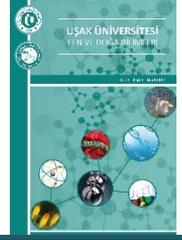




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Research Article

The Comparison of the Canidae Taxa with Karyotype Symmetry/Asymmetry Index (S/A₁)

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Abstract

The family Canidae is placed in the suborder Caniformia in the order Carnivora. There are both domestic and wild species in Canidae. The family consists of at least 35 wild species in 13 genera. The number of chromosomes in Canidae is divided into 2 groups. (i) The chromosome numbers are $2n = 54, 66, 74, 76,$ and 78 with mostly acrocentric autosomes. (ii) The chromosome numbers are $2n = 34, 36, 38,$ and 50 with mostly metacentric and submetacentric autosomes. The S/A_1 formula measures the symmetry or asymmetry of the karyotype in higher animals and humans. In this study, the formula was applied to the Canidae species. After the detailed literature review, S/A_1 data and karyotype types of 25 female taxa and 17 male taxa were determined. According to the S/A_1 values, a dendrogram was drawn showing karyological variations among the taxa. The results will contribute to the phylogeny of mammals.

Keywords: *Canidae, carnivora, karyotype, phylogeny, symmetry/asymmetry index.*

Özet

Canidae familyası, Carnivora takımının Caniformia alt takımında yer almaktadır. Canidae familyasında hem evcil hem de yabancı türler bulunmaktadır. Familya, 13 cins içerisinde yer alan en az 35 yabancı türden oluşur. Canidae familyasında kromozom sayısı 2 gruba ayrılır. (i) Çoğunlukla akrosentrik otozomlardan oluşan kromozom sayıları $2n = 54, 66, 74, 76$ ve 78 'dir. (ii) Çoğunlukla metasentrik ve submetasentrik otozomlardan oluşan kromozom sayıları, $2n = 34, 36, 38$ ve 50 'dir. S/A_1 formülü, yüksek hayvanlarda ve insanlarda karyotip simetrisini veya asimetrisini ölçer. Bu çalışmada, formül Canidae türlerine uygulanmıştır. Ayrıntılı literatür taramasının ardından 25 dişi ve 17 erkek taksonun S/A_1 verileri ve karyotip tipleri belirlenmiştir. S/A_1 değerlerine göre taksonlar arasındaki karyolojik varyasyonları gösteren bir dendrogram çizilmiştir. Sonuçlar, memelilerin filogenisine katkıda bulunacaktır.

Anahtar Kelimeler: *Canidae, carnivora, karyotip, filogeni, simetri/asimetri indeksi.*

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1. Giriş

The cytotaxonomy contains comparative studies of karyotype analyses. The primary chromosomal data such as basic chromosome number (x), diploid chromosome number ($2n$), and chromosome lengths could be replaced numerically through polyploidy and aneuploidy, as well as through structural arrangements containing deletion, inversion, and translocation. The chromosomal variations change the centromere position and the morphology of chromosome and affect the karyotype asymmetry. For this reason, the karyotype asymmetry is one of the most important parameters supporting the morphological characters [1-4].

Canidae (Fischer de Waldheim, 1817) is placed in the suborder Caniformia (Kretzoi, 1938) in the order Carnivora (Bowdich, 1821). There are both domestic and wild species in Canidae. The family consists of at least 35 wild species in 13 genera. The Canidae are the most widespread family of extant Carnivora. They are distributed naturally in all continents except Antarctica [5]. The number of Canidae taxa decreases with especially human impacts. According to the International Union for the Conservation of Nature (IUCN) Red List, four species are categorized as Endangered (EN) and only one species is categorized as Critically Endangered (CR). *Dusicyon australis* (Kerr, 1792) (Falkland Island wolf) and *Dusicyon avus* (Oliver, 1926) are categorized as Extinct (EX) [6].

