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RESEARCH ARTICLE

Prion protein gene polymorphisms in Turkish native goat breeds

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Abstract

Susceptibility to 'scrapie' disease in goats is influenced by polymorphisms of the prion protein (*PRNP*) gene. The aim of this study was to identify *PRNP* gene polymorphisms in a total of 356 scrapie disease-free goats from 10 Turkish native breeds. Eighteen single-nucleotide polymorphisms were detected in the caprine *PRNP* open-reading frame. Ten previously described amino acid substitutions (I142M, H143R, N146S, N146D, R151H, R154H, P168Q, R211Q, Q222K and P240S) and two novel dimorphisms (G134E and Q163P) were identified. The strongest association between caprine *PRNP* and relative resistance to scrapie disease has been reported previously for polymorphisms at codons 146 (S/D) and 222 (K). In the present study, these three PrP variants were relatively rare with 6.3%. This is the first report on *PRNP* gene variation in Turkish native goat breeds and our knowledge of these polymorphisms will assist goat breeding programmes to reduce the risk of scrapie.

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Introduction

Goat production is economically and socially important in Turkey. An estimated 500,000 farm households keep goats and goat production contributes directly to the income of nearly 3,000,000 people through conversion of natural vegetation into valuable products such as meat, milk, hair (mohair), skin and manure (Gürsoy 2006). All goat breeds farmed in Turkey are well adapted to the marginal lands of Anatolia and contribute to the livelihood of resource-poor farmers living under extremely difficult conditions in the semiarid areas and highlands of the country (Yilmaz *et al.* 2012).

Scrapie is a fatal, neurodegenerative disease that affects sheep and goats. It is a member of the transmissible spongiform encephalopathies (TSEs) also known as prion diseases that include Creutzfeldt–Jakob disease (CJD) in humans and bovine spongiform encephalopathy (BSE) in cattle. In these diseases, a neuronal glycoprotein known as prion protein PrP^{C} (encoded by *PRNP* gene) is converted into an abnormal protease-resistant isoform (PrP^{Sc}), which accumulates in the central nervous system and lymphoid tissues (Prusiner 2004). Caprine PrP^{C} contains 256 amino acids which were folded into two domains, of which only the C-terminal globular domain (position 102–234) is essential for the conversion into pathogenic PrP^{Sc}. There have been no reported scrapie cases in either sheep or goats in Turkey, but the World Organisation for Animal Health (OIE) does not consider Turkey, free of scrapie disease in accordance with their regulations (OIE 2010).

In sheep and goats, the resistance or susceptibility to scrapie is strongly controlled by polymorphisms of the *PRNP* gene and modulated by the strain of prion disease agent (Goldmann 2008). It is well established that the ovine allele encoding PrP^{C} with amino acids: alanine (A), arginine (R) and arginine (R) at codons 136, 154 and 171, respectively (short: ARR) is associated with a high protection against classical forms of scrapie disease; this association appears to be applicable to scrapie outbreaks worldwide. In contrast, PrP variants (VRQ or ARQ) are associated with susceptibility and this is more agent-strain-dependent (Hunter 1997). Genetic association of *PRNP* with atypical forms of scrapie disease is slightly more complicated and involves different amino acid substitutions such as L141F (Benestad *et al.* 2008). With EU decision 2003/100/EC (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003D0100), each member state in the European community has introduced breeding strategies to increase the frequency of the resistance-associated

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PrP variant, ARR in their sheep populations. *PRNP* genotyping of all native Turkish sheep breeds led to the identification of a considerable number of polymorphisms and helped to evaluate the genetic risk for both classical and atypical scrapie (Meydan *et al.* 2012, 2013a, b).

