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Yaks and their crossbreds: effects of stocking density, pasture site and altitude on performance, behavior and metabolic adaptation in the Himalayan Mountains of Nepal

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List of Abbreviations

^{0}C	Degree Centigrade
ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
AGDP	Agricultural Gross Domestic Product
AGDP	Agriculture Gross Dometic Product
ALP	Agroscope Liebefeld- Posieux
AMS	Acute Mountain Sickness
ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
CBS	Central Bureau of Statistics
CMS	Chronic Mountain Sickness
CP	Crude Protein
D	Dimjos
DADO	District Agriculture Development Office
DLSO	District Livestock Development Office
DM	Dry Matter
ECM	Energy Corrected Milk
F1	First Filial Generation
F2	Second filial Generation
FAO	Food and Agriculture Organization
g	Gram
GDP	Gross Dometic Product
HDI	Human Development index
HH	Household
HKH	Hindu-Kush Himalaya
HR	Heart Rate
HRV	Heart Rate Variability
ICIMOD	International Centre for Integrated Mountain Development

IGF	Insulin Like Growth Factor
IPCC	Intergovernmental Panel on Climate Change
KCA	Kanchenjunga Conservation Area
kg	Kilogram
LDH	Lactate Dehydrogenase
m	Meter
m a s l	Meter above sea level
MDH	Malate Dehydrogenase
MY	Milk yield
NDF	Neutral Detergent Fiber
NS	Non-significant
P	Probability (>0.05 or <0.05)
RMSSD	Root Mean Square Of Successive Differences in Inter-Beats Intervals
RR	Respiration Rate
RT	Rectal Temperature
SD	Stocking Density
SEM	Standard Error of Mean
SNF	Solids -not-Fat
SPSS	Statistical Packages for Social Sciences
THI	Temperature Humidity index
U	Urangs
UNDP	United Nations Development Program
USD	United States Dollar
Y	Yak

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Summary

Transhumant livestock herding at high altitude in the Himalayan mountains of Nepal is characterized by the seasonal movement of animals for grazing pastures situated at different altitudes. In the Kanchenjunga Conservation Area (KCA) of Nepal, the yaks (*Bos grunniens*) and the first generation (F_1) crossbred females of yak and cattle being either (locally called) Dimjo chauries (shortly Dimjos, cattle-yak crossbreds, *B. taurus* × *B. grunniens,*) or Urang chauries (shortly Urangs, yak-cattle crossbreds, *B. grunniens* × *B. indicus*) are the major bovine genotypes kept in transhumance for milk production. In that system, they are moved towards high alpine pastures in summer and returned to low altitude mixed forest areas in winter. There are almost no scientific studies on transhumant yaks and crossbreds, and because their performance is expected to vary differently depending on seasonal herbage growth and altitude of pasture sites along the transhumance route, a project was performed where the traditional transhumant pastoral systems of the KCA of Nepal was analyzed in detail from biological and social aspects.

In a first study (2010), at first, a survey was conducted in order to characterize the bovine livestock husbandry system within the Kanchenjunga Conservation Area with a major focus on transhumant production systems with yaks and their crossbreds from KCA. Information from 240 households across different altitude i.e. high (2000-4200 m) and low (1400-2000 m) and trekking routes applied from Phungling Taplejung i.e. east (crossing KCA in direction to Mt. Kanchejunga), and the west (in direction to Olangchung Gola). Data were analyzed for 192 households for some basic of livestock systems. The household mean livestock ownership and the household income contribution from the livestock sector was higher at the high altitude areas of KCA, and high for also families who live close to high altitude areas. The household income contribution of yaks and their crossbreds was higher for large number of families at high altitudes. The majority of the respondents were not concerned about the rangeland conditions but were positive about rangeland improvement.

In a second study (2010), it was aimed to assess the effect of stocking density (SD) on general performance and activity pattern of Dimjos (without calves) across pasture sites of different altitudes along a common transhumant route. The two SD were four lactating Dimjos in high SD and two in low SD. This was replicated at each of five different pasture sites. The five selected pastures selected at the common route representing upward (pastures at 3200 m, 4000 m and 4500 m and downward movement (at 4000 m and 2600 m) are traditionally used by local herders. Groups of two yaks (with calves) were replicated at low SD at the three high altitude pasture sites (4000 m, 4500 m and 4000 m again). Pedometer devices were used for assessment of activity pattern. The

data collection period lasted for 9 days at each pasture site and for eight consecutive days for milk and behavior data collection. The daily milk yield was higher for low SD crossbreds. The milk fat content increased across the pasture sites in Dimjos, while the protein content decreased probably mostly in to response to changing feed composition. At cost of walking, lying time increased across the pasture sites. High SD forced animals for longer walking and lying time but lowered the standing time as compared to low SD. Dimjos even at low SD were not superior to yaks in performance at pastures of above 4000 m, however produced higher milk amount when maintained at low SD as compared to high SD.