The Canidae is one of the most important members of the world's wildlife. Therefore, many taxonomic and cytotaxonomic studies have been reported related canids till now. The number of chromosomes in Canidae is divided into 2 groups. (i) The chromosome numbers are $2n = 54, 66, 74, 76,$ and 78 with mostly acrocentric autosomes [7-8]. (ii) The chromosome numbers are $2n = 34, 36, 38,$ and 50 with mostly metacentric and submetacentric autosomes [7-8]. In addition, there are B chromosomes in the family Canidae. B chromosomes are supernumerary chromosomes, which do not follow Mendelian rules of inheritance. They have been found in many species [9].

The objective of this study is to show karyological variations among the taxa with S/A_1 data of the Canidae.

2. Materials and Methods

2.1. The Formula S/A_1 (Symmetry/Asymmetry Index)

The formula reported by Eroğlu [10] is given below. In the formula, the number of chromosomal groups is important.

$$S/A_1 = [(1 \times M) + (2 \times SM) + (3 \times A) + (4 \times T)] / 2n \quad (1)$$

The explanations of the abbreviations are metacentric (M), submetacentric (SM), acrocentric (A), telocentric (T) and diploid number ($2n$).

2.2. Sample Application for Symmetric Karyotype or Asymmetric Karyotype

In this study, the formula was applied to the Canidae species. The Canidae includes carnivorous mammals such as wolf, dog, coyote, and fox. After obtaining karyotype formulae with a detailed literature review, S/A_1 data and karyotype types of 25 female taxa and 17 male taxa were determined (Table 1). In addition, Table 1 contains the scientific name, common name and author of the taxa. The scientific names were checked

from the IUCN Red List [6] as the scientific names of some species are reported differently in the literature. The genus *Lycalopex* is an important example. This genus is named as *Lycalopex* [11] and *Pseudalopex* [12].

Table 1. The karyotype formulae, index values and karyotype types of the taxa

Species Scientific name /common name	2n	Autosomes and sex chromosomes	S/A ₁	Karyotype type	References
<i>Canis lupus</i> (Linnaeus, 1758) (Gray wolf)	78	76A X = SM, Y = M	2.9744 (F) 2.9615 (M)	Between symmetric and asymmetric	[20-21]
<i>Canis lupus familiaris</i> (Linnaeus, 1758) (Domestic dog)	78	76A X = SM, Y = SM	2.9744 (F) 2.9744 (M)	Between symmetric and asymmetric	[22-24]
<i>Canis rufus</i> (Audubon and Bachman, 1851) (Red wolf)	78	76A X = SM, Y ?*	2.9744 (F)	Between symmetric and asymmetric	[14]
<i>Canis latrans</i> (Say, 1823) (Coyote)	78	76A X = SM, Y minute**	2.9744 (F)	Between symmetric and asymmetric	[15]
<i>Canis mesomelas</i> (Schreber, 1775) (Black-backed jackal)	78	76A X = SM, Y = SM	2.9744 (F) 2.9744 (M)	Between symmetric and asymmetric	[25]
<i>Cuon alpinus</i> (Pallas, 1811) (Dhole)	78	76A X = SM, Y minute**	2.9744 (F)	Between symmetric and asymmetric	[19]
<i>Lycaon pictus</i> (Temminck, 1820) (African wild dog)	78	76A X = M, Y = M	2.9487 (F) 2.9487 (M)	Between symmetric and asymmetric	[26]
<i>Chrysocyon brachyurus</i> (Illiger, 1815) (Maned wolf)	76	74A X = SM, Y = A	2.9737 (F) 2.9868 (M)	Between symmetric and asymmetric	[27-28]
<i>Atelocynus microtis</i> (Sclater, 1883) (Short-eared dog)	74	72A X = SM, Y ?*	2.9730 (F)	Between symmetric and asymmetric	[13]
<i>Speothos venaticus</i> (Lund, 1842) (Bush dog)	74	72A X = SM, Y = M	2.9730 (F) 2.9595 (M)	Between symmetric and asymmetric	[29]
<i>Lycalopex culpaeus</i> (Molina, 1782) (Culpeo)	74	72A X = SM, Y = A	2.9730 (F) 2.9865 (M)	Between symmetric and asymmetric	[30]
<i>Lycalopex griseus</i> (Gray, 1837) (South American grey fox)	74	72A X = SM, Y = A	2.9730 (F) 2.9865 (M)	Between symmetric and asymmetric	[13,31]
<i>Lycalopex gymnocercus</i> (G. Fischer, 1814) (Pampas fox)	74	72A X = SM, Y = A	2.9730 (F) 2.9865 (M)	Between symmetric and asymmetric	[28]
<i>Lycalopex vetulus</i> (Lund, 1842) (Hoary fox)	74	72A X = M, Y ?*	2.9459 (F)	Between symmetric and asymmetric	[13]
<i>Cerdocyon thous</i> (Linnaeus, 1766) (Crab-eating fox)	74	4M + 26SM + 42A X = SM, Y = A	2.5135 (F) 2.5270 (M)	Between symmetric and asymmetric	[28,32]
<i>Urocyon littoralis</i> (Baird, 1857) (Island fox)	66	2SM + 62A X = SM, Y minute**	2.9394 (F)	Between symmetric and asymmetric	[17]
<i>Urocyon cinereoargenteus</i> (Schreber, 1775) (Grey fox)	66	2M + 62A X = SM, Y = M	2.9091 (F) 2.8939 (M)	Between symmetric and asymmetric	[13]
<i>Nyctereutes procyonoides procyonoides</i> (Gray, 1834) (Chinese raccoon dog)	54 + B	2M + 8SM + 42A X = M, Y = SM	2.7037 (F) 2.7222 (M)	Between symmetric and asymmetric	[33-35]
<i>Nyctereutes procyonoides viverrinus</i> (Temminck, 1838) (Japanese raccoon dog)	38 + B	8M + 18SM + 10A X = M, Y minute**	2.0000 (F)	Symmetric	[18]
<i>Vulpes velox</i> (Say, 1823) (Swift fox)	50	8M + 40SM X = M, Y = SM	1.8000 (F) 1.8200 (M)	Symmetric	[36]
<i>Vulpes macrotis</i> (Merriam, 1888) (Kit fox)	50	8M + 40SM X = M, Y = SM	1.8000 (F) 1.8200 (M)	Symmetric	[36]
<i>Vulpes lagopus</i> (Linnaeus, 1758) (Arctic fox)	50	28M + 16SM + 4A X = M, Y = A	1.4800 (F) 1.5200 (M)	Symmetric	[37]
<i>Vulpes vulpes fulvus</i> (Desmarest, 1820) (American red fox)	34 + B	22M + 10SM X = M, Y = A	1.2941 (F) 1.3529 (M)	Symmetric	[38]
<i>Vulpes vulpes</i> (Linnaeus, 1758) (Red fox)	34 + B 36 + B	26M + 6SM X = SM, Y = A 26M + 6SM X = M, Y = A	1.2353 (F) 1.2647 (M) 1.1765 (F) 1.2353 (M)	Symmetric	[39-40]
<i>Vulpes ferrilata</i> (Hodgson, 1842) (Tibetan fox)	36 + B	30M + 6SM X***, Y***	1.1667 (F)	Symmetric	[16]

Abbreviations: M, metacentric; SM, submetacentric; A, acrocentric; F, female; M, male.

* There is no male in the karyotype study, ** Could not determine the type of chromosome, *** Not identified

According to the S/A_1 data, a dendrogram showing karyological variations among the taxa was drawn. The dendrograms showing karyological relationships were drawn with chromosome numbers, karyotype types, and S/A_1 values by Past 4.12 software. The dendrograms contain the karyotypes of 25 females and 17 males, respectively. Eight taxa are missing from two reasons in the male dendrogram. (i) The male karyotype has not been reported in the karyotype studies of *Canis rufus*, *Atelocynus microtis* and *Lycalopex vetulus* [13-14]. (ii) The male karyotype has been reported in the karyotype studies of *Canis latrans*, *Cuon alpinus*, *Urocyon littoralis*, *Nyctereutes procyonoides viverrinus*, and *Vulpes ferrilata*, but the type of Y chromosome has not been reported for being too small [15-19].

