al. (2010), therefore the appropriate amount and quality of colostrum is crucial for proper development and ensuring passive immunity during the first 4 months of the puppy's life (Hemmings 2018). In the postnatal period in puppies, although the digestive system is completely formed in terms of structure, it is still immature and in the postnatal period there is a gradual increase in digestive functions until behavioral weaning at the age of 4-6 weeks, when the digestive tract is ready for a change in feeding habits (Hawthorne et al. 2004, Rossi et al. 2021). In order to avoid excessive load on the digestive tract, the food should be adjusted in terms of consistency and number of portions (Hemmings 2016).

Many orthopedic diseases in dogs may be the result of improper nutrition during puppyhood (Lauten et al. 2002). Deficiency or lack of certain nutrients in the diet that are important for bone development may have long-term effects in the future. Particular attention should be paid to the metabolism related to calcium absorption (Tryfonidou et al. 2003, Mack et al. 2015). Excess dietary calcium is stored in the skeletal bones of growing puppies. Therefore, to avoid calcium overdose, an ideal calcium to phosphorus ratio of 1.2:1 should be maintained. The calcium content in the food of large and giant breed dogs should be approximately 1%, and the phosphorus level should be approximately 0.8% in dry matter (Laflamme 2001, Villarreal et al. 2019). Moreover, puppies of large and giant breeds are genetically "programmed" to grow quickly (Lauten 2006). However, too much body weight resulting from an inadequately balanced diet may put too much strain on the developing skeleton and lead to diseases of the musculoskeletal system. Overfeeding puppies may result in skeletal deformations, especially in large and giant breeds. Therefore, puppies should never be fed ad libitum and their body weight should be closely monitored. The energy value of food for large breed puppies should be from 3.5 to 4.0 kcal g^{-1}, with a fat content of less than 15% in dry matter (Richardson et al. 1998, Lauten 2006, Rolph et al. 2014, Johnson et al. 2020). Puppy guardians must regularly assess the condition of puppies and their weight gain, regardless of what food their animals are fed (Hall et al. 2020) Optimal body weight gain is not the same as maximum body weight gain (Debraekeleer 2010, Hemmings 2016).

The type of dog's diet during puppyhood may influence the occurrence or absence of symptoms of atopy/skin allergies in adulthood (Hemida et al. 2021). Exposure to various environmental factors in early life, including a diet, influence the development of the immune system. Scientists have proven that dogs fed with highly processed animal products have a higher tendency to develop atopic dermatitis in adulthood, and its first symptoms appear by the age of 3 (Santoro et al. 2016, Marsella et al. 2017, Hemida et al. 2021). Also, deworming the bitch during pregnancy reduces the risk of undesirable allergies, including food allergies, in puppies (Hemida et al. 2020).

With the constant development of veterinary medicine, dogs are living to an increasingly old age. Older pets are becoming an increasing percentage of patients in veterinary offices. The aging process is influenced by factors such as breed size, genetics, nutrition, and environment (Hyung-hak 2018). Aging can cause numerous changes in the gastrointestinal tract and is also associated with reduced activity, which contributes to reduced MER (Laflamme 2005, Laflamme 2012). Gastrointestinal changes that occur with age include slower transit time, altered enzymatic activity, impaired circulation, and reduced secretion of hydrochloric acid and bile, which contributes to decreased digestive capacity (Harper 1998, Hall et al. 2003, Fahey et al. 2008). The age at which a dog's activity declines may vary between breeds

and even between individuals (Groves 2019). All this means that aging patients require different nutrition than younger ones. As dogs age, MER declines by approximately 25%, with the greatest decline at middle age (7 years) – Metzger (2005).

Appropriate nutrition for aging dogs is intended to support health and vitality, prevent age-related health disorders, and improve the dog's quality of life and life expectancy. Currently, more attention is being paid to nutritionally balanced dog food depending on their age (Schauf et al. 2016, Jung 2018). Additionally, many diseases common in older dogs may be nutrient sensitive, meaning that a diet may play an important role in disease management (Hyung-hak 2018). Tooth loss is a common problem in older dogs, which can make it difficult for them to eat dry food with large kibble sizes (Kim et al. 2021).