In the third study (adaptation study, 2011), two crossbred genotypes, i.e. Dimjos and Urangs, and purebred yaks, with each genotypic group consisting of six multiparous lactating animals, were assessed for their ability to adapt to high altitude first at high altitude (4700 m) in August and then at medium altitude (3000 m). The experimental period was 12 days at high altitude and 14 days at medium altitude and included first 6 and 8days as adaptation and last 6 days of measurement period at each altitudinal site. Each group of genotype was observed for general performance, physiologic parameters (respiration rate, rectal temperature, heart rate and heart rate variability) and blood parameters (glucose, lactate and hemoglobin) and activity pattern at both altitudes. The Dimjos always had higher milk yield and higher milk fat content than Urangs and had a higher daily yield of important milk components than yaks and Urangs. As influenced by lactation, daily yields of milk fat and protein declined from high to medium altitude but remained highest for Dimjos. The higher milk yield of the Dimjos compared with that of the Urangs was consistent with the blood metabolic and with the physiological parameters at cost of similar activity pattern. In comparison to yaks, Dimjos were even not so well adapted than yaks at high altitude but were clearly better than Urangs as revealed from the physiologic and metabolic traits measured. Dimjos also produced highest milk yield as compared to yaks and Urangs with similar fat content as that of high altitude and maintained the body weight lost at high altitude until arrived at medium altitude.

The results of the project well illustrated the importance of yaks and their crossbreds with cattle in the livelihood of the smallholder transhumant herders of the Himalayan Mountains. As an option to achieve higher milk production, Dimjo type crossbreds are the better option for increasing milk production at low SD in the restricted areas such as in Kanchenjunga Conservation Area of Nepal, where land expansion for grazing is impossible. Furthermore, Dimjos were better than Urangs concerning high altitude tolerance which was obvious from better milk yield and milk fat content, physiologic and metabolic conditions. The activity behavior of Dimjos was similar to that of yaks and Urangs but Urangs were clearly stressed as compared to yaks at high altitude. Thus, for high altitude conditions, yaks are even a better livestock genotype as compared to any of the crossbreds. With respect to the amount of consumable milk, the Dimjo type crossbreds have another advantage to yaks due to their longer lactation period and the keeping practice without calves, while almost half of milk is consumed by calves in yaks.

Zusammenfassung

Das Hüten von transhumanten Tieren im Himalaya von Nepal ist charakterisiert durch die saisonale Beweidung in verschiedenen Höhenlagen. In der Kanchenjunga Conservation Area (KCA) von Nepal, sind die Yaks (Bos grunniens) und die erste weibliche Kreuzungsgeneration (F_1) von Yak und Rinder, lokal auch Dimjo chauries genannt (kurz Dimjos, *B. taurus* × *B. grunniens*) oder Urang chauries (kurz Urangs, *B. grunniens* × *B. indicus*) die wichtigsten Rindergenotypen, die in Transhumanz für die Milchproduktion gehalten werden. In diesem System werden sie im Sommer in Richtung Hochalpen bewegt und im Winter im zurück zu niedriger gelegenen Mischwäldern gebarcht. Es gibt fast keine wissenschaftlichen Studien über transhumant gehaltene Yaks und Kreuzungen. Da die Leistungen der transhumant gehaltenen Yaks und Kreuzungen voraussichtlich, je nach saisonalem Futterwachstum und Weidehöhe entlang der Transhumanzroute variieren, wurde ein Projekt durchgeführt, welches die traditionellen Transhumanz Weidesysteme der KCA von Nepal repräsentiert, und die biologischen und sozialen Aspekte im Detail analysiert.

In der ersten Studie (2010), wurde zunächst eine Umfrage durchgeführt, um das Rinderhaltungssystem innerhalb des KCA zu charakterisieren und mit einem Schwerpunkt auf transhumante Produktionssysteme mit Yaks und deren Kreuzungen zu analysieren. Es wurden Angaben von 240 Haushalten in unterschiedlichen Höhenlagen, z.B. niedrig (1400-2000m) und hoch (2000-4200m) gesammelt und von Trekking-Routen ab Phungling Taplejung nach Osten in Richtung Mt. Kanchenjunga und West-Route in Richtung Olangchung Gola von KCA, und die Daten wurden für 192 Haushalte für einige Grundlagen von Viehhaltunssystemen analysiert. Das mittlere Vieheigentum und der Betrag vom Haushaltseinkommen aus Viehhaltung, war höher bei Haushalten aus hochgelegenen Gebieten des KCA. Die Einkommen der Haushalte, betreffend Yaks und ihre Kreuzungen, war höher für eine große Zahl von Familien, welche in hohen Berggebieten leben und ebenso hoch für Familien, die in etwas niedrigeren Berggebieten leben. Die Mehrheit der Befragten waren nicht besorgt über die Weidelandbedingungen, waren aber positiv eingestellt gegenüber Weidelandverbesserungen.

In der zweiten Studie (2010), ging es darum, die Wirkung der Besatzdichte (SD) auf die allgemeine Leistung und Aktivitätsmuster von Dimjos (ohne Kälber) auf Weiden unterschiedlicher Höhenlage entlang einer üblichen Transhumanzroute zu beurteilen. Die beiden angewendeten Besatzdichten waren 4 stillende Dimjos in hoher SD und 2 in niedrigen SD, welche zweimal an fünf verschiedenen Standorten repliziert wurden. Bei den fünf ausgewählten Weiden handelt es sich um die, von den Hirten traditionell ausgewählten Weiden bei 3200 m, 4000 m und 4500 m bei der Aufwärtsbewegung, und um die Weiden bei 4000 m und 2600 m bei der Abwärtsbewegung Yaks (mit Kälbern) wurden zweimal bei niedriger Besatzdichte an den drei Standorten Hochalp

4000 m, 4500 m und 4000 m repliziert. Die Schrittzähler wurden für die Beurteilung der Aktivität verwendet. Die Datenerhebung dauerte 9 Tage lang pro Weide und 8 aufeinander folgenden Tagen für die Erfassung von Milch- und Verhaltensdaten. Die tägliche Milchleