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# Morphological Comparisons of Seven Chromosomal Forms of *Spalax leucodon* Nordmann, 1840 (Mammalia: Rodentia) in Turkey

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**Abstract:** The morphological structure of seven chromosomal forms of *Spalax leucodon* was studied using numerical taxonomical methods. Fifty-five skull and external characters were used in multivariate analysis. The diploid number of chromosome is diverse even in adjacent localities. Discriminant Function Analysis (DFA) revealed the presence of three distinct groups for both males and females. DFA separated the three chromosomal forms (2n = 60, 50 and 56 NW) from each other. *S. l. cilicicus* has 2n = 60, 56 SW, 54, 52, 40 chromosomal forms; *S. l. turcicus* contains 2n = 56 NW; and *S. l. nehringi* includes 2n = 50 chromosomal form. $M_2$ and $M_3$ have 2 alveoli cubicles in chromosomal forms of 2n = 40, 50, 54, 56 NW, 56 S, while $M_{2,3}$ have 1 cubicles in chromosomal forms of 2n = 60 and 52.

**Key words:** *Spalax leucodon*, morphology, morphometry

## INTRODUCTION

The genus *Spalax* is one of the taxa of which taxonomy is rather complicated. According to the morphological studies, *Spalax leucodon* Nordmann, 1840 and *Spalax ehrenbergi* Nehring, 1898 were distributed in Turkey. *S. leucodon* is represented by five subspecies (*S. l. nehringi* Satunin, 1898; *S. l. armeniacus* Mehely, 1909; *S. l. cilicicus* Mehely, 1909; *S. l. anatolicus* Mehely, 1909; *S. l. turcicus* Mehely, 1909) in Turkey (Mursaloglu, 1979; Kivanc, 1988).

On the basis of diploid chromosomal number and fundamental number, a total of twenty one chromosomal forms were recorded from Turkey (Butler *et al*., 1993; Nevo *et al*., 1994, 1995; Ivanitskaya *et al*., 1997; Sozen *et al*., 1999, 2000a,b; Kankılıç *et al*., 2005). Although karyotypic forms are considered by Nevo *et al*. (1994, 1995) as biological species, morphological studies determining the taxonomic status of these diverse karyotypic forms in Turkey are very poor. Thus there is a continuing debate on whether these karyotypic forms determined in Turkey are separate species, or not. However, karyotypic forms of *S. ehrenberg*i in Israel were described as different biological species adapted at multiple organizational levels to their different environments (Nevo *et al*., 2001). This study was aimed to analyse morphologic aspects of chromosomal forms of *Spalax leucodon* in Turkey.

## MATERIALS AND METHODS

A total of 166 adult subterranean mole rats (91 males, 75 females) of *S. leucodon* were collected from 2000 to 2003 in Turkey (Fig. 1 and Table 1). All specimens were assigned into seven groups on the basis of taxonomic criteria and diploid number of chromosome (Fig. 1). Age determination was made according to Kivanc (1988). Cranial and dental characters were measured using a calliper compass. The external, cranial character measurements (mm) and weight (g) were taken from all specimens examined. Then, specimens were skinned in the standard museum manner.

Measurements of 55 characters were used in morphometric analyses. The univariate analysis included descriptive statistics (means and standard deviations) for each variable (Table 1). On the other hand, the multivariate analysis included DFA (Discriminant Function Analysis) and MANOVA. Initially, an overall measure of sexual dimorphism was obtained by one-way multivariate analysis of variance (MANOVA). DFA and MANOVA were conducted using SPSS and NCSS (Hintze, 2001) statistical software programs. Phenetic relationships among groups were obtained by cluster analysis. Similarity coefficient was calculated and dendogram was constructed using UPGMA in the NTSYS-pc 2.1 (Rohlf, 1994).

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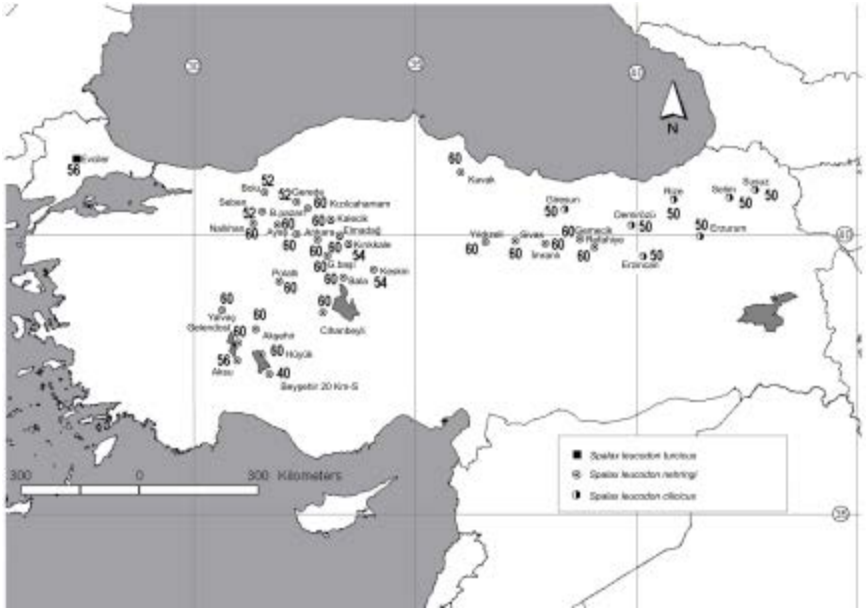


Fig. 1: A map showing the sampling localities of *S. leucodon* specimens examined