To date, worldwide, more than 40 amino acid substitutions have been described in the caprine *PRNP* open-reading frame (ORF) but only a few of them—I142M, H143R, G145D, N146S/D, Q211R and Q222K—have been proven to be associated with resistance to scrapie disease. Several case/control studies performed in Italy (Acutis *et al.* 2006; Vaccari *et al.* 2006) and France (Barillet *et al.* 2009) demonstrated a high protective effect of the K222 variant against classical scrapie. The codon 146 variants, S146 and D146 have been similarly associated with scrapie resistance in Cypriot herds (Papasavva-Stylianou *et al.* 2011; Ortiz-Pelaez *et al.* 2014). Modulation of classical scrapie disease by amino acid substitutions in codons 142, 143, 145, 154 and 211 has been shown by studies from UK, Italy, France and Greece (Goldmann *et al.* 1996; Billinis *et al.* 2002; Vaccari *et al.* 2006; Barillet *et al.* 2009; González *et al.* 2009; Bouzalas *et al.* 2010; Colussi *et al.* 2010; Maestrale *et al.* 2015). The strength of the K222 association with scrapie and BSE resistance was confirmed in experimental challenges (Acutis *et al.* 2012; White *et al.* 2012; Aguilar-Calvo *et al.* 2014, 2015). It is therefore, likely that, similar to the ovine ARR allele in goats a universal, relative strain-independent protection from classical scrapie is conferred by K222, S146 and D146.

As yet there has been no study on the caprine *PRNP* gene variation in Turkey. Although, there have been no officially reported cases of scrapie in Turkish goats, information regarding *PRNP* gene polymorphisms in Turkish goat breeds may assist future goat breeding programmes to reduce the possible risk of scrapie. Additionally, the combination of old breed types and substantial environmental adaptations raises particular interest to explore genetic variation in the *PRNP* gene. The objective of this study was to genotype 10 Turkish goat breeds to determine polymorphisms of the *PRNP* ORF and evaluate their theoretical genetic susceptibility to scrapie.

Materials and methods

Sampling and DNA extraction

A total of 356 unrelated healthy goats of 2–5 years old were randomly sampled from 10 breeds (for details, see table 1). Blood samples were collected from the jugular vein into EDTA vacutainers and stored at –20°C until genomic DNA extraction, which was carried out using a salting-out method (Miller *et al.* 1988). All procedures were approved by the Animal Experimentations Local Ethics Board at Ankara University.

PCR assay and DNA sequencing

A 489 bp fragment (*PRNP* codons 103–249) was amplified by PCR. The amplification reactions were prepared in a final volume of 50 μL containing as follows; 1×PCR buffer, 0.8 mM dNTPs, 1.5 units *Taq* DNA polymerase, 1.5 mM $MgCl_2$, 20 pmol of forward TCAAGGTGGTAGCCACAGTCAGT and reverse CTATCCTACTATGAGAAAAATGAG primers (Billinis *et al.* 2002) and ~1 μg genomic DNA. Amplification was performed using an initial denaturation of 5 min at 95°C, followed by 40 cycles of 60 s at 95°C, 60 s at 60°C and 90 s at 72°C and a final extension of 7 min at 72°C. PCR products were resolved by electrophoresis on 2% agarose gels. After gel electrophoresis, the amplicons were purified using a Qiamp Mini Kit (Qiagen, Valencia, USA). The purified samples were sequenced by Big Dye Terminator chemistry on an ABI 3100 Avant Automated DNA Sequencer (Applied Biosystems, Foster City, USA). Haplotypes and pairwise F_{ST} values were calculated with DNASP (Librado and Rozas 2009) and ARLEQUIN (Excoffier *et al.* 2005), an unrooted neighbour-joining (NJ) dendrogram was generated with SPLITS TREE4 (Huson and Bryant 2006).

Results

We found 12 amino acid substitutions: G134E, I142M, H143R, N146D, N146S, R151H, R154H, Q163P, P168Q,

Table 1. Sampling localities, sample size (*n*) and sex of Turkish native goat breeds.

Breed	Abbreviation	Sampling location	*n*	Sex
Akkeçi	AKK	Ankara	16	13♀ + 3♂
Ankara (Angora)	ANK	Çankırı	15	12♀ + 3♂
		Ankara	23	19♀ + 4♂
Gökçeada (Imroz)	GOK	Çanakkale	20	16♀ + 4♂
Halep (Damascus)	HLP	Şanlıurfa	32	27♀ + 5♂
Honamlı	HNM	Antalya	42	36♀ + 6♂
Kıl (Hair goat)	KIL	Konya	25	20♀ + 5♂
		Ankara	25	20♀ + 5♂
Malta	MLT	Edirne	28	23♀ + 5♂
Norduz	NRD	Van	46	40♀ + 6♂
Kilis	KLS	Gaziantep	20	16♀ + 4♂
		Kilis	20	16♀ + 4♂
Saanen	SNN	İzmir	44	38♀ + 6♂
Total			356	296♀ + 60♂

R211Q, Q222K and P240S (figure 1). Two of them have not been reported previously: in codon 134, a substitution of GGA → GAA leading to amino acid change glycine (G) → glutamic acid (E) and in codon 163 substitution CAA → CCA leading to amino acid change glutamine (Q) → proline (P). These novel polymorphisms were detected in Norduz and Angora goats, respectively. In addition, six silent mutations at codons 119 (t → c), 133 (g → c), 138 (t → c), 141 (t → c), 179 (g → t) and 219 (c → t) were observed, only 119, 133 and 141 were novel. All amino acid substitutions and silent mutations, and their distributions in Turkish native goat breeds are shown in table 2.