Physiological condition of dogs

Pregnancy and lactation are considered the most critical periods in animal nutrition. Proper feeding and management of animal reproduction both begin during the growth of the mother. Pregnancy in a female dog lasts on average 63 days, divided into 21-day trimesters (Puttock 2020). The energy demand of pregnant animals increases significantly in the last period of pregnancy, which breeders and dog guardians must know and remember (Fontaine 2012). Lactation is also extremely demanding, and energy requirements can increase three times the basal requirement, especially in the case of large litters (Greco 2008) (Table 4). The optimal weight at the end of pregnancy should not exceed the weight of the bitch before mating by more than 15-25%, and after giving birth: by 5-10% (Greco 2008).

Table 4

Average energy requirement of dogs during the reproductive period (FEDIAF 2021)

Females	Reproduction phase	Energy demand	
Pregnancy	the first 4 weeks of pregnancy	132 kcal * (kg $BW^{0.75}$)$^{-1}$	550 kJ * (kg $BW^{0.75}$)$^{-1}$
	last 5 weeks of pregnancy	132 kcal * (kg $BW^{0.75}$)$^{-1}$ + + 26 kg^{-1} BW	550 kJ * (kg $BW^{0.75}$)$^{-1}$ + + 110 kg^{-1} BW
Lactation	lactating females	kcal	kJ
	from 1 to 4 puppies	132 * (kg $BW^{0.75}$)$^{-1}$ + + 24*n* x kg BW x L	550 * (kg $BW^{0.75}$)$^{-1}$ + + 100*n* x kg BW x L
	5 to 8 puppies	132 * (kg $BW^{0.75}$)$^{-1}$ + (96 + 12*n*) x x kg BW x L	550 * (kg $BW^{0.75}$)$^{-1}$ + + (400 + 50*n*) x kg BW x L

n – number of puppies, L – 0.75 in week 1 of lactation; 0.95 in week 2; 1.1 in week 3 and 1.2 in week 4

Appropriate supply of nutrients to a pregnant dog supports the proper growth and development of the fetus. Both overfeeding and undernutrition can have a negative impact on fertilization and the number of fetuses. Female dogs of breeds predisposed to dystocia (bulldogs, terriers) and miniature breeds are particularly sensitive to incorrect feeding during pregnancy. Poor nutrition of the bitch during pregnancy may cause metabolic disorders and hormonal balance, increased neonatal mortality, eclampsia, or insufficient lactation after giving birth (Ivanova et al. 2018).

The percentage of nutrients in the ration for a pregnant bitch should include: proteins 27-34%, fat 18-20% with an appropriate balance between polyunsaturated fatty acids omega-3 and omega-6, carbohydrates 20-30%, 1% calcium and 0.8% phosphorus. During pregnancy, the demand for protein in the diet increases by up to 70% (Ivanova et al. 2018). Protein deficiencies can lead to reduced birth weight and reduced chances of survival for puppies. On the 35th day of pregnancy, the demand for calcium and phosphorus increases due to the rapid growth of the pups' skeletal system (Gajanayake et al. 2018).

Health condition of dogs

Castration, i.e. the permanent removal of the sexual gonads in dogs, causes huge changes in their physiology. The resulting changes in hormonal balance cause an imbalance between energy consumption and energy expenditure, leading to the accumulation of fat mass and weight gain (Phungviwatnikul et al. 2020). As a consequence, the risk of obesity increases (Kawauchi et al. 2017). Estrogen is involved in the regulation of food intake in the central nervous system (Asarian et al. 2006). Therefore, surgical castration in dogs inhibits the appetite suppression effect and reduces the animals' resting metabolic rate. This is prevented by implementing appropriate nutritional management in the post-castration phase, focusing on the correct balance of energy and protein requirements in a personalized diet (Jeusette et al. 2004, Vendramini et al. 2020). Reducing MER after castration requires strict control of energy supply, which involves reducing the amount of food consumed, among others protein, to maintain optimal body weight (Schauf et al. 2016). However, castration, as a routine procedure performed to prevent diseases of the reproductive system and to reduce homelessness, contributes to the occurrence of obesity in companion animals (Lefebvre et al. 2013). It is recommended that the energy value of the diet of dogs after castration is reduced by 30%. Nevertheless, the diet should always be tailored to the individual needs of the animal (Gajanayake et al. 2018).