Table 1: The means of external and cranial measurements of adult male and female specimens in Turkey Standard errors are in parenthesis

| Body and skull variables (mm) | 2n = 60 population | | 2n = 56 S population | | 2n = 54 population | | 2n = 52 population | | 2n = 50 population | | 2n = 40 population | | 2n=56NW population |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male N = 61 | Female N = 56 | Male N = 3 | Female N = 2 | Male N = 4 | Female N = 2 | Male N = 4 | Female N = 10 | Male N = 13 | Female N = 3 | Male N = 3 | Female N = 2 | Male N = 3 |
| TBL | 216.4 (2.8) | 204.2 (2.3) | 205.6 (2.4) | 194.5 (10) | 205.2 (12) | 193.0 (2.1) | 217.2 (9.5) | 210.1 (3.3) | 217.6 (6.1) | 212.0 (11) | 197.0 (6.2) | 192.0 (4.2) | 183.3 (9.5) |
| HFL | 28.6 (0.24) | 27.2 (0.19) | 29.0 (0.47) | 28.5 (0.35) | 28.5 (0.83) | 27.0 (0.71) | 28.5 (0.75) | 27.2 (0.50) | 30.2 (0.49) | 28.3 (0.54) | 28.0 (0.47) | 28.0 (0.00) | 28.3 (0.54) |
| W (g) | 215.1 (9.2) | 176.2 (5.8) | 190 ( 10.8) | 170.0 (14) | 187.7 (14) | 165.5 (18) | 216 (24.3) | 179.0 (20) | 224 (29.3) | 185.0 (18) | 162.7 (16) | 158.5 (19) | 118.0 (8.0) |
| ZB | 36.3 (0.58) | 33.6 (0.31) | 2.7 (0.05) | 33.6 (0.99) | 35.6 (2.47) | 33.5 (0.03) | 35.3 (2.15) | 32.1 (0.39) | 35.8 (1.53) | 35.3 (0.98) | 34.0 (1.53) | 31.1 (1.55) | 37.3 (0.45) |
| ZP | 5.98 (0.12) | 5.62 (0.11) | 6.63 (0.09) | 6.80 (0.21) | 6.82 (0.65) | 5.50 (0.07) | 7.12 (0.32) | 7.00 (0.15) | 7.58 (0.36) | 6.27 (0.05) | 6.47 (0.12) | 6.45 (0.46) | 7.03 (0.43) |
| IC | 7.39 (0.07) | 7.23 (0.06) | 7.50 (0.17) | 7.40 (14.8) | 7.67 (0.22) | 7.65 (0.03) | 7.37 (0.10) | 7.19 (0.07) | 7.45 (0.16) | 6.77 (0.10) | 7.57 (0.27) | 7.65 (0.03) | 8.27 (0.03) |
| CBL | 45.8 (0.59) | 42.7 (0.32) | 43.5 (0.54) | 43.1 (1.31) | 44.0 (2.27) | 42.1 (0.28) | 44.9 (2.23) | 41.1 (0.52) | 46.0 (1.48) | 44.1 (1.00) | 43.5 (1.23) | 40.8 (0.85) | 44.1 (.044) |
| CNL | 49.1 (0.63) | 45.8 (0.34) | 46.5 (0.64) | 46.2 (1.63) | 47.2 (2.37) | 44.9 (0.25) | 48.5 (2.30) | 44.4 (0.53) | 49.5 (1.64) | 47.3 (1.08) | 46.7 (1.47) | 43.5 (1.02) | 47.8 (0.39) |
| ONL | 47.1 (0.59) | 44.0 (0.32) | 44.9 (0.63) | 44.5 (1.59) | 45.5 (2.14) | 43.6 (0.35) | 46.6 (2.09) | 43.0 (0.46) | 47.5 (1.62) | 45.3 (1.09) | 44.7 (1.29) | 41.7 (1.06) | 46.3 (0.41) |
| BL | 43.6 (0.59) | 40.6 (0.32) | 41.1 (0.66) | 40.8 (1.45) | 42.2 (2.26) | 40.2 (0.25) | 42.9 (2.27) | 39.1 (0.48) | 43.7 (1.50) | 42.1 (1.06) | 41.5 (1.47) | 38.3 (0.78) | 42.4 (0.33) |
| NL | 19.4 (0.29) | 17.9 (0.17) | 18.5 (0.07) | 17.4 (0.67) | 17.6 (0.97) | 17.3 (0.60) | 19.2 (0.68) | 17.9 (0.25) | 19.4 (0.77) | 18.4 (0.84) | 17.6 (0.52) | 16.3 (0.60) | 17.9 (0.60) |
| NB | 6.39 (0.08) | 5.96 (0.05) | 6.77 (0.12) | 6.60 (0.28) | 5.95 (0.23) | 5.75 (0.32) | 6.35 (0.29) | 5.79 (0.09) | 6.65 (0.21) | 6.03 (0.14) | 6.50 (0.57) | 5.75 (0.18) | 6.30 (0.29) |
| PL | 9.69 (0.16) | 9.34 (0.14) | 9.68 (0.49) | 9.73 (0.37) | 8.94 (0.28) | 8.15 (0.18) | 9.40 (0.41) | 9.32 (0.33) | 9.75 (0.21) | 8.50 (0.31) | 7.93 (0.34) | 8.55 (0.46) | 8.28 (0.28) |
| PBL | 11.0 (0.17) | 11.3 (0.17) | 10.9 (0.50) | 10.4 (0.37) | 11.0 (0.28) | 12.5 (0.04) | 12.1 (0.25) | 12.2 (0.22) | 11.6 (0.40) | 10.1 (0.13) | 11.2 (0.11) | 12.1 (0.74) | 14.3 (0.51) |
| PBF | 8.27 (0.23) | 9.44 (0.17) | 10.2 (0.66) | 10.4 (0.00) | 8.25 (1.61) | 9.33 (1.02) | 9.14 (0.76) | 9.66 (0.26) | 8.88 (0.60) | 8.59 (0.68) | 8.46 (0.48) | 9.40 (0.61) | 10.5 (0.37) |
| FPL | 19.7 (0.30) | 18.3 (0.20) | 18.5 (0.26) | 20.0 (0.95) | 19.7 (1.06) | 17.9 (0.24) | 19.7 (0.96) | 18.4 (0.23) | 20.4 (0.86) | 18.8 (0.62) | 19.0 (0.49) | 18.3 (0.35) | 18.5 (1.29) |
| MB | 13.6 (0.11) | 13.0 (0.09) | 13.7 (0.09) | 13.1 (0.39) | 13.2 (0.21) | 12.6 (0.07) | 13.4 (0.34) | 12.3 (0.25) | 13.7 (0.14) | 12.8 (0.15) | 13.6 (0.49) | 13.5 (0.03) | 12.7 (0.14) |
| FRL | 32.3 (0.46) | 29.8 (0.28) | 30.1 (0.52) | 30.0 (0.95) | 31.1 (1.86) | 29.6 (0.18) | 31.5 (1.49) | 29.3 (0.33) | 32.3 (1.19) | 31.3 (0.78) | 30.4 (1.09) | 28.0 (0.99) | 29.8 (1.67) |
| BCL | 17.8 (0.27) | 16.3 (0.10) | 17.1 (0.29) | 16.8 (0.64) | 16.9 (0.74) | 16.0 (0.28) | 17.9 (0.91) | 15.7 (0.23) | 17.6 (0.48) | 17.0 (0.31) | 17.4 (0.59) | 16.1 (0.00) | 16.8 (0.19) |
| CD | 20.1 (0.26) | 19.1 (0.15) | 19.7 (0.22) | 19.6 (0.85) | 20.5 (1.06) | 20.4 (0.07) | 20.3 (1.00) | 19.2 (0.17) | 20.6 (0.59) | 20.1 (0.42) | 19.2 (0.46) | 17.9 (0.28) | 20.5 (0.26) |
| CTBL | 18.0 (0.24) | 17.0 (0.15) | 18.0 (0.33) | 17.7 (1.02) | 17.9 (0.83) | 17.4 (0.35) | 17.8 (0.74) | 16.9 (0.16) | 18.2 (0.61) | 17.8 (0.28) | 17.3 (0.12) | 16.2 (0.21) | 17.5 (0.21) |
| EMD | 2.52 (0.03) | 2.40 (0.03) | 2.19 (0.07) | 2.43 (0.04) | 2.56 (0.14) | 2.50 (0.09) | 2.43 (0.14) | 2.44 (0.06) | 2.68 (0.11) | 2.50 (0.11) | 2.40 (0.13) | 2.50 (0.09) | 2.45 (0.07) |
| DL | 17.7 (0.32) | 16.2 (0.18) | 16.2 (0.26) | 16.2 (0.71) | 17.0 (1.09) | 15.9 (0.67) | 16.9 (1.11) | 15.2 (0.24) | 17.5 (0.81) | 17.3 (0.43) | 16.4 (0.38) | 15.2 (0.74) | 15.9 (1.00) |
| PL | 9.58 (0.16) | 8.89 (0.11) | 8.33 (0.26) | 7.69 (0.14) | 9.14 (0.45) | 8.55 (0.46) | 9.17 (0.56) | 8.67 (0.23) | 9.77 (0.38) | 9.38 (0.38) | 8.85 (0.31) | 7.89 (0.56) | 8.42 (0.54) |
| FPL | 12.0 (0.19) | 10.9 (0.27) | 11.9 (0.09) | 12.1 (0.37) | 11.9 (0.74) | 11.2 (0.42) | 12.0 (0.69) | 10.5 (0.24) | 12.5 (0.48) | 11.9 (0.35) | 11.8 (0.55) | 11.0 (0.28) | 11.5 (0.44) |
| BPL | 13.7 (0.21) | 12.6 (0.15) | 11.9 (0.15) | 11.8 (0.14) | 13.1 (0.54) | 12.8 (0.23) | 13.4 (0.73) | 12.8 (0.31) | 14.9 (0.57) | 14.6 (0.55) | 12.9 (0.47) | 11.8 (0.74) | 12.0 (0.77) |
| SL | 16.3 (0.21) | 15.5 (0.15) | 15.7 (0.21) | 15.0 (0.95) | 15.7 (0.90) | 16.3 (0.21) | 15.6 (0.61) | 14.7 (0.16) | 15.8 (0.53) | 16.0 (0.22) | 15.3 (0.62) | 13.7 (0.56) | 14.9 (0.40) |
| RB | 9.61 (0.12) | 8.88 (0.07) | 9.07 (0.05) | 8.80 (0.42) | 9.47 (0.48) | 8.75 (0.11) | 9.27 (0.39) | 8.85 (0.09) | 9.80 (0.31) | 9.20 (0.05) | 9.57 (0.48) | 8.55 (0.32) | 9.93 (0.72) |
| IFL | 3.35 (0.06) | 3.29 (0.06) | 3.24 (0.09) | 3.42 (0.00) | 3.38 (0.09) | 3.29 (0.09) | 3.51 (0.16) | 3.02 (0.10) | 3.53 (0.16) | 3.27 (0.16) | 3.64 (0.45) | 3.42 (0.00) | 3.11 (0.16) |
| IFB | 1.12 (0.02) | 1.19 (0.02) | 1.22 (0.04) | 1.12 (0.04) | 1.08 (0.05) | 1.05 (0.00) | 1.12 (0.07) | 0.98 (0.05) | 1.28 (0.05) | 1.01 (0.09) | 1.26 (0.17) | 0.92 (0.09) | 1.18 (0.06) |
| MFB | 2.65 (0.04) | 2.45 (0.04) | 2.76 (0.11) | 3.09 (0.05) | 2.76 (0.08) | 2.50 (0.09) | 2.89 (0.16) | 2.77 (0.06) | 2.69 (0.07) | 2.54 (0.19) | 2.80 (0.14) | 2.30 (0.14) | 3.24 (0.07) |
| FIB | 3.85 (0.07) | 3.75 (0.07) | 3.97 (0.21) | 3.95 (0.03) | 3.90 (0.25) | 3.35 (0.18) | 4.95 (1.11) | 3.65 (0.10) | 4.44 (0.18) | 3.97 (0.11) | 4.63 (0.83) | 3.40 (0.07) | 4.87 (0.37) |
| FIL | 7.13 (0.14) | 6.45 (0.10) | 6.90 (0.25) | 7.05 (0.32) | 7.27 (0.57) | 6.55 (0.32) | 6.05 (0.37) | 6.58 (0.08) | 7.29 (0.40) | 6.53 (0.45) | 5.73 (0.93) | 5.90 (0.14) | 6.97 (0.43) |
| FMH | 6.13 (0.05) | 6.09 (0.05) | 6.37 (0.12) | 6.30 (0.14) | 6.35 (0.32) | 5.45 (0.18) | 6.22 (0.08) | 6.12 (0.07) | 6.60 (0.11) | 6.37 (0.05) | 6.13 (0.22) | 6.45 (0.25) | 6.33 (0.23) |
| TBL | 12.2 (0.15) | 11.5 (0.11) | 12.3 (0.25) | 12.2 (0.28) | 11.6 (0.52) | 11.0 (0.37) | 12.0 (0.51) | 11.2 (0.14) | 12.6 (0.30) | 11.8 (0.33) | 11.9 (0.40) | 11.6 (0.18) | 11.3 (0.47) |
| TBW | 7.63 (0.06) | 7.36 (0.06) | 8.42 (0.12) | 8.28 (0.29) | 7.46 (0.12) | 7.89 (0.18) | 8.05 (0.09) | 7.28 (0.15) | 7.85 (0.10) | 7.71 (0.19) | 7.80 (0.16) | 6.97 (0.28) | 7.58 (0.47) |
| AML | 29.4 (0.41) | 27.3 (0.24) | 28.0 (0.33) | 28.1 (0.92) | 29.1 (1.82) | 27.3 (0.03) | 28.3 (1.48) | 26.3 (0.34) | 29.4 (1.09) | 28.6 (0.81) | 26.9 (0.39) | 26.1 (1.13) | 27.9 (1.43) |
| MD | 7.71 (0.13) | 7.20 (0.09) | 6.87 (0.07) | 6.95 (0.32) | 7.40 (0.45) | 6.95 (0.18) | 7.47 (0.54) | 7.02 (0.12) | 7.50 (0.37) | 7.47 (0.41) | 6.67 (0.20) | 6.35 (0.25) | 7.47 (0.58) |
| CPH | 16.9 (0.28) | 15.5 (0.15) | 17.5 (0.95) | 15.3 (0.46) | 16.0 (1.10) | 15.2 (0.11) | 15.9 (0.72) | 14.8 (0.20) | 17.1 (0.76) | 16.3 (0.38) | 15.5 (0.57) | 14.5 (0.71) | 15.8 (1.19) |
| ARML | 31.2 (0.41) | 29.2 (0.26) | 29.8 (0.28) | 29.6 (1.20) | 31.1 (1.72) | 29.7 (0.00) | 30.2 (1.39) | 27.9 (0.39) | 31.7 (0.94) | 30.3 (0.76) | 28.6 (0.57) | 28.4 (1.06) | 30.2 (1.24) |