3. Results

The diploid chromosome number in the family Canidae is a wide range. According to the Table 1, it is observed from $34 + B$ in the red fox to 78 in the wolf and the dog. Although the diploid chromosome number in many taxa is greater than 50, there are 50 or fewer chromosomes in only Japanese raccoon dog and *Vulpes* taxa (Figure 1 and 2). As an interesting note, these taxa have both the smaller number of chromosomes and symmetric karyotype together with the smallest index values.

In Figure 1, while the karyotype is symmetric type in the 2 genus and 7 taxa, the karyotype is between symmetric and asymmetric in the 10 genus and 18 taxa. The S/A_1 values of 25 female taxa are 1.1667-2.9744. In Figure 2, while the karyotype is symmetric type in only one genus and 5 taxa, the karyotype is between symmetric and asymmetric in the 8 genus and 12 taxa. The S/A_1 values of 17 male taxa are 1.2353-2.9868.

4. Discussion

In Figures 1 and 2, there are similarities in the positive direction between female dendrogram consisting of 25 taxa and male dendrogram consisting of 17 taxa. In this regard, the dendrograms were very similar to the phylogenetic tree building by combining the phylogenetic information of the Canidae [41]. This phylogenetic tree is a composite tree with 36 source trees and 180 elements.

The results of wolves and dogs are quite close. The karyotypes of these taxa are between symmetric and asymmetric together with coyote and foxes excluding *Vulpes* taxa. The karyotypes of *Vulpes* taxa are the symmetric type together with the Japanese raccoon dog. Because of the karyotype homology and other similarities, the taxa can interbreed and produce fertile generations [42]. There are many reports regarding hybridizations of canids as wolf-dog [43], red wolf-coyote [44], gray wolf-coyote [45], and Ethiopian wolf-domestic dog [46].

In Figure 1, while *Canis* taxa and Dhole have the highest index value, in Figure 2, *Lycalopex* taxa and maned wolf have the highest index value. The main reason is a heteromorphism between X and Y chromosomes. While the Y chromosome of these taxa is acrocentric as autosomal chromosomes, the Y chromosome of other taxa is similar with the X chromosome. It was reported that there are high numbers of chromosomes with mostly acrocentric autosomes and low numbers of chromosomes with mostly metacentric or submetacentric autosomes and the heteromorphism between X and Y chromosomes [7-8]. Crab-eating fox is an exception species with high numbers of chromosomes and 30 bi-armed autosomes [28,32].

The chromosome numbers of red fox and American red fox have been determined as $2n = 34, 36, \text{ and } 38$ [23,38-40]. This variation in chromosome number was attributed to the loss or gain of what was described as microchromosomes or B chromosomes [47]. These chromosomes are very small and like the acrocentric Y chromosome. Ellenton and Basrur reported that there were variable numbers (0–8) of B chromosomes in the red foxes [48]. But the most common numbers were 2 or 3. It was believed that B chromosomes in the red foxes were evolutionary remnants of the centric fragments derived from the Robertsonian translocations [49]. Yang et al. supported to this suggestion with comparative chromosome painting [50]. In addition, the raccoon dog has B chromosomes. It was reported that the numbers of B chromosomes were variable in the Chinese raccoon dog (1–4) [33] and Japanese raccoon dog (2–7) [18]. Although closely related subspecies, the chromosome numbers of the Chinese raccoon dog (*Nyctereutes procyonoides procyonoides*) and Japanese raccoon dog (*Nyctereutes procyonoides viverrinus*) are quite different [18,33-35]. For this reason, while the karyotype of Chinese raccoon dog is between symmetric and asymmetric, the karyotype of the Japanese raccoon dog is symmetric. It was suggested that the reduced diploid number in the Japanese raccoon dogs was achieved by fusion of 16 acrocentric to form eight metacentric and submetacentric elements [34].

As a result, the karyotypes of Canidae taxa were used for the comparison with karyotype symmetry/asymmetry index. The results will contribute to the phylogeny of mammals.

