Journal of Nepal Agricultural Research Council
Vol.11:51-57, December 2025
ISSN: 2392-4535 (Print), 2392-4543 (Online)
DOI: https://doi.org/10.3126/jnarc.v11i01.88673

Pattern and Use of Yak-cattle Hybridization in Hindu-Kush Himalayas: A Review

Neena Amatya Gorkhali[1], Saroj Sapkota[1@], Tashi Dorji[2], Bhoj Raj Pokharel[1,] Mana Raj Kolakshyapati[3] and Nirajan Bhattarai[4]

[1]National Animal Breeding and Genetics Research Centre, Nepal Agricultural Research Council, Khumaltar, Nepal: NAG: neenagorkhali@hotmail.com, https://orcid.org/0000-0003-3592-4652; @ sarose.sapkota@gmail.com, https://orcid.org/0000-0002-2930-2219

[2]Iational Centre for Integrated Mountain Development, Nepalntern

[3]Institute of Agriculture and Animal Science, Tribhuwan University, Chitwan, Nepal

[4]Agriculture and Forestry University, Chitwan, Nepal

Received: March 15, 2025, Revised: Dec.. 25, 2024, Accepted: Dec. 30, 2025
Published: December, 2025.

The authors declare that there is no conflict of interest.

ABSTRACT

Yak (*Bos grunniens*) is an iconic animal for the Hindu-Kush Himalayan (HKH) regions of Central Asia and is an important source of food security and means of livelihood for people in this region. At lower elevations, interspecies hybridization between yak and local hill cattle (*Bos indicus)* is common to combine the yak's hardiness with the productivity of cattle. In some countries, some researchers have demonstrated successful hybridization of yak with commercial dairy breeds such as Holstein-Friesian (*Bos taurus*) through artificial insemination to produce improved hybrids to increase milk production. In Bhutan, a unique triple crossing between yak, cattle, and mithun (as a terminal sire) is common for meat production. The hybrids, however, are less adapted to the harsh conditions and high altitudes typical of yak and are kept at intermediate elevations between cattle and yak habitat. So, to produce the best F1 hybrid, it needs to conserve and maintain the best gene pool of both pure Yak and hill cattle, taking care of the economic and biological limits such as reproductive rate and survival rate of Yak. There is circumstantial evidence that some inbreeding is likely to have occurred with yak as a result of traditional pure-breeding methods and, in some countries, because of insufficient interchange of breeding stock across national boundaries. From the review, it can be concluded that the pure yak population should be maintained in the mountain region under community-based selective pure breeding with a defined breeding protocol for genetic improvement. Similarly, to enhance the productivity of hybrid yak cattle, selection in the hill cattle together with pure yak is warranted to get the maternal inheritance in the yak hybrid populations. Introgressive hybridization, however, plays an important role in the improvement of yak management and breeding in an intermediate zone between cattle and yak habitats.

Keywords: high altitude, F1 hybrids, genetic pool, molecular technologies, conservation

सारांश

याक (*Bos grunniens*) हिन्दू-कुश हिमालय (HKH) क्षेत्रका बासिन्दाहरुको एक अभिन्न अङ्ग हो। नेपालको पुर्व देखि सुदुर पस्चिमका उच्च पहाडि तथा हिमाली क्षेत्रमा बसोवास गर्ने मानिसहरुको जीवन निर्वाहमा योगदान पुर्याउने एक महत्त्वपूर्ण प्रजातिको रुपमा लिईन्छ। यसले त्यहाँका बासिन्दाहरुलाई दूध, मासु, ऊन, यातायात र याकका वर्णशंकर जस्ता आवश्यक उत्पादनका स्रोतहरू उपलब्ध गराई उनिहरुको जिविकोपार्जनमा महत्वपूर्ण योगदान पुराईरहेको पाईन्छ। याकहरूबाट कम उचाइमा पाईने पहाडी गाई (*Bos indicus*) र हिमाली क्षेत्रमा पाईने लुलु वा जुर्रो नभएका

अन्य नश्लका गाईहरु (*Bos taurus*) सँग प्रजनन् गराई वर्णशंकर निकालिन्छ। यस् प्रकारको वर्णशंकर बनाउने प्रक्रियाबाट याकको सहनशीलता र गाईको उच्च उत्पादकत्वसँगको संयोजनले स्थानीय आवश्यकतालाई पुरा गर्न सहयोग गरेको छ । प्राकृतिक प्रजनन वा कृत्रिम गर्भाधान मार्फत गरिने यो प्रकृयाले सुधारिएका तथा उच्च उत्पादनशिल विशेषता भएका वर्णशंकर उत्पादन गर्छ, यद्यपि यस्ता वर्णशंकरहरुलाई उच्च व्यवस्थापनको आवश्यकता पर्दछ। तर यी वर्णशंकरहरू कठोर उच्च हिमाली वातावरणमा कम अनुकूलित हुने हुदा कम हिउ पर्ने उच्च पहाडी क्षेत्रमा मात्र पाल्न योग्य हुन्छन। पछिल्ला पुस्ताहरुमा उत्पादकत्वमा कमी हुँदै जानु र पहिलो पुस्ता (F1) भाले(झोपो)मा बाँझोपनका कारण वर्णशंकरको स्थिर संख्या (breeding population) कायम राख्ने प्रयास असफल भएको छ, यो नै याक वर्णशंकरको प्रमुख चुनौती हो । तसर्थ, शुद्ध याक र पहाडी गाई दुवैको जीन पूल (gene pool) को संरक्षण अत्यन्त आवश्यक छ। याक पालनका जैविक सीमाहरूलाई संन्तुलित गर्दै, उत्कृष्ट पहिलो पुस्ता (F1) वर्णशंकर उत्पादनका लागि शुद्ध जातहरुको संरक्षणले महत्त्वपूर्ण भूमिका खेल्दछ। हाइब्रिडले शुद्ध याकले उच्च-उचाइ अनुकुलनसंग सम्बन्धित जीनहरू स्थानीय गाईमा प्रवाह गराउन मद्दत गर्छ, जसले अनुकूलन र पालनपोषणलाई सहज बनाउँछ। यो नतिजालाई हालसम्म गरिएका अणु–स्तरीय (DNA level) अध्ययनहरूले पुष्टि गरेका छन । शारीरिक तौल, दूध, मासु, र ऊन जस्ता उत्पादनसंग संबन्धित विशेषताहरूलाई लक्षित गर्दै, समुदायमा-आधारित छनौट प्रजनन कार्यक्रमहरु सञ्चालन गर्न र गराउन सिफारिस गर्नु आजको आवश्यकता हो। यस्ले गर्दा याकको gene pool संरक्षणसँगै उत्पादन र उत्पादकत्वमा सुधार ल्याउन सहयोग पुग्दछ। यसैबीच, वर्णशंकर प्रजनन् विधिको प्रयोगबाट प्राप्त पहिलो पुस्ताको उत्पादनशीलता र व्यवस्थापनमा सुधारका लागि मध्यवर्ती क्षेत्रका कृषकहरुको भूमिका अत्यन्त महत्वपूर्ण रहन्छ। शुद्ध जातको याक संरक्षण तथा पहाडी गाईमा छनौट प्रजनन विधिको प्रयोगसंगै परिणामलाई एकीकृत रुपमा व्यवस्थापन गरेमा मात्र वर्णशंकर उत्पादनलाई दिगो रुपमा टिकाई राख्न सकिन्छ । चुनौतीपूर्ण हिमाली वातावरणमा याक वर्णशंकरको दिगो स्थायी सम्भावनाहरु सुनिश्चित गर्नुपर्ने आजको महत्वपूर्ण कार्य हो भने यसका लागि यससंग संबन्धित सबै सरोकारवालाहरु दृढ संकल्प सहित लाग्नु पर्ने देखिन्छ ।

INTRODUCTION

The Yak is an iconic symbol of the Hindu-Kush Himalayan (HKH) region and is specifically adapted to a high-altitude environment. Yak can survive in the harsh environment of high altitude, such as low temperature, low atmospheric oxygen, and high solar radiation. Yaks are multi-purpose animals that provide the herders with animal protein and fat in the form of milk and meat, as well as with draught power and manure. Furthermore, yak hide, wool, and hair are used for clothing, apparel, carpet, housing, and its dung as fuel is of paramount importance in a treeless landscape. Additionally, yak is one of the livestock species that can fully utilize the available grassland resources. Yaks are inextricably linked to local livelihoods, playing key roles in not only agri-biodiversity conservation but also cultural heritage, livelihood strategies, and all aspects of socio-economic development in high mountain areas (Weiner, Han, and Long 2003). Despite many constraints and a lack of opportunities, herders are, therefore, still keeping on rearing yak in high altitude and at lower elevations. It is common to hybridize yaks with cattle to combine the yak's hardiness with the productivity of cattle. Hybridization of yak with exotic cattle has been encouraged by the strength of the better growth rates and much higher milk production of these "improved" hybrids relative to the yak. This article is intended to provide a brief overview of the yak's distribution, breeds, and breeding management with special focus on yak-cattle hybridization in the Hindu-Kush Himalayas.