Table 1: Continued

| Body and skull variables (mm) | 2n = 60 population | | 2n = 56 S population | | 2n = 54 population | | 2n = 52 population | | 2n = 50 population | | 2n = 40 population | | 2n = 56NW population |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male N = 61 | Female N = 56 | Male N = 3 | Female N = 2 | Male N = 4 | Female N = 2 | Male N = 4 | Female N = 10 | Male N = 13 | Female N = 3 | Male N = 3 | Female N = 2 | Male N = 3 |
| ALML | 30.2 (0.38) | 28.2 (0.26) | 29.1 (0.26) | 29.0 (1.02) | 30.3 (1.58) | 28.5 (0.14) | 29.8 (1.56) | 27.6 (0.30) | 30.9 (0.98) | 29.3 (0.63) | 28.0 (0.28) | 27.4 (0.99) | 28.8 (1.05) |
| $ALM^{1-3}$ | 7.73 (0.07) | 7.57 (0.07) | 7.98 (0.07) | 7.76 (0.28) | 7.76 (0.20) | 7.63 (0.00) | 7.66 (0.07) | 7.57 (0.12) | 8.29 (0.10) | 7.89 (0.12) | 8.02 (0.11) | 7.63 (0.00) | 7.40 (0.03) |
| $CLM^{1-3}$ | 6.72 (0.07) | 6.61 (0.08) | 6.70 (0.16) | 6.51 (0.05) | 6.74 (0.22) | 6.97 (0.09) | 6.70 (0.19) | 6.85 (0.10) | 6.70 (0.12) | 6.97 (0.16) | 6.92 (0.09) | 6.84 (0.00) | 6.44 (0.27) |
| UIAL | 6.55 (0.09) | 6.14 (0.07) | 6.31 (0.06) | 6.17 (0.19) | 6.31 (0.29) | 6.11 (0.14) | 6.80 (0.29) | 6.09 (0.12) | 6.98 (0.26) | 6.44 (0.12) | 6.49 (0.26) | 6.18 (0.09) | 7.32 (0.41) |
| UIW | 2.27 (0.04) | 2.16 (0.03) | 2.10 (0.00) | 2.17 (0.14) | 2.16 (0.16) | 2.04 (0.05) | 2.30 (0.11) | 2.12 (0.03) | 2.37 (0.16) | 2.15 (0.09) | 2.06 (0.04) | 1.97 (0.09) | 2.37 (0.21) |
| $CLM^1$ | 2.58 (0.03) | 2.55 (0.02) | 2.63 (1.62) | 2.69 (0.04) | 2.66 (0.12) | 2.63 (0.00) | 2.72 (0.05) | 2.74 (0.04) | 2.86 (0.04) | 2.80 (0.07) | 2.72 (0.07) | 2.76 (0.09) | 2.63 (0.12) |
| $CLM^2$ | 2.31 (0.03) | 2.26 (0.03) | 2.23 (0.12) | 2.37 (0.00) | 2.30 (0.06) | 2.36 (0.09) | 2.27 (0.12) | 2.40 (0.04) | 2.44 (0.04) | 2.45 (0.09) | 2.37 (0.62) | 2.23 (0.09) | 2.23 (0.10) |
| $CLM^3$ | 1.85 (0.03) | 1.82 (0.02) | 1.88 (0.03) | 1.77 (0.05) | 1.93 (0.08) | 1.90 (0.04) | 1.79 (0.09) | 1.81 (0.04) | 1.85 (0.05) | 1.61 (0.13) | 1.84 (0.15) | 1.69 (0.09) | 1.87 (0.10) |
| $CBM^2$ | 2.33 (0.02) | 2.27 (0.03) | 2.23 (0.06) | 2.23 (0.09) | 2.27 (0.08) | 2.23 (0.09) | 2.36 (0.04) | 2.31 (0.05) | 2.37 (0.05) | 2.28 (0.13) | 2.37 (0.62) | 2.17 (0.01) | 2.10 (0.00) |
| $ALM_{1-3}$ | 7.49 (0.10) | 7.29 (0.07) | 7.36 (4.58) | 7.42 (0.23) | 7.46 (0.12) | 7.69 (0.04) | 7.39 (0.07) | 7.41 (0.09) | 7.88 (0.15) | 7.67 (0.09) | 7.45 (0.19) | 7.82 (0.05) | 7.36 (0.45) |
| $CLM_{1-3}$ | 6.54 (0.07) | 6.44 (0.08) | 6.57 (0.12) | 6.44 (0.09) | 6.64 (0.13) | 6.70 (0.09) | 6.64 (0.07) | 6.82 (0.07) | 6.99 (0.11) | 6.97 (0.06) | 6.74 (0.09) | 6.70 (0.09) | 6.57 (0.16) |
| $CLM_1$ | 2.39 (0.03) | 2.37 (0.03) | 2.28 (0.07) | 2.23 (0.09) | 2.43 (0.06) | 2.43 (0.04) | 2.50 (0.06) | 2.56 (0.03) | 2.60 (0.02) | 2.49 (0.06) | 2.45 (0.07) | 2.63 (0.00) | 2.37 (0.16) |
| $CLM_2$ | 2.17 (0.02) | 2.17 (0.02) | 2.32 (0.04) | 2.23 (0.09) | 2.37 (0.00) | 2.30 (0.05) | 2.30 (0.06) | 2.31 (0.03) | 2.40 (0.06) | 2.41 (0.03) | 2.37 (0.62) | 2.50 (0.09) | 2.23 (0.06) |
| $CLM_3$ | 2.06 (0.03) | 2.00 (0.03) | 2.10 (0,00) | 2.04 (0.05) | 1.99 (0.10) | 2.04 (0.05) | 1.94 (0.09) | 2.04 (0.03) | 2.06 (0.07) | 2.02 (0.07) | 2.02 (0.07) | 1.77 (0.05) | 1.96 (0.11) |
| LIW | 2.26 (0.04) | 2.14 (0.03) | 2.10 (0.06) | 2.10 (0.09) | 2.20 (0.17) | 2.10 (0.00) | 2.30 (0.13) | 2.26 (0.04) | 2.37 (0.09) | 2.28 (0.16) | 2.06 (0.09) | 2.23 (0.09) | 2.49 (0.16) |

TBL = Total Body Length, HFL = Hind Foot Length, W = Wight (g), ZB = Zygomatic Breadth, ZP = Breadth of zygomatic plate, IC = Interorbital Constriction, CBL = Condylobasal length, CNL = Condylonasal length, ONL = Occipitonasal length, BL = Basal Length, NL = Nasal length, NB = Nasal Breadth, PL = Parietal Length, PBL = Breadth of parietal on lambdoid seam, PBF = Breadth of parietal on forward seam, FPL = Frontalia + parietalia length, MB = Mastoid Breadth, FRL = Length of face region, BCL = Length of brain capsule, CD = Depth of Cranium, CTBD = Depth of cranium except tympanic blister, EMD = Diatemer of external meatus, DL = Diastema Length, PL = Palatal Length, FPL = Length of forward palatal, BPL = Length of behind palatal, SL = Subraoccipital Length, RB = Rostrum Breadth, IFL = Length of incisive foramen, IFB = Breadth of incisive foramen, MFB = Breadth of mesopterygoid fossa, FIB = Breadth of foramen infraorbitalia, FIL = Length of foramen infraorbitalia, FMH = Foramen magnum height, BL = Length of tympanic bulla, TBW = Width of tympanic bulla, AML = Angular Mandible Length, MD = Mandiple Depth, CPH = Height of coronoid process, ARML = Articular mandible length, ALML = Alveolar mandible length, $ALM^{1-3}$ = Alveolar length of $M^1$-$M^3$, $CLM^{1-3}$ = Coronar length of $M^1$-$M^3$, UIAL = Alveolar length of upper incisors, UIW = Width of the upper incisor, $CLM^1$ = Coronar length of $M^1$, $CLM^2$ = Coronar length of $M^2$, $CLM^3$ = Coronar length of $M^3$, $CBM^2$ = Coronar breadth of $M^2$, $ALM_{1-3}$ = Alveolar length of $M_1$-$M_3$, $LM_{1-3}$ = Coronar length of $M_1$-$M_3$, $CLM_1$ = Coronar length of $M_1$, $CLM_2$ = Coronar length of $M_2$, $CLM_3$ = Coronar length of $M_3$, 5LIW = Width of the lower incisor

## RESULTS

**Nonmetric morphological characteristics:** All chromosomal forms have foramen subra-condyloideum above both sides of the occipital condyles. In adult and old specimens, the width of parietal bones is nearly equal to its length. The foramen post palatines are positioned in the front of the line between $M^2$ and $M^3$ in all samples. In all chromosomal forms apart from 2n = 50 and 60, the posterior margin of palate attain backwards the line connecting the rear edges of the alveoli of the last upper molars. In chromosomal forms of 2n = 40, 50 (Susuz and Selim populations), 52, 56 NW, lachrymal projections on the anterior orbital margins were invisible. The nasal bone is extending and passing through the back of the line connecting to the rear edges of infraorbital foramen in only chromosomal forms of 2n = 56S and 2n = 50. There is a nerve puncture in the both sides of nasal bone in only 2n = 50 (in Susuz population, N = 1). In chromosomal forms of 2n = 50 and 54, the portion behind the palate has a well- developed styloid process.

**Molar morphology:** Alveoli cubicles and roots of the molar teeth showed structural differences within chromosomal forms. Figure 2 shows alveoli cubicles of $M^{1, 2, 3}$ and $M_{1, 2, 3}$. In chromosomal forms of 2n = 40, 50, 52, 54, 56S, 56 NW and 60, $M^1$ has 2, 3, 3, 3, 2, 4, 1 alveoli cubicles, respectively. $M_1$ has 2 alveoli cubicles in all chromosomal forms. $M_{2, 3}$ have two alveoli cubicles in chromosomal forms of 2n = 40, 50, 54, 56 NW, 56 S, while chromosomal forms of 2n = 60 and 52 have one cubicles in $M_{2, 3}$.

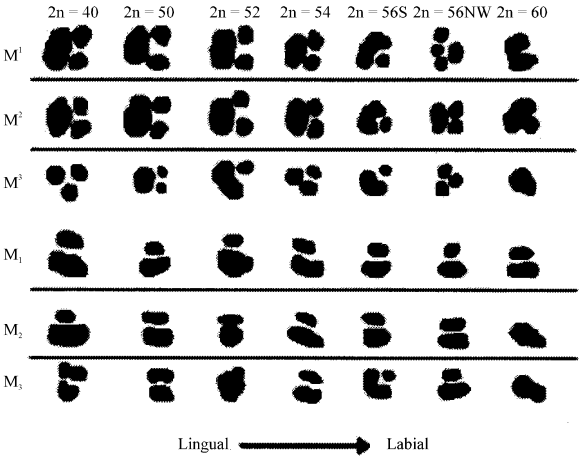


Fig. 2: Alveoli cubicles of upper and lower molar teeth in seven chromosomal forms of *Spalax leucodon*

In all chromosomal forms, structural differences in enamel fold patterns on crowns of the molars from young to old individuals are showed in Fig. 2. In young specimens, $M^1$ has two labial and one lingual enamel fold. As age progressing, at first, the labial enamel fold in the anterior is closed. After that, the labial enamel fold in the posterior is closed. Finally, lingual enamel fold is closed and chewing surface of the molar of the adult specimens has three enamel islands in the shape of smiling man. These three enamel islands end because of tooth erosion.

In all chromosomal forms, chewing surface of $M^2$ of young specimens contains two parts; one of them is located on the anterior side and the other one is on the

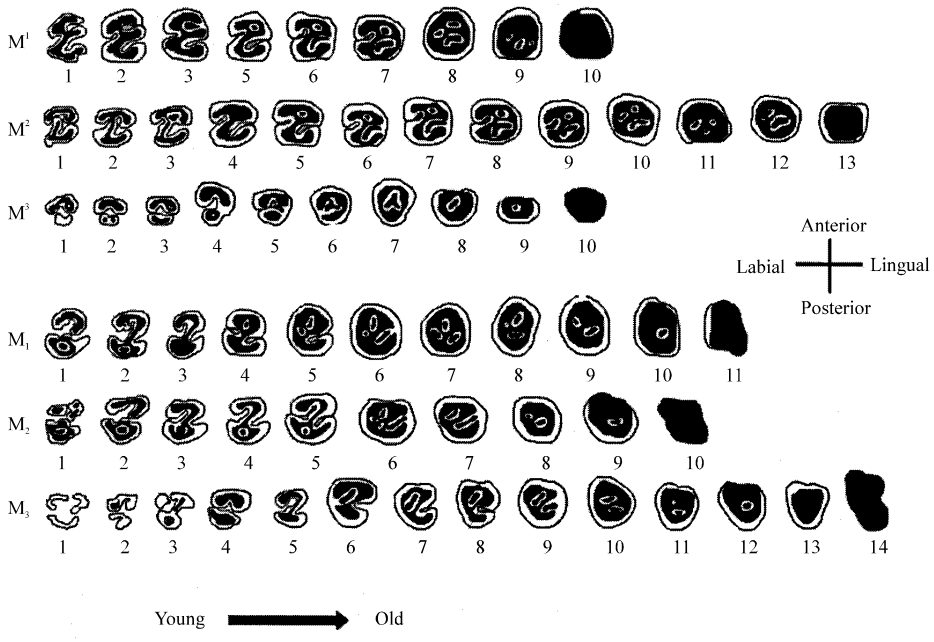


Fig. 3: Variations in enamel folds on upper and lower molar teeth of *Spalax leucodon*

posterior side. These parts are fused and enamel fold that is big on labial and small on lingual are developed in young individuals. The order of closure for intruding folds is as follows: firstly, the lingual enamel folds in the anterior; secondly, the lingual enamel folds in the posterior and finally, labial enamel fold.

Figure 3 shows that chewing surface of the second upper molar ($M^3$) in young specimens contains two parts which are fused in the course of time. Adults have one lingual enamel fold. The enamel fold in lingual forms the three armed-enamel island by fusing. Chewing surface of the first lower molar ($M_1$) in young specimens contains two parts. There is an addition enamel island in posterior part of the chewing surface in young individuals. The small island ends soon after fusing of anterior and posterior parts. $M_1$ bears two (on lingual and labial) converging folds on the chewing surface in mature specimens. The lingual enamel fold makes two enamel islands. The enamel fold in labial forms one island. Chewing surface of the first lower molar ($M_1$) in old specimens contains three enamel islands.

Chewing surface of the second lower molar ($M_2$) in young specimens consists of three parts; two in anterior and one in posterior. The three parts are fused and two enamel fold are formed on chewing surface. Firstly, enamel fold in lingual and then fold in labial are fused.

Chewing surface of the third lower molar ($M_3$) in old specimens contains two enamel islands. In young specimens, the third upper molar ($M_3$) has three parts. In the most common forms there are two folds. In mature specimens, chewing surface of $M_3$ has two enamel islands.

**Metric morphological characteristics**

**Male-female sexual dimorphism:** The means of external and cranial measurements for each sex of seven karyotypic forms and their standard errors are shown in Table 1. The means of male measurements were significantly larger than that of females. There are a gradient in body size and weight for each sex as follows 2n = 50 > 52 > 60 > 56S > 54 > 40 > 56 NW. The morphometric comparisons between the two sexes by Hottelling-$T^2$ criterion showed statistically significant differences, Hotelling-Lawley Trace Value = 1.257, ($p<0.001$); therefore, males and females were separately evaluated for subsequent analysis. The sexual dimorphism in *S. leucodon* was mostly expressed by different characters ($p<0.001$), but, statistically significant values were not discovered between the two sexes for 16 of the 55 skull and body variables. These variables (FPL, MB, FIL, FIB, $ALM^{1-3}$, UIW, $CLM^1$, $CLM^2$, $CLM^3$, CBM2, $ALM_{1-3}$, $CLM_{1-3}$, $CLM_1$, $CLM_2$, $CLM_3$ and LIW) were shown in Table 1.

**Discriminant function analysis and MANOVA:** Total variation in DFA for male specimens was explained by six

components. The first discriminant function (DF-1) derived from males separates 2n = 50 chromosomal form from the others and explained 64.3% of total variability. The second, the third and the fourth variates explained the rest of the variation, 29.2, 4.0 and 2.0%, respectively. In DFA, 89.0% of male individuals were correctly classified into their group. In male individuals, classification results of DF showed all 2n = 60 chromosomal form (except one), all the 2n = 50 and all the 2n = 56 NW being classified correctly. In addition to this, three chromosomal forms (2n = 60, 56 NW and 50) were separated and were situated in distinct regions in vertical elongation of the plot. However, 2n = 56 SW, 54, 52 and 40 chromosomal forms was not separated from others and they located in a region distribution of 2n = 60 chromosomal form (Fig. 5). DFA of female specimens was explained by 4 components. DFA of females showed 86.7% correct classification. The first canonical variate explained most of the variation (87.4%). The second, the third and the fourth variates explained the rest of the variation, 10.4%, 1.3% and 0.9%, respectively. Misclassifications were observed in the 2n = 52 chromosome forms with 2 out of 10 individuals classified into the 2n = 60 chromosome form. DFA showed that all 2n = 56 SW, 54, 40 females and all the 2n = 50 and 60 were correctly classified. The plots of functions 1 and 2 for females indicated that 2n = 50 chromosomal form largely separated from the other groups.

MANOVA multivariate analysis was performed on both male and female for 52 relative measurements of skull variables. This analysis revealed that some of these characters were statistically significant. In male specimens among chromosomal forms, MANOVA scores revealed statistically significant variation in skull parameters (breadth of zygomatic plate, coronar length of $M_2$, ($p<0.001$), breadth of parietal on forward seam, length of behind palatal, breadth of foramen infraorbitalia, foramen magnum height, alveolar length of $M^1$-$M^3$, coronar length of $M^1$, coronar length of $M_2$, $p<0.05$). In female specimens among chromosomal forms, MANOVA scores showed significant variation in skull parameters (breadth of zygomatic plate, ($p<0.001$); breadth of parietal on forward seam, length of behind palatal, subraoccipital length, width of tympanic bulla, ($p<0.05$); breadth of incisive foramen, breadth of mesopterygoid fossa, $p<0.01$).

Dendrograms of samples from seven chromosomal forms were constructed by UPGMA based on the Manhattan distances of centroids of seven groups in a discriminant function analysis. The data for cluster analysis were divided into two groups due to sexual dimorphism, only males were utilized in this paper (Fig. 6).

## DISCUSSION

Morphological comparisons of seven chromosomal forms were achieved by studying external and cranial characteristics of mole rat in the genus *Spalax*. Not all of the chromosomal forms were correctly classified. Thus based on the results of this study, it is hard to assign new taxonomic status to all these chromosomal forms distributed in Turkey.

Kivanc (1988) classified the specimens from distribution area of 2n = 60, 56 SW, 54, 52, 40 chromosomal forms as *S. l. cilicicus*, from distribution area of 2n = 50 as *S. l. nehringi* and from distribution area of 2n = 56 NW as *S. l. turcicus*. According to Kivanc (1988), *S. l. nehringi* is distinguished from the other subspecies by the presence of a well developed styloid process on the portion behind the palate. In distribution area of *S. l. cilicicus*, all specimens of chromosomal form of 2n = 54 possess these foramina. According to our non-metric morphological evaluations, the 2n = 54 (Kırıkkale population) chromosomal form exhibits non-metric morphological aspects of *S. l. nehringi*. Furthermore, the $M^1$ of all specimens of this chromosomal form has three alveoli cubicles. This is different from the findings of Kivanc (1988) for *S. l. cilicicus*. We included this karyotypic form in *S. l. nehringi* based on its non-metric morphological characteristics. According to Kivanc (1988), chromosomal form of 2n = 56 in Aksu (Isparta) is similar to *S. l. cilicicus*. Our non-metric morphological evaluations showed that this karyotype possibly belongs to *S. l. anatolicus* instead of *S. l. cilicicus*, because the $M^1$ of all specimens of this forms have two alveoli cubicle. Kivanc (1988), who evaluated specimens in distribution area of chromosomal form of 2n = 56 NW in Thrace, indicated that $M^1$ of all specimens in this region has three alveoli cubicle. The results of the present study showed that 2n = 56 NW chromosomal form is distinguished from the other subspecies on four alveoli cubicle. But, the other morphological characters of this chromosomal form are consisted with the finding of Kivanc (1988).

In the comprehensive study on morphology of *S. ehrenbergi* in Israel (Nevo *et al*., 1988), morphological differentiations were observed in each chromosomal form based on increase in aridity index and their adaptations to the climatic diversity of Israel. According to Nevo *et al.* (1988), body size of northern animals living in cooler and more productive mesic environments is larger than that of southern animals living in warmer and less productive xeric environment. Our data support those of Nevo *et al.* (1988) and in this study, the biggest body size and weight

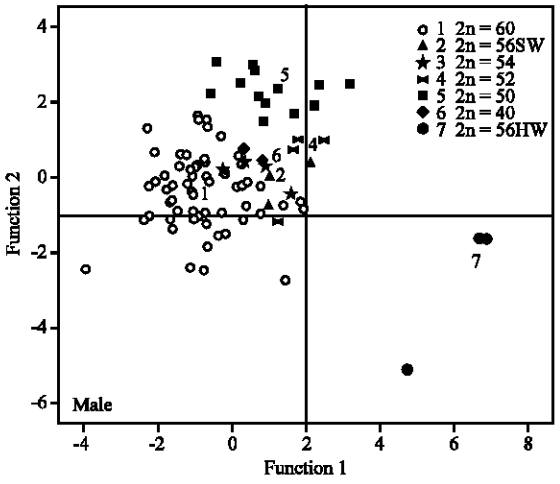


Fig. 4: The result of discriminant function analysis of male specimens of *S. leucodon* in Turkey