Genotypes Seq1/Seq1, Seq2/Seq2 or Seq1/Seq2 (for allelic sequences, see table 3) were found in 82% of all goats. Seq1 is considered to be the caprine wild-type PrP^C sequence and it was found here as predominant variant with a frequency of 0.56 (402/712). Differing only in position 240 (P → S) was Seq2 with a frequency of 0.26; this allele is often regarded as the PrP ruminant archetype as it is most similar to PrP of other species. The remaining 64 (18%) goats gave rise to 15 protein sequences, eight with P240 and seven with S240 confirming that the codon 240 dimorphism lies at the root of PrP protein divergence (Seq3–Seq13, table 3).

The new dimorphisms, G134E and P163Q were found in more than one animal in heterozygous genotypes (figure 2). Four amino acid dimorphisms were detected in only one breed each: E134 in Norduz, H151 in Damascus, P163 in Angora and K222 in the nonindigenous Saanen. While the resistance-associated K222 variant was not found in the native breeds, other resistant PrP variants with polymorphisms such as S146 and D146 were present in two and four of nine indigenous breeds, respectively; with average frequencies of 0.17 (S146) and 0.04 (D146) in those breeds or a combined frequency of 0.059 for all breeds. The M142 and Q211 variants were only detected in Akkeçi and Saanen goats with combined breed frequencies of 0.534 and 0.17, respectively. Based on pairwise F_{ST} values calculated from the frequencies of observed *PRNP* haplotypes, a phylogenetic tree was constructed as a representation of the genetic relationship among the Turkish goat breeds at the *PRNP* locus (figure 3).

Discussion

Scrapie is a fatal disease for which no treatment is available. It can have devastating consequences for small farm holdings

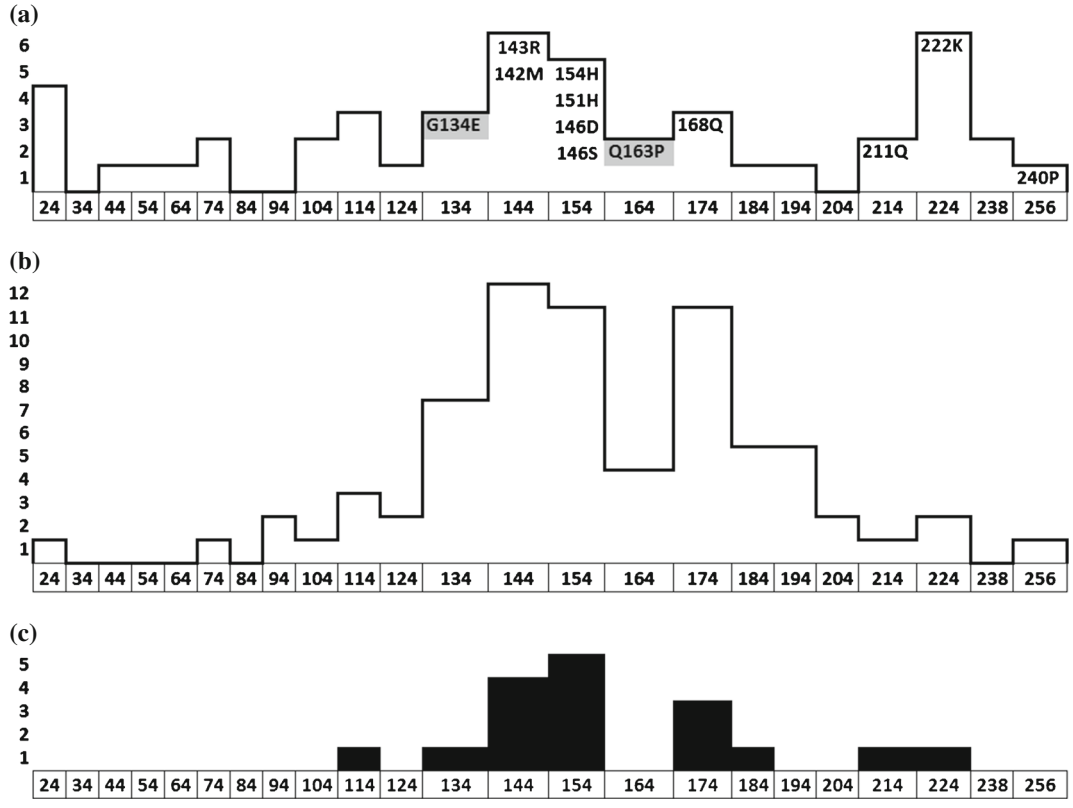


Figure 1. Histograms showing the number of amino acid substitutions (polymorphisms) on *PRNP*. Sequence is divided into consecutive blocks of 10 amino acids with the exception of the first block (amino acids 1–24, signal peptide) and last block (239–256, signal peptide). (a) Distribution of 47 caprine polymorphisms including the substitutions described in this study; 134E and 163P are novel polymorphisms. (b) Shown for comparison is the distribution of 71 ovine polymorphisms. (c) Distribution of 17 ovine and caprine polymorphisms that have been shown to be associated with scrapie disease susceptibility and resistance in worldwide case/control studies.

Table 2. Number of various *PRNP* gene polymorphisms and their distributions in Turkish native goat breeds.

Variation			Breeds										
DNA†	Change	Protein	AKK	ANK	GOK	HLP	HNM	KIL	MLT	NRD	KLS	SNN	Total
357T → C	GCT/GCC	None*	–	–	–	–	2	–	–	–	–	–	2
399G → C	CTG/CTC	None*	–	1	–	–	–	–	–	–	–	–	1
401G → A	GGA/GAA	G134E*	–	–	–	–	–	–	–	2	–	–	2
414T → C	AGT/AGC	None	5	11	4	4	7	10	7	6	12	8	74
423T → C	CTT/CTC	None*	–	1	–	–	–	–	–	–	–	–	1
426A → G	ATA/ATG	I142M	10	–	–	–	–	–	–	–	–	14	24
428A → G	CAT/CGT	H143R	–	–	–	–	10	–	–	2	–	–	12
436A → G	AAT/GAT	N146D	–	–	–	–	2	4	–	–	6	2	14
437A → G	AAT/AGT	N146S	–	–	–	14	–	8	–	–	–	–	22
452G → A	CGT/CAT	R151H	–	–	–	2	–	–	–	–	–	–	2
461G → A	CGT/CAT	R154H	–	2	–	6	2	–	–	2	–	–	12
488A → C	CAA/CCA	Q163P*	–	2	–	–	–	–	–	–	–	–	2
503C → A	CCA/CAA	P168Q	–	4	–	–	4	–	4	2	–	2	16
537G →T	GTG/GTT	None	–	–	–	–	–	5	–	–	–	–	5
632G → A	CGA/CAA	R211Q	4	–	–	–	–	–	–	–	–	4	8
657C → T	ACC/ACT	None	–	–	–	–	–	–	–	3	–	–	3
664C → A	CAG/AAG	Q222K	–	–	–	–	–	–	–	–	–	3	3

Numbers represent the number of animals with those polymorphisms, either homozygous or heterozygous. †DNA positions are given to the nucleotide positions of NM_001314247. *Polymorphisms not reported previously, these were confirmed by sequencing twice and in both the directions on DNA from different PCR reactions. AKK, Akkeçi; ANK, Angora; GOK, Imroz; HLP, Damascus; HNM, Honamlı; KIL, Hair goat; MLT, Malta; NRD, Norduz; KLS, Kilis; SNN, Saanen.

Table 3. Deduced protein variants of *PRNP* gene and their frequencies in Turkish native goat breeds.

	PRNP codon																					
Seq.	134	142	143	146	151	154	163	168	211	222	240	AKK	ANK	GOK	HLP	HNM	KIL	MLT	NRD	KLS	SNN	Total
1	G	I	H	N	R	R	Q	P	R	Q	P	0.125	0.632	0.700	0.436	0.500	0.580	0.606	0.672	0.675	0.500	0.564
2	–	–	–	–	–	–	–	–	–	–	S	0.375	0.261	0.300	0.158	0.285	0.280	0.322	0.240	0.250	0.216	0.260
3	E	–	–	–	–	–	–	–	–	–	P	0	0	0	0	0	0	0	0.022	0	0	0.003
4	–	M	–	–	–	–	–	–	–	–	P/S	0.375	0	0	0	0	0	0	0	0	0.159	0.037
5	–	–	R	–	–	–	–	–	–	–	P/S	0	0	0	0	0.119	0	0	0.022	0	0	0.017
6	–	–	–	S	–	–	–	–	–	–	P/S	0	0	0	0.281	0	0.100	0	0	0	0	0.039
7	–	–	–	D	–	–	–	–	–	–	P	0	0	0	0	0.024	0.040	0	0	0.075	0.023	0.020
8	–	–	–	–	H	–	–	–	–	–	S	0	0	0	0.031	0	0	0	0	0	0	0.003
9	–	–	–	–	–	H	–	–	–	–	P/S	0	0.027	0	0.094	0.024	0	0	0.022	0	0	0.017
10	–	–	–	–	–	–	P	–	–	–	P	0	0.027	0	0	0	0	0	0	0	0	0.003
11	–	–	–	–	–	–	–	Q	–	–	P	0	0.053	0	0	0.048	0	0.072	0.022	0	0.023	0.022
12	–	–	–	–	–	–	–	–	Q	–	S	0.125	0	0	0	0	0	0	0	0	0.045	0.011
13	–	–	–	–	–	–	–	–	–	K	S	0	0	0	0	0	0	0	0	0	0.034	0.004

AKK, Akkeçi; ANK, Angora; GOK, Imroz; HLP, Damascus; HNM, Honamlı; KIL, Hair goat; MLT, Malta; NRD, Norduz; KLS, Kilis; SNN, Saanen.

and the only long term prevention method is differential selection against susceptible and for resistant *PRNP* genotypes. In recent years, reports of caprine *PRNP* polymorphisms and case–control studies in different European countries have revealed the value of the genetic approach to minimize disease risk. In Turkey, scrapie control breeding programmes have not been established for sheep and goats because there have not been any confirmed scrapie cases. Although, all Turkish native sheep breeds have been *PRNP* genotyped to evaluate the genetic risk for both classical and atypical scrapie (Meydan *et al.* 2012, 2013a, b), this is the first study to genotype *PRNP* in all Turkish native goat breeds.

A total of 17 different PrP^C protein sequences were deduced from the DNA sequences among which the wild-type PrP^C is the most common in Turkish goats and also the predominant allele in all breeds except Akkeçi goats (table 3). Corbiere *et al.* (2013) reported that the S240P polymorphism appears to have no direct impact on scrapie disease risk, which is important as this S240P dimorphism is the only amino acid change that occurs in various combinations with the other amino acid substitutions. The remaining 18% of the goats carried at least one of the other PrP^C variant and this frequency is not dissimilar to European populations (Goldmann 2008). Discounting the very common polymorphism S240P, on an average, one amino acid substitution was