Yak breeds and distribution in HKH region

With a scientific basis using advanced molecular techniques, using evidence based on a combination of fossil evidence and mitochondrial DNA studies, domestication was suggested to be about five thousand years ago (Qi et al., 2008), which was earlier claimed to be the first domesticated in the late Stone Age around ten thousand years ago (Zeuner, 1963). The yak was classified as *Bos grunniens* by Linnaeus in 1766, but more recent evidence favors *Poephagus grunniens* due to morphological distinctions from other cattle (Corbet and Hill, 1980).

Wild yak and domestic yak represent two distinct populations. While wild yaks are close to being an endangered species, with not more than 15 thousand, and domestic yaks number around 14.2 million in the world, with most of them living in China (Wiener. Han JL, Long RJ 2003). Except for China, countries of the HKH regions, such as India, Bhutan, Nepal, Afghanistan, and Pakistan, also have a few distributions. China alone has a population of around 17 million distributed in eight provinces, and does not appear to have experienced the same marked decline in yak numbers noted in peripheral countries. China is therefore

known as "the cradle of yak". Afghanistan has 2,500 heads of yak in Wakhan, Little and Big Pamirs; Pakistan has 42,000, in eastern Hindu-Kush, Karakoram, Himalaya; India has 40,000-51,000, in the mid-Himalayan zone of five states; Nepal has 70,200 (yaks and yak hybrids), in 28 northern districts of Nepal; Bhutan has 48,400, in high-altitude areas of nine districts (Dzongkhag) (Ning, Shaoliang, Joshi, and Bisht 2016).

The HKH region has different breeds of yak. Some twelve different breeds of yak are recognized in China. India has also claimed four yak breeds. They appear to differ both in looks (colour, etc.) and in aspects of performance. However, most of these "breeds" are restricted to particular localities so that, in terms of their performance, any genetic differences are confounded with the environment in which they are kept. For instance, even though there are many types in Nepal, they are all given one name, "Nepalese Yak". Recent techniques of molecular genetics have, however, started to show some degree of genetic distance between the yak populations (Zhang G.X. *et al*. 2008). Although the yak breeding faces serious challenges, the HKH region still has a higher level of genetic diversity, and wild yaks coexist in the same environment. So, we have the opportunity to examine genetic diversity and improve the quality of the yak breed.

Crossing of domestic yak with wild yak occurred naturally over the centuries in areas where wild yak territory bounded on domestic yak herds. The cross was recognized as being more vigorous and larger than the domestic yak. In recent times, these advantages have been recreated by using semen from captured wild yak bulls on domestic yak females. Amongst others, this has led to the creation of the Datong breed, built on several generations of selection starting from the initial cross.

History of Yak-cattle hybridization

The yak lives in alpine and sub-alpine regions at altitudes ranging from 2500 to 6000 m with a cold semi-humid climate. Yak can be hybridized with cattle. Cross-breeding was commonplace in areas where the distributions of yak and local cattle adjoined or overlapped, and is reported to have occurred for the past 3,000 years. As recorded in more recent times (but probably noted even in ancient times), the hybrids appear to have many of the fitness characteristics of the yak and the better productivity of the cattle. Hybrid males are, however, sterile, and hence the F1 type cannot be fixed (hybrid females can, however, be backcrossed). The hybrids are especially favored at the lower elevations of yak distribution, where better feed is available.

Yak-cattle hybridization is one of the most important adaptation strategies for climate change patterns, which has been adopted knowingly or unknowingly from ancient times in this region. Moreover, the yak and yak hybrids follow the transhumance farming system traditionally in Bhutan and Nepal to utilize summer and winter pasture (FAO, 2003). The transhumance farming system optimizes grass availability throughout the year, ensures parasitic control, and is a strategic adaptation to changes in the weather patterns. Again, yak and yak hybrids are seasonal breeders. The breeding season reaches its peak in July and August - sometimes till October when they are still in the alpine pasture areas, and temperatures are at their highest, and grass growth is at its best. Parturition occurs from April to July in the lower elevations, closer to the home villages. In Bhutan and Nepal, yak hybrid production system, therefore, is an integral component of the ecosystem of the mountain and upper slope areas and is a major economic activity of those communities (Pradhan, Hitchcock, and Miller, 2000; Dong et al., 2009; FAO, 2003). This production system is not uncommon in countries of the HKH region and other yak-bearing countries such as Kyrgyzstan, Mongolia, and Russia. Yaks live in mountain areas (above 3000 m asl), while yak hybrids are predominantly raised in the upper slope regions (above 2000 m asl). The yaks and yak hybrids are managed by a traditional transhumance management system, i.e., the herders move with their herds as they graze.

Normally, yaks are crossed with indigenous taurine and indicine cattle. China is way developed in the case of livestock development; hybridization of yak females with exotic breeds of cattle was started around 1939, which has not yet been introduced in other countries. The breeds included the Holstein Friesian, Shorthorn, Simmental, etc. More recently, Charolais, Hereford, Limousin, and others have been added to

those available for 'crossing' with yak" (Weiner 2013). Hybridizing was tried initially by natural mating for a long period of times ~~years,~~ and during the latter period, artificial insemination (AI) with exotic bull semen became the predominant practice for hybridizing (FAO, 2003). Hybridization of yak with exotic cattle has been encouraged on the strength of the better growth rates and much higher milk production of these "exotic" hybrids relative to the yak. The extra production has, however, to be paid for by better feeding, provision of shelter, and better all-around management and health care. Moreover, detecting estrus in yak females is an arduous and challenging task. Detection of estrus is essential as a prelude to the use of AI, as skilled manpower is demanded in yak localities to have access to AI. These constraints restrict the opportunities of AI for hybridization, yet natural crossing is widespread. This genetic differentiation corresponds to different breeding practices such as crossing with wild yaks, cattle, Mithun, etc. In western Bhutan, yaks reared are pure-bred, whereas in eastern Bhutan, about 53% of the yaks are hybridized with cattle, and to some extent in central Bhutan (Dorji et al 2002). In Bhutan, a unique triple crossing between yak, cattle, and Mithun (as a terminal sire for meat production) is also common to produce more meat.

Implication of yak-cattle hybridization

Economically, the most important aspects, such as productive, reproductive, and fitness traits of the yak and yak hybrid, will be briefly summarized in this section. Yak hybrids have multiple purposes and are consequently priced higher compared to *Bos taurus* and *Bos indicus* breeds. They provide protein to the mountain communities in terms of milk, milk products, and meat. The animals are well-adapted to cold climates and are used for the draft as well as transportation. Their tail switches are of great religious significance not only for Buddhists but also for Hindus. Their body hair and hide are widely used for many household goods. In the mountain areas, especially in Nepal, that cater to tourists, the male hybrid (Jhopa) is increasingly used for transporting, carrying trekking equipment, and commercial products. These animals carry up to 60 kg loads and cover a distance of 20 km a day (Shrestha 1990). Jhopas are more versatile than yak as they can survive comfortably below 2000 m asl.

Yak-cattle hybridization produces fertile female and sterile male hybrids. Seven hybrid generations of sterile males and fertile females have been produced by backcrossing the fertile female offspring in each generation with male yak or cattle (Joshi 1982; Khan et al, 2016). The hybrid has greater milk and meat production capabilities, as well as a better ability to withstand warmer climates at lower altitudes, than the yak (Joshi 1982; Zhang 2000; Wiener *et al*. 2003). F1 hybrids have more milk yield by 25% (DLS Annual Report, Rasuwa district, 2005). F1 male hybrids produce 22% higher meat production with better draughtability. These hybrids are better adapted to the intermediate zone between cattle and yak habitats.

Characteristics of yak and yak hybrids

The purebred female yak, locally called nak in Nepal, is not a good milk producer, but they are hardy animals able to withstand extreme cold and snow blizzards. The naks normally produce approximately 220 litres of milk during an average lactation of 167 days or 1.3 litres of milk per day (Shrestha 1990) and milk production is affected by season and climate (Sapkota et al 2022). The milk is high in fat (above 6.6%), and non-fat solids are approximately 11%. These animals are also a good source of organic manure for cropping and as fuel. The hybridization practice leads to a 200% increase in milk productivity (1L/day at the lactation peak for a pure female yak to 3L/day for a hybrid) in Bhutan (Dorji et al, 2002). In the case of Nepal, the female hybrid (chauri) is raised to produce milk and milk products such as butter and cheese (ghee and chhurpi) for home consumption and increasingly for the domestic and international markets. Chauris can produce 300–540 litres of milk in 120–180 days or 2.5–3.0 litres of milk per day. Chauri milk is approximately 6.5% fat and 10.9% non-fat solids (Joshi 1982; Shrestha 1990).

The productivity reduces if the F1 hybrids are further crossed with yak, which indicates that the F1 hybrids are better in order to get better production from this system (Sanjit Maiti et al, 2014). There is an obvious benefit economically with F1 hybrids, so it's better to recommend the yak herders to maintain yak-cattle hybrid to improve production (Sanjit Maiti et al, 2014). In Nepal, traditionally only chauris and first-cross

jhopa are kept, and progeny of chauris are culled, as farmers know that they are uneconomic to rear (Pradhan, Hitchcock, and Miller, 2000).

Use of molecular techniques to identify introgression of cattle into the yak population

In yak, a mitochondrial DNA (mtDNA)-specific fragment has been described (Ward *et al.* 1999), and cattle autosomal microsatellite loci are now commonly used for the study of their genetic diversity (Ritz *et al*. 2000; Dorji *et al.* 2002; Xuebin *et al*. 2002, 2005; Qi 2004; Nguyen *et al*. 2005). The use of these genetic markers was also used to assess the occurrence, frequency, and importance of cattle introgression in individual yak or in domestic yak populations across the geographical range of the species (Xue-bin Qi *et al*. 2010). Generally, cattle bulls are commonly used to hybridize with yak cows at relatively high altitudes, while reciprocal crossing is practiced at low altitudes of their distribution range (Phillips *et al.* 1946; Cai 1980; Joshi 1982; Zhang 1989; Adachi & Kawamoto 1992; Davaa 1996; Tshering *et al.* 1996). Hybrid males are sterile, and their fertility does not resume until the fourth backcrossing generation (Deakin *et al.* 1935; Cai 1989; Tumennasan *et al.* 1997; Zhang 2000; Hisabumi *et al.* 2002), and therefore, male-mediated cattle introgression in yak is impossible (Jianlin *et al.* 2002), and thus the cattle genes are only introduced into the yak genome by hybridization of female F_1 hybrids to yak. Contrary in Nepal, yak mtDNA lineage was observed in Lulu phenotype animals in high altitude (Takeda et al., 2004), which revealed that male-mediated cattle in the yak. Cattle introgression is, however, an ongoing process and might have been relatively more important in recent times.

Using whole-genome sequencing, genes of considerable adaptive importance and domestication due to introgression among different members of the Bos genus to yak or vice versa have been identified (Wu et al, 2018). For example, genes under domestication selection in cattle (for example, MITF) were introgressed from domestic cattle to yak. Also, genes in the response-to-hypoxia pathway (for example, EGLN1, EGLN2, and HIF3a) have been introgressed from yak to Tibetan cattle, probably facilitating their adaptation to high altitude. The advancement of the scientific technique illustrates the importance of introgression as a source of adaptive variation and during domestication. The advancement in molecular techniques revealed that introgressive hybridization contributed to the improvement of yak management and breeding (Qui et al, 2012).

CONCLUSION

The yak hybrids have greater milk and meat production capabilities, as well as a better ability to withstand a warmer climate at lower altitudes than the yak. Hybridization has introgressed genes of considerable adaptive importance, which have helped facilitate adaptation in connection with both domestication and environmental changes. Introgression and admixture have previously been considered a detrimental process to avoid. Introgression and admixture have previously been considered a detrimental process to avoid. With the advancement of molecular techniques, it has been demonstrated that hybridization is an important natural process of significant importance for adaptation. Every response to climate change by the farmers is not always the best one. The cautious plan should be done for yak-cattle inter-species mating. To protect yak genetic integrity, the hybridization between yak and cattle should, therefore, be tightly controlled, and to enhance the productivity of hybrid yak cattle, selection in the hill cattle together with pure yak is warranted to get the maternal inheritance in the yak hybrid populations.