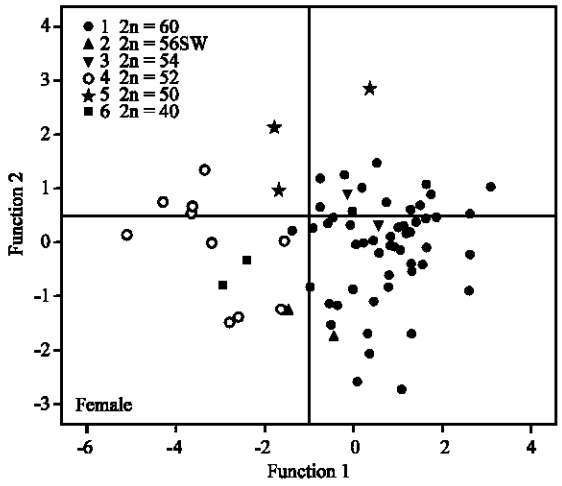


Fig. 5: The result of discriminant function analysis of male specimens of *S. leucodon* in Turkey

were observed in chromosomal forms of 2n = 52 living in cover and environment with abundant food. We determined a statistically significance differences between sexes by studying a great number of cranial characters of *S. leucodon* supporting the findings of Nevo *et al.* (1988) for *S. ehrenbergi* in Israel. Females in all the chromosomal forms are generally smaller than males.

In this study, discriminant analysis separated three chromosomal forms (2n = 60, 50 and 56 NW) from each other. DFA revealed the presence of three distinct groups for both male and female (Fig. 4 and 5). Three groups are: *S. l. cilicicus* has 2n = 60, 56 SW, 54, 52, 40 chromosomal forms; *S. l. turcicus* contains 2n = 56 NW; and *S. l. nehringi* includes 2n = 50 chromosomal form, respectively. The results of metric morphological analysis are consistent with the findings of Kivanc (1988), while non-metric morphological findings did not agree with the literature. In addition to DFA, the classification obtained by UPGMA shown in dendrogram (Fig. 6) is also consistent with the classification of Kivanc (1988).

Wahrmann *et al.* (1969) stated that the distribution of each of the chromosomal forms of *S. ehrenbergi* in Israel displayed a general correspondence with climatic regions characterized by increasing aridity. When these chromosomal forms along with increasing aridity confronted, new selective environmental conditions (homozygote karyotypes) fixed within local populations as an adaptation for life in arid habitats (Wahrmann *et al.*, 1969). Climatically, Turkey is very heterogeneous in terms of geographic position and structure and surrounded by the Mediterranean Sea in the south and Aegean Sea in the west. Aridity stress was increased towards the inland, Central Anatolia and Southeast Anatolia from other regions. But this increasing in aridity shows a discontinuous state. According to recent studies on geology and geophysics, Turkey is exposed to a lot of deformation on both horizontal and vertical direction. The Central Anatolia Plateau is diverged from all directions because it is surrounded by mountain ranges. Fixation of new chromosomal forms is considerably fast in members of this genus having restricted movement ability. Consequently, twenty-one chromosomal forms in Turkey were reported (Butler *et al.*, 1993; Nevo *et al.*, 1994, 1995; Ivanitskaya *et al.*, 1997; Sozen *et al.*, 1999, 2000a, b; Kankılıç *et al.*, 2005). According to our results in this study, the diploid number of chromosome is variable even in localities that are very close to each other. For example, in Beyşehir, a population in rainy and humid areas in foot of the Sultan mountains covered with forests has 2n = 40, while another population in dry, cultivated and steppe areas in 15 km away from 2n = 40 has 2n = 60 (Kankılıç *et al.*, 2005). A similar phenomenon was found in morphological characteristics of those populations. The DFA clustering (Fig. 4 and 5) were well expressed this situation. Karyotypically separated forms (2n = 40, 54, 56 and 60) are morphologically clustered together, because their distributional areas (exposed climatical conditions on morphology) were similar.

Although chromosomal forms are considered by Nevo *et al.* (1994, 1995) as biological species, genetic and morphologic studies on chromosomal forms are poor in Turkey. When the number of diploid chromosomes (2n) and morphological characters of chromosome forms (NF) are taken into consideration, populations which have the same diploid chromosome number possess considerably distinct morphological characters. For example, in this study specimens of 2n = 56 SW (Isparta) and 2n = 56 NW

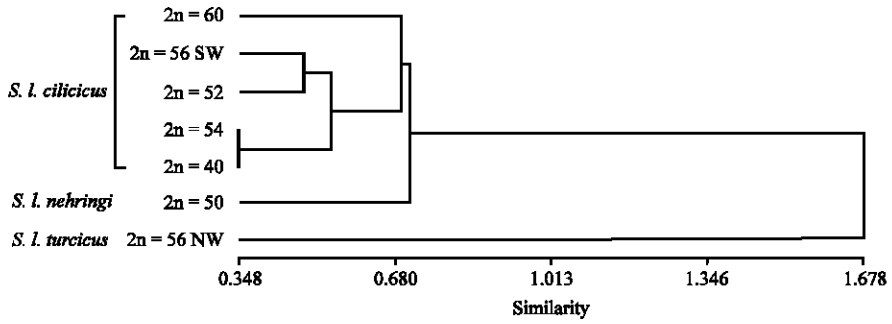


Fig. 6: UPGMA phenogram of chromosomal forms of *Spalax leucodon* based on Manhattan distances among centroids of groups in discriminant function analysis (Males)

(Thrace) chromosomal forms displayed considerable differences in both non-metric and metric morphological characters.

Numerical taxonomy uses a large number of characters and gives equal weight to all of the characters used to construct a classification. The classification obtained by numerical taxonomy gave more information than did conventional methods on the relationship between S*palax* taxa (Kivanc, 1988) used in present study. Although this study added new finding to the literature, it is somewhat known about genera, species and subspecies distributed and morphological aspect chromosomal forms in Turkey. A comprehensive study covering all S*palax* species seems to be necessary to construct a more satisfactory classification.

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