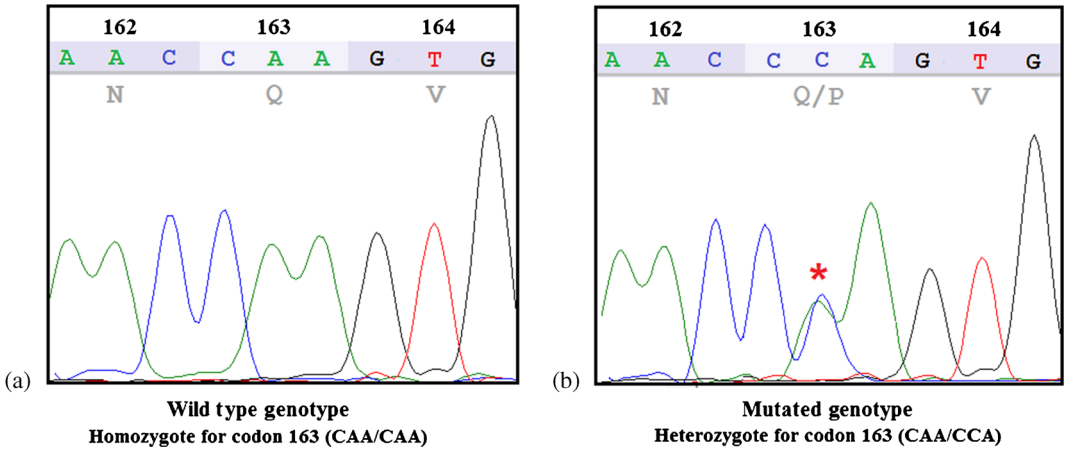


Figure 2. Sequence chromatogram for codon 163 of *PRNP* in homozygote and heterozygote animals. (a) Homozygous genotype 163QQ deduced from sequence CAA; (b) heterozygous genotype 163 (QP) deduced from sequence C(C+A)A representing CAA (Q) and CCA (P). Red star indicates the polymorphic site. Q, glutamine; P, proline.

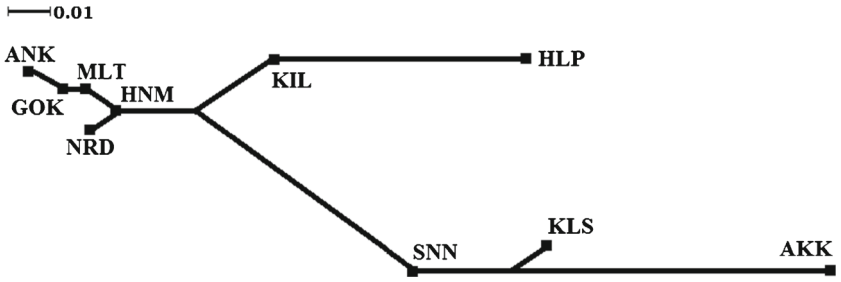


Figure 3. NJ dendrogram for Turkish native goat breeds based on *PRNP* haplotypes. AKK, Akkeçi; ANK, Angora; GOK, Imroz; HLP, Damascus; HNM, Honamlı; KIL, Hair goat; MLT, Malta; NRD, Norduz; KLS, Kilis; SNN, Saanen.

found for every 36 genotypes revealing that Turkish goats are at least as genetically varied in this locus as Turkish sheep, for which we genotyped on average 52 animals/substitution (Meydan *et al.* 2013a).

Ten of 12 amino acid substitutions observed here have previously been described in goats from several countries including Mediterranean countries (Greece, Cyprus, Spain, Morocco, Italy), whereas two were novel (G134E and Q163P). A priori predictions of the effect that these amino acid changes may have on scrapie susceptibility are not yet possible, but neither the substitution is conservative, so that structural changes may be likely for these variants. It should be noted that the codon positions of 134 and 163 fall into a region of PrP^C (figure 1, a&b), in which there are 15 known disease-associated amino acid changes (figure 1c) and 14/15 are conferring a degree of resistance (Goldmann 2008).

Both S146 (Seq6) and D146 (Seq7) have been associated with strong protection from classical scrapie in Cypriot goats (Papasavva-Stylianou *et al.* 2011). With a combined frequency of 5.9% and representation in five of 10 breeds, they could become target alleles for resistance breeding. Indeed, S146 was the most frequent PrP variant (18/64) in Damascus goats suggesting that this resistance-associated polymorphism may be maintained in the Damascus-related breeds independent of the presence of scrapie. K222 (Seq13) is another strongly protective PrP^C variant; only Turkish Saanen goats carried the K222 with a frequency of 3.4%, which is similar to other European populations. Further surveys are needed to confirm this estimate and whether it is truly absent from the indigenous breeds.

From the point of view of future breeding programmes for the eradication of scrapie, the most valuable polymorphisms to be found in this study are S146, D146 and K222 (K). This evaluation is based of course on the assumption that if prion strains were circulating in Turkey, they would be similar to European prion strains and therefore *PRNP* genetics would follow the same rules. As there are no detected scrapie cases in Turkey, this remains speculative, but prion disease genetics in sheep has shown strongly resistance-associated PrP^C variants that appear to be universally effective.

In this study, the combined frequency of these three resistance-associated PrP variants in all Turkish goat breeds was ~6.3%, which is a low starting point for breeding programmes. However, when only the five breeds which carried these alleles are considered, the combined frequency of 18.8% (39/208) represents a realistic foundation for breeding

strategies. Additionally, it should be noted that M142, H154 and Q211 also have partially protective effects on classical scrapie and they contribute another 6.5% of the total surveyed goats or 20.2% of the six breeds in which the alleles were found.

While Damascus goats had the largest proportion of resistance-associated PrP variants, others like Imroz and Malta breeds had no goats in this category (table 2). The nonindigenous Saanen breed, which is reared in southern part of Turkey, appeared to be the most variable breed in Turkey with seven variants and cross-breeding with indigenous breeds may be advantageous from the scrapie perspective. As expected from their breed history, Akkeçi and Saanen goats shared many haplotypes (table 2); their genetic similarity can be seen on the neighbour joining (NJ) dendrogram (figure 3). The most resistant Turkish goat breed may be Damascus, further research is needed to confirm this finding.

The earliest evidence of goat domestication was found in the central Anatolia (modern day Turkey) (Zeder 2008). Thus, it is likely that some of the Turkish native goat breeds of today are some of the oldest living descendants of their first domesticated ancestors, and Anatolian (Turkish) native breeds may be the special ones in maintaining very valuable genetic diversity. Our caprine *PRNP* gene survey supports this view by showing that Turkish breeds are genetically diverse and that they share a considerable number of *PRNP* polymorphisms with the breeds of the world.

In conclusion, this study is the first report to identify the *PRNP* gene polymorphism in Turkish native goat breeds. Two novel amino acid dimorphisms, G134E and Q163P were observed and dimorphisms associated with high resistance to scrapie were present among them were S146, D146 and K222. This result is encouraging with regard to goat breeding programmes to reduce the risk of scrapie in Turkey.

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References

Acutis P. L., Bossers A., Priem J., Riina M. V., Peletto S., Mazza M. *et al.* 2006 Identification of prion protein gene polymorphisms in goats from Italian scrapie outbreaks. *J. Gen. Virol.* **87**, 1029–1033.

Acutis P. L., Martucci F., D'Angelo A., Peletto S., Colussi S., Maurella C. *et al.* 2012 Resistance to classical scrapie in experimentally challenged goats carrying mutation K222 of the prion protein gene. *Vet. Res.* **43**, 8.

Aguilar-Calvo P., Espinosa J. C., Pintado B., Gutiérrez-Adán A., Alamillo E., Miranda A. *et al.* 2014 Role of the goat K_{222}-PrP^C polymorphic variant in prion infection resistance. *J. Virol.* **88**, 2670–2676.

Aguilar-Calvo P., Fast C., Tauscher K., Espinosa J.-C., Groschup M. H., Nadeem M. *et al.* 2015 Effect of Q_{211} and K_{222} *PRNP* polymorphic variants in the susceptibility of goats to oral infection with Goat-BSE. *J. Infect. Dis.* **212**, 664–672.

Barillet F., Mariat D., Amigues Y., Faugeras R., Caillat H., Moazami-Goudarzi K. *et al.* 2009 Identification of seven haplotypes of the caprine PrP gene at codons 127, 142, 154, 211, 222 and 240 in French Alpine and Saanen breeds and their association with classical scrapie. *J. Gen. Virol.* **90**, 769–776.

Benestad S. L., Arsac J. N., Goldmann W. and Nöremark M. 2008 Atypical/Nor98 scrapie: properties of the agent, genetics, and epidemiology. *Vet. Res.* **39**, 19.

Billinis C., Panagiotidis C. H., Psychas V., Argyroudis S., Nicolaou A., Leontides S. *et al.* 2002 Prion protein gene polymorphisms in natural goat scrapie. *J. Gen. Virol.* **83**, 713–721.

Bouzalas I. G., Dovas C. I., Banos G., Papanastasopoulou M., Kritas S., Oevermann A. *et al.* 2010 Caprine PRNP polymorphisms at codons 171, 211, 222 and 240 in a Greek herd and their association with classical scrapie. *J. Gen. Virol.* **91**, 1629–1634.

Colussi S., Vaccari G., Rasero R., Maroni Ponti A., Ru G., Sacchi P. *et al.* 2010 Prospects for applying breeding for resistance to control scrapie in goats: the current situation in Italy. *Small Rumin. Res.* **88**, 97–101.

Corbiere F., Perrin-Chauvineau C., Lacroux C., Costes P., Thomas M., Bremaud I. *et al.* 2013 PrP-associated resistance to scrapie in five highly infected goat herds. *J. Gen. Virol.* **94**, 241–245.