REFERENCES

Adachi A and Y Kawamoto. 1992. Hybridization of yak and cattle among the Sherpas in Solu and Khumbu, Nepal. Report of the Society for Researches on Native Livestock **14**:79–87.

Cai L. 1989. Sichuan Yak. Chengdu, P. R. China: Sichuan Ethnic Press.

Cai L.1980. The nomenclature for the hybrids of yak with cattle (in Chinese) *Journal of China Yak* **2**:20–3.

Corbet GB & JE Hill (1980). *A world list of mammalian species*. British Museum (Natural History) and Cornell University Press.

Davaa M. 1996. Conservation and Management of Domestic yak Genetic Diversity in Mongolia. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD), pp. 41–6. Proceedings of a Workshop on Conservation and Management of Yak Genetic Diversity. 29-31 October, 1996.

Deakin A, GW Muir, and AG Smith. 1935. Hybridisation of domestic cattle, bison and yak. Report of the Wainwright Experiment, Department of Agricuture, Dominion of Canada. **479**:5–29.

Dong SK, L Wen, L Zhu, JP Lassoie, ZL Yan, KK Shrestha, et al. 2009. Indigenous yak and yak-cattle crossbred management in the high altitude areas of northern Nepal: a case study from Rasuwa district. *Afr J Agric Res*. **4**:957–967.

Dorji T, M Goddard, J Perkins, N Robinson and W Roder. Genetic. 2002. Diversity in Bhutanese yak (*Bos Grunniens*) Populations Using Microsatellite Markers. Nairobi, Kenya: International Livestock Research Institute (ILRI), **pp** 197–201. Proceedings of the third International Congress on Yak. Lhasa, Tibet, P.R. China, 4-9 September, 2000.

Food and Agriculture Organization of the United Nations. (2003). *Community-Based Management of Animal Genetic Resources: Proceedings of the workshop held in Mbabane, Swaziland, 7–11 May 2001* (Animal Production and Health Paper). FAO.

Hisabumi T, K Tumennasan, H Kazuyuki, AC Chandley and H Yasuo. 2002. Fertility investigation in F_1 hybrid and backcross progeny of cattle (*Bos taurus*) and yak (*B. gruniens*) in Mongolia.: II. Little variation in gene products studied in male sterile and fertile animals. *Niigata Journal of Health and Welfare* **2**:42–52.

Jianlin H, JW Ochieng, JEO Rege and O Hanotte. 2002. Low Level of Cattle Introgression in yak Populations From Bhutan and China: Evidences From Y-Specific Microsatellites and Mitochondrial DNA Markers. Nairobi, Kenya: International Livestock Research Institute (ILRI), **pp** 190–6. Proceedings of the third International Congress on Yak. Lhasa, Tibet, P.R. China, 4-9 September, 2000.

Joshi DD. 1982. Yak and Chauri Husbandry in Nepal. Kathmandu: His Majesty's Government Press.

Khan B, S Abbas and MZ Khan. Khan G, Anjum M, Baig S and Jamal S, 2016. In: Wu N, Yi S, Joshi S and Bisht N, 2016. Yak on the move: Transboundary challenges and opportunities for yak raising in a changing Hindu Kush Himalayan region, Kathmandu ICIMOD. **pp** 167-180

Nguyen TT, S Genini, F Menetrey, M Malek, P Vogeli, MR Goe and G Stranzinger. 2005. Application of bovine microsatellite markers for genetic diversity analysis of Swiss yak (*Poephagus grunniens*) *Animal Genetics* **36**:484–9.

Ning W, Y Shaoliang, S Joshi and N Bisht. (2016). *Yak on the move: transboundary challenges and opportunities for yak raising in a changing Hindu Kush Himalayan region* (**pp**. xi+-198).

Phillips RW, IA Tolstoy and RG Johnson. 1946. Yaks and yak-cattle hybrids in Asia. *Journal of Heredity* **37**:163–70.