Obesity is the most common medical disease in dogs and is associated with the presence of comorbidities, reduced quality of life, and shortened life span (Robertson 2003, Flanagan et al. 2017). There are many risk factors for obesity in dogs - age, gender, castration, metabolic rate, breed and genetic predispositions. Some dog breeds are more predisposed to developing obesity than others. Individuals particularly at risk of developing this disease

include Beagles, Labrador Retrievers, Cocker Spaniels, King Charles Spaniels, miniature Schnauzers, Pugs, and Dachshunds. Moreover, non-breed animals are particularly susceptible to this disease. On the other hand, there are breeds that seem resistant to developing obesity (including Greyhounds) – Jeusette et al. (2006). Race-specific predisposition to obesity is partly related to genetic factors, and more specifically, the ratio of lean body mass to body fat (Muñoz-Prieto et al. 2018, Cline et al. 2021, Chitty 2023). A dog's owner has the opportunity to prevent obesity in his animal, for example by checking the quality and quantity of the food it eats. When assessing the risk of obesity in a dog, one should take into account not only the assessment of the dog itself, but also the assessment of the level of knowledge, beliefs and lifestyle of its owner (Courcier et al. 2010, Hemmings 2016). The highest percentage of obesity in dogs is related to their improper nutrition. Obesity in companion animals often results from the increasing incidence of obesity in humans (Kienzle et al. 2002, Lean et al. 2006). Moreover, pet owners' misperception of their dog's body condition leads to the practice of overfeeding and this is a risk factor for obesity (Yam et al. 2017). The motivation of the guardian and the type and strength of the bond between the guardian and the dog are also important (Webb et al. 2020). Obesity in dogs not only affects their health, but also the economic status of the owner due to the need to treat many diseases caused by obesity (Phungviwatnikul et al. 2020).

Behaviour and welfare

Behavioural problems may cause difficulties in maintaining proper body weight in dogs (Luño et al. 2018). Stress-induced emotional eating is a change in eating behaviour in order to cope with negative emotional states such as stress, anxiety or depression. This is an emotion regulation strategy (Blechert et al. 2014, Turton et al. 2017, Luño et al. 2018). It may manifest itself as excessive appetite, distorted appetite, or greedy eating.

The type of diet can be important when working to change behaviour in dogs. Research confirms that a diet rich in tryptophan may reduce the level of territorial aggression, and a high-protein diet without tryptophan supplementation may result in a high level of dominance aggression. Also, omega-3 deficiency may be associated with mood and behavioural disorders (Sechi et al. 2017).

A properly balanced diet may help reduce the occurrence and severity of clinical symptoms of cognitive dysfunction syndrome in geriatric dogs (Cognitive Dysfunction Syndrome – CDS) – Pan et al. (2018). It is believed that as many as 20 to 68% of middle-aged and older dogs experience cognitive dysfunction or behavioural changes that may manifest themselves in varying degrees of mental impairment (Moyers 2015). Many scientific studies analyze factors that may affect the nutritional needs of dogs, which may ultimately affect the health and condition of animals (Table 5).

Table 5

Optimization and personalization of dog nutrition depending on age, physiological condition, castration and behavior