Excoffier L., Laval G. and Schneider S. 2005 Arlequin ver. 3.0: an integrated software package for population genetics data analysis. *Evol. Bioinformatics* **1**, 47–50.

Goldmann W. 2008 PrP genetics in ruminant transmissible spongiform encephalopathies. *Vet. Res.* **39**, 30.

Goldmann W., Martin T., Foster J., Hughes S., Smith G., Hughes K. *et al.* 1996 Novel polymorphisms in the caprine PrP gene: a codon 142 mutation associated with scrapie incubation period. *J. Gen. Virol.* **77**, 2885–2891.

González L., Martin S., Sisó S., Konold T., Ortiz-Peláez A., Phelan L. *et al.* 2009 High prevalence of scrapie in a dairy goat herd: tissue distribution of disease-associated PrP and effect of PRNP genotype and age. *Vet. Res.* **40**, 65.

Gürsoy O. 2006 Economics and profitability of sheep and goat production in Turkey under new support regimes and market conditions. *Small Rumin. Res.* **62**, 181–191.

Hunter N. 1997 PrP genetics in sheep and the implications for scrapie and BSE. *Trends Microbiol.* **5**, 8.

Huson D. H. and Bryant D. 2006 Application of phylogenetic networks in evolutionary studies. *Mol. Biol. Evol.* **23**, 254–267.

Librado P. and Rozas J. 2009 DnaSP v5: a software for comprehensive analysis of DNA polymorphism data. *Bioinform.* **25**, 1451–1452.

Maestrale C., Cancedda M. G., Pintus D., Masia M., Nonno R., Ru G. *et al.* 2015 Genetic and pathological follow-up study of goats experimentally and naturally exposed to a sheep scrapie isolate. *J. Virol.* **89**, 10044–10052.

Meydan H., Yüceer B., Degirmenci R., Özkan M. M. and Yildiz M. A. 2012 Prion protein gene polymorphism and genetic risk evaluation for scrapie in all Turkish native sheep breeds. *Virus Genes.* **45**, 169–175.

Meydan H., Özkan M. M., Yildiz M. A. and Goldmann W. 2013a Novel polymorphism in ovine prion protein gene. *Anim. Genet.* **44**, 588–591.

Meydan H., Özkan M. M. and Yildiz M. A. 2013b Genetic risk assessment for atypical scrapie in Turkish native sheep breeds. *Small Rumin. Res.* **111**, 16–22.

Miller S. A., Dykes D. D. and Polesk H. F. 1988 A simple salting out procedure for extracting DNA from human nucleated cells. *Nucl. Acids. Res.* **16**, 1215.

OIE 2010 World Organisation for Animal Health. Terrestrial Animal Health Code, Chapter 14.9. Scrapie (http://www.oie.int).

Ortiz-Pelaez A., Georgadou S., Simmons M. M., Windl O., Dawson M., Arnold M. E. *et al.* 2014 Allelic variants at codon 146 in the PRNP gene show significant differences in the risk for natural scrapie in Cypriot goats. *Epidemiol. Infect.* **143**, 1304–1310.

Papasavva-Stylianou P., Windl O., Saunders G., Mavrikiou P., Toumazos P. and Kakoyiannis C. 2011 PrP gene polymorphisms in Cyprus goats and their association with resistance or susceptibility to natural scrapie. *Vet. J.* **187**, 245–250.

Prusiner S. B. 2004 *Prion biology and diseases*, 2nd edn. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, USA.

Vaccari G., Di Bari M. A., Morelli L., Nonno R., Chiappini B., Antonucci G. *et al.* 2006 Identification of anallelic variant of the goat PrP gene associated with resistance to scrapie. *J. Gen. Virol.* **87**, 1395–1402.

Yilmaz O., Kor A., Ertugrul M. and Wilson R. T. 2012 The domestic livestock resources of Turkey-Goat breeds and types and their conservation Resources. *Anim. Genet. Resources.* **51**, 105–116.

White S. N., Reynolds J. O., Waldron D. F., Schneider D. A. and O'Rourke K. I. 2012 Extended scrapie incubation time in goats singly heterozygous for PRNP S146 or K222. *Gene* **50**, 49–51.

Zeder M. A. 2008 Domestication and early agriculture in the Mediterranean basin, origins, diffusion and impact. *Proc. Natl. Acad. Sci. USA* **105**, 11597–11604.

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