Pradhan SL, DK Hitchcock and D Miller. 2000. Yak hybridization in the central upper slope region of Nepal: A community resource management strategy. In: Jianlin H, Richard C, Hanotte O, McVeigh C and Rege JEO (eds): Yak production in central Asian highlands. Proceedings of the third international congress on yak held in Lhasa, PR China, 4-9 September 2000. ILRI (International Livestock Research Institute), Nairobi, Kenya. pp 146- 157

Qi XB, JL Han and R Blench. 2008. Understanding the yak pastoralism in Central Asian Highlands: genetic evidence for origin, domestication and dispersion of domestic yak, in: A. Sanchez-Mazas, R. Blench, M.D. Ross, I. Peiros & M. Lin (ed.) Past human migrations in East Asia: matching archaeology, linguistics and genetics: 427-442. London and New York: Routledge, Taylor & Francis Group.

Qi X-B. 2004. Genetic Diversity, Differentiation and Relationship of Domestic yak Populations - a Microsatellite and Mitochondrial DNA Study. Lanzhou, P.R. China: Lanzhou University.

Qi Xue-bin, H Jianlin, G Wang, JE Rege and O Hanotte. 2010. Assessment of cattle genetic introgression into domestic yak populations using mitochondrial and microsatellite DNA markers. Animal *genetics*, *41*(3), 242–252. **DOI**: https://doi.org/10.1111/j.1365-2052.2009.01989.x

Qiu Q, G Zhang and T Ma. 2012. The yak genome and adaptation to life at high altitude. *Nature Genetics* 44: 946-949. **DOI**: https://doi.org/10.1038/ng.2343CrossRefGoogle Scholar

Ritz LR, ML Glowatzki-Mullis, DE MacHugh and C Gaillard. 2000. Phylogenetic analysis of the tribe Bovini using microsatellites. *Animal Genetics* **31**:178–85.

Maiti S, SK Jha, S Garai, A Nag, R Chakravarty, KS Kadian, ... and RC Upadhayay. (2014). Adapting to climate change: Traditional coping mechanism followed by the Brokpa pastoral nomads of Arunachal Pradesh, India. *Indian Journal of Traditional Knowledge*, ***13***(4), 752-761.

Sapkota S, KP Acharya, R Laven and N Acharya. (2022). Possible consequences of climate change on survival, productivity and reproductive performance, and welfare of Himalayan Yak (Bos grunniens). *Veterinary sciences*, ***9***(8), 449.

Takeda K, M Satoh, SP Neopane, BS Kuwar, HD Joshi, NP Shrestha, ... and H Hanada (2004). Mitochondrial DNA analysis of Nepalese domestic dwarf cattle Lulu. *Animal Science Journal*, ***75***(2), 103-110.

Tshering L, P Gyamtsho and T Gyeltshen. 1996. Yaks in Bhutan. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD), pp 13–24. Proceedings of a Workshop on Conservation and Management of Yak Genetic Diversity. 29-31 October, 1996.

Tumennasan K, T Tuya, Y Hotta, H Takase, RM Speed and AC Chandley. 1997. Fertility investigations in the F_1 hybrid and backcross progeny of cattle (*Bos taurus*) and yak (*B. grunniens*) in Mongolia. *Cytogenetics and Cell Genetics* **78**:69–73.

Ward TJ, JP Bielawski, SK Davis and JW Templeton. 1999. Identification of domestic cattle hybrids in wild cattle and bison species: A general approach using mtDNA markers and the parametric bootstrap. Animal Conservation **2**:51–57.

Wiener G, JL HAN and RJ Long (Eds.). (2003). The yak. Regional Office for Asia and the Pacific, Food and Agriculture Organization of the United Nations.

Zeuner FE. A History of Domesticated Animals. Hutchinsons: London, 1963; 352–353.

Zhang GX, WS Chen, M Xue, ZG Wang, H Chang, X Han, XJ Liao and DL Wang DL 2008. Analysis of genetic diversity and population structure of Chinese yak breeds (*Bos grunniens*) using microsatellite markers. J. Genet. Genomics, **35**: 233-238

Zhang RC. 1989. China Yak. Lanzhou, P.R. China: Gansu Scientific & Technology Press.

Zhang RC. 2000. Interspecies hybridization between yak, *Bos taurus* and *Bos indicus* and reproduction of the hybrids. In: Zhao XX, Zhang RC, editors. Recent advances in yak reproduction. International Veterinary Information Service. (http://www.ivis.org) Paper No. A1304.0900.

||-------|||-------||