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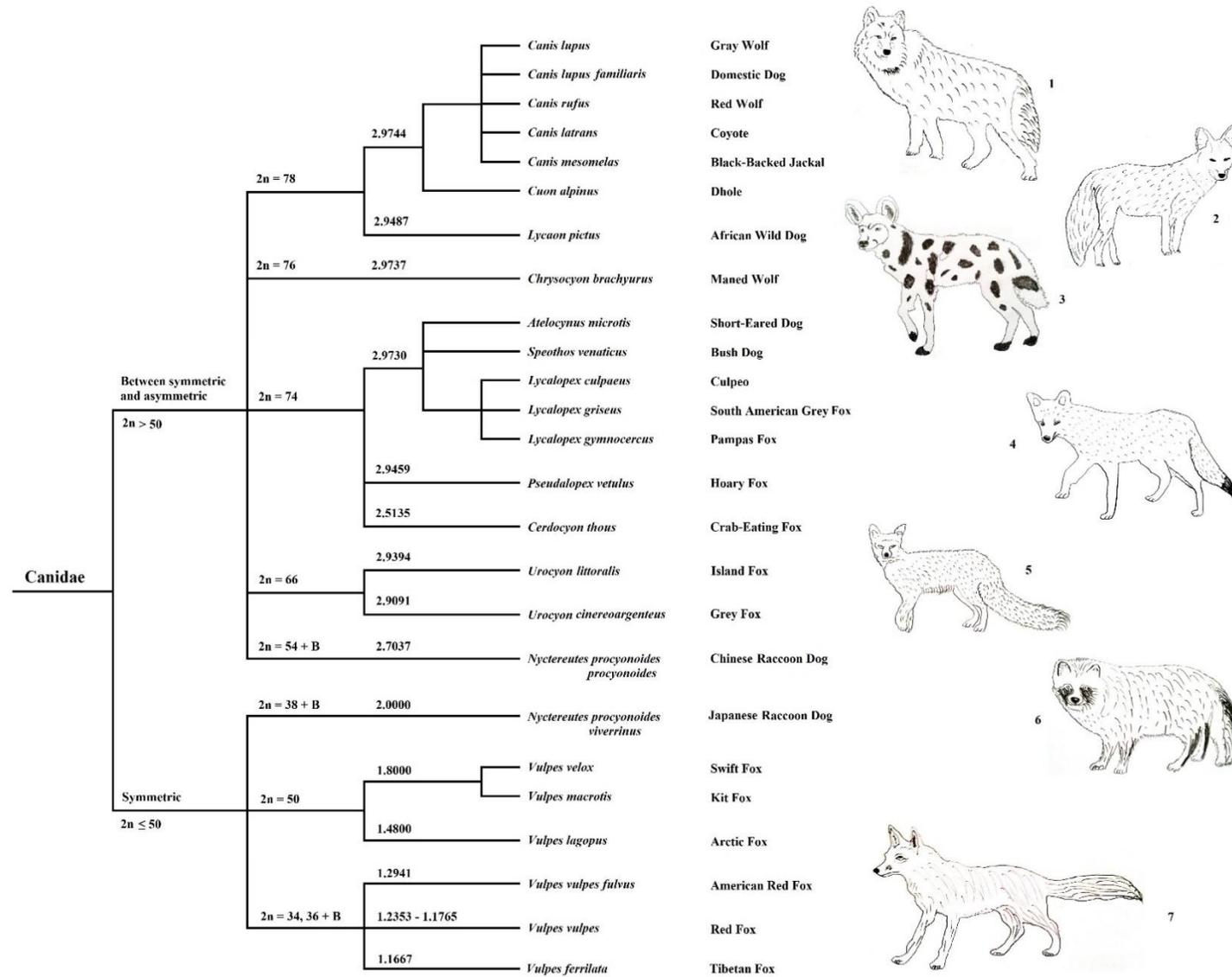


Figure 1. The dendrogram shows relationships of the female index values among the species of canids. (1) *Canis lupus*; (2) *Cuon alpinus*; (3) *Lycaon pictus*; (4) *Lycalopex vetulus*; (5) *Urocyon cinereoargenteus*; (6) *Nyctereutes procyonoides*; (7) *Vulpes vulpes*.