Nutrition modifying factor	Sources	Description of the experiment	Results
Age	Villarreal et al. (2019)	20 small breed dogs. Housing of dogs: before and between group tests, in individual cages for the duration of the experiment. Seven pairs of commercially available puppy food were used and offered (two-bowl preference trials) to the dogs twice over 14 days during each round.	The taste preferences of small breed puppies aged 5-8 months were maintained when they were reassessed at 14-17 months of age. In six of the seven studies, dogs were consistent in their preferences as adults and as puppies.
	Hemida et al. (2021)	4022 dogs. The research was conducted using the DogRisk questionnaire. Dog breeds have been divided into breeds prone to allergies and breeds not prone to allergies. The test tested 46 foods and the ratio of 4 main diet types for their association with the occurrence of AASS later in life in 4022 dogs.	It has been proven that consuming at least 20% of the diet as raw food or less than 80% of the diet as dry food was significantly associated with a reduced incidence of AASS in adult dogs. No raw food or 80% or more dry food in the diet is associated with an increased incidence of AASS in adult dogs.
	Dobenecker et al. (2013)	30 Beagle dogs and 38 Foxhound mixed breed dogs aged from 6 weeks to 28 weeks. After weaning at the age of 6 weeks, the food rations sufficient to meet the energy requirements of each individual puppy were adjusted every other day according to growth level, guaranteeing a development consistent with the recommended weight curve for the respective breed size. The food and therefore energy intake of the puppies were registered daily.	Foxhound-Boxer-Ingelheim Labrador crossbreds (FBIs) had higher energy intakes expressed as multiples of maintenance than Beagles, suggesting that during the major period of growth, the energy requirement is not a function of age.
	Böswald et al. (2019)	49 puppies. The study compared the demand for calcium and phosphorus for growing dogs based on the calculation of NRC requirements and the factor method. Extrapolation was made in groups between the age ranges 5-6 and 7-12 months.	It was shown that the calcium requirement for giant breed puppies (mature with a body weight of 60 kg) aged less than 7 months was consistent between the extrapolation and the factorial approach, but too high for medium and miniature breeds. Similar conclusions were obtained regarding phosphorus.
Pregnancy and lactation	Wright-Rodgers et al. (2005)	12 Labrador Retriever females aged 2 to 4 years. Dogs were randomly assigned to 1 of 4 dietary groups. All diets contained adequate amounts of linoleic acid (LA) and varying amounts of α-linolenic acid (ALA). Diets marked Lo/Lo- diet containing small amount of ALA and small amounts of (n-3) LCPUFA Lo/Mod- diet containing small amount of ALA and moderate amounts of (*n*-3) LCPUFA Lo/Hi- diet containing small amount of ALA and large amounts of (*n*-3) LCPUFA Hi/Lo- diet containing large amount of ALA and small amounts of (*n*-3) LCPUFA.	All dogs gained weight during gestation. During lactation, body weights returned to normal nonpregnant values. Gestation – Dogs in the Lo/Hi group had lower plasma cholesterol concentrations (all fractions) than dogs fed the Lo/Lo and Hi/Lo diets. Lactation – The plasma EC (esterified cholesterol) fraction was lower in the Lo/Hi group than in the other 3 groups during lactation. Neonate – Plasma TC concentrations were lower in the Lo/Mod and Lo/Hi groups (i.e., the fish oil groups) compared with the other 2 groups. Puppies in the Lo/Lo group had higher FC (free cholesterol) and EC concentrations than those in the other groups. Plasma TG concentrations were higher in the Hi/Lo group than in the other groups.

cont. Table 5

Nutrition modifying factor	Sources	Description of the experiment	Results
Castration	Phungviwatnikul et al. (2020)	Healthy adult female Beagles (28 dogs). Twenty-four dogs were neutered and randomly divided into 3 research groups and fed for 24 weeks with the following diets: COSP – moderate protein and moderate fiber diet; HP-HF- high-protein, high-fiber diet; HP-HF-O - high-protein diet, rich in fiber and omega-3 acids and medium-chain fatty acids. Four dogs underwent sham surgery and were fed a control diet (COSH). After castration, dogs were fed to maintain BW for 12 weeks (restricted phase) and then had unlimited access to food for 12 weeks (ad libitum phase).	Period 1-12 weeks: Groups: HP-HF and HP-HF-O: cholesterol, CALP HP-HF-O: ALP serum concentration HP-HF and HP-HF-O: WBC and neutrophils Period 13-24 weeks: Groups: HP-HF and HP-HF-O: feed intake (g/d) Groups: COSP: BCS HP-HF and HP-HF-O: cholesterol in blood serum HP-HF-O serum leptin -, COSP serum CRP.
	Simpson et al. (2019)	2764 Golden Retriever dogs. This study was conducted using data collected as part of the Golden Retriever Lifetime Study. The dogs were divided into 4 groups depending on the time at which gonadectomy was performed: - intact (reference) - ≤ 6 months - > 6 months - ≤12 months - > 12 months Dogs were excluded from analysis if they were overweight or obese at entry into the study and/or had a previously diagnosed orthopedic injury. Body weight was assessed by a veterinarian according to the Purina Body Condition Scale (BCS).	Compared to intact dogs, all gonadectomy age categories showed increased risk for the development of overweight/obesity. Compared to intact dogs, dogs who were ≤ 6 months at gonadectomy had increased risk for orthopedic injury Dogs that underwent gonadectomy at 6-12 months of age had a 42% increased risk of being overweight/obese compared to the group that was older than 12 months at the time of gonadectomy. Additionally, among healthy dogs, females have a 43% greater risk of being overweight/obese compared to males.
Behaviour	Sechi et al. (2016)	69 animals. Dogs were randomly assigned to a control diet group (n=34) or a nutraceutical diet group (n=35) and fed for a period of 45 days according to the manufacturer's instructions. Blood samples were collected from each dog before and after 45 days of diet administration.	In the group in which nutraceuticals were used, the concentration of serotonin, dopamine and ß-endorphins increased significantly compared to the control group.
	Luno et al. (2018)	1118 dogs of various breeds, aged from 6 months to 13 years. The research was conducted using a survey addressed to caregivers and people working in an animal clinic. The survey focused on the aspect of emotional eating or obesity in animals.	The study shows that a large proportion of owners perceive that their dogs exhibit emotional eating or changes in food intake in response to stress (especially noise) or other negative emotional and medical conditions. Dogs that were rated as very voracious were overweight significantly more often than dogs which showed no interest in their food at all.
	Pan et al. (2018)	87 dogs (48 males and 39 females) of various breeds, aged 9 to 16 years. The dogs were assigned to 3 experimental groups of 29 animals in each - Control - 6.5% MCT diet- 6.5% MCT oil (medium chain triglyceride) + BPB (Brain Protection Blend) - 9% MCT diet – 9% MCT oil + BPB. The effect of a combination of MCT and BPB on CDS symptoms in older dogs was evaluated. The dogs were fed the assigned diet for 90 days.	Dogs fed the 6.5% MCT diet showed significant improvement from baseline in all 6 CDS symptom categories. Dogs fed the 9% MCT diet did not significantly improve most symptoms from baseline.