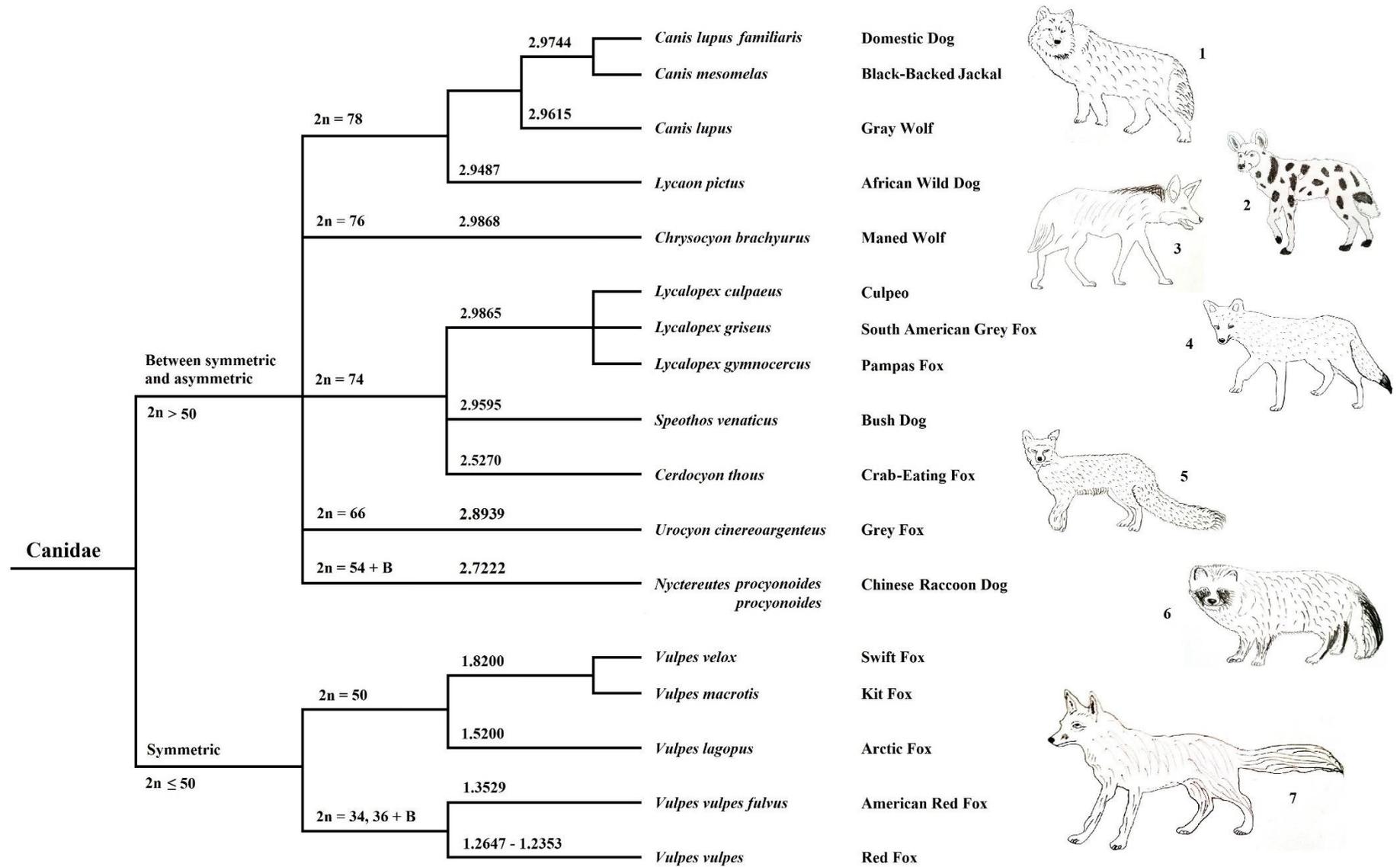


Figure 2. The dendrogram shows relationships of the male index values among the species of canids. (1) *Canis lupus*; (2) *Lycaon pictus*; (3) *Chrysocyon brachyurus*; (4) *Lycalopex vetulus*; (5) *Urocyon cinereoargenteus*; (6) *Nyctereutes procyonoides*; (7) *Vulpes vulpes*.

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