Qualitatively and quantitatively, unbalanced nutrition always harms dogs' health. The method of feeding influences the dog's behavioural condition. Overfeeding the dog, lack of variety in the diet, and malnutrition may contribute to self-aggressive or aggressive behaviour, hyperactivity or fatigue (Vučinić et al. 2023). The most common problems related to eating behaviour include biting objects, eating inedible things, coprophagia, aggression resulting from food competition and vocalization. Therefore, care should be taken to balance food doses and ensure the correct size of meals, frequency of feeding, diversification of the diet and physical activity (Tynes, Landsberg 2021).

CONCLUSIONS

A properly selected diet for a dog is an important preventive measure. Following the rules of dog nutrition allows you to meet their natural needs - both nutritional and behavioural ones. The diet of young dogs should be twice as high in protein, higher in fat, and therefore higher in calories than the diet of adults. During intensive growth, young animals should be fed food rich in highly digestible proteins and easily digestible calcium. The protein content in the diet should not be lower than 25%. The nutrition of adult dogs depends on many factors, including physical activity, general condition, physiological status, or castration. According to the nutritional guidelines, the minimum protein content in the diet of adult dogs is 18% on a dry matter basis and decreases as the animal ages. Due to the growing popularity and promotion of castration, it is very important to know how to feed such animals properly, therefore it is recommended that the energy value of the diet of dogs after the procedure is 30% lower than that of dogs that have not undergone this procedure. A high-protein and high-fiber diet may limit weight gain and fat tissue growth and reduce serum cholesterol, triglycerides, ALP, CALP and leptin levels in dogs after castration. Pregnancy and lactation are considered the most nutritionally demanding periods. Appropriate nutrition of a pregnant dog supports the proper growth and development of fetuses, prevents postpartum tetany after pregnancy and ensures optimal lactation. During pregnancy, the demand for protein in the diet increases by up to 70% in relation to living needs. In the second and third pregnancy period, the demand for calcium and phosphorus also increases due to the intensive growth and mineralization of the puppies' skeletal system. It is important to supplement pregnant and breastfeeding bitches with omega-3 and omega-6 acids for the proper development of the puppies' nervous system. A properly selected diet is important in preventing animals from maintaining proper body weight. Light food should contain at least 25% protein, 10% fat, and 8% dietary fiber. The diet has also been used to eliminate behavioural disorders, because an excessive supply of protein in the diet may contribute to aggressive behavior, and food too rich in corn may in-

crease hyperactivity. Omega-3 fatty acid deficiency may also be associated with mood and behavioral disorders.

To properly feed one's pets, one must constantly update your knowledge and follow the nutritional requirements for dogs developed by the National Research Council (NRC) and The European Pet Food Industry Federation (FEDIAF).

Author contributions

M.B., B.K. J.W., A.G. – methodology; A.G. – software; B.K, R.K., M.K. – conceptualization; investigation – A.G., M.B., J.W., methodology – B.K. – visualization B.K., A.G., M.B., J.W. – writing – original draft preparation; M.K., B.K., R.K. – writing – review & editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board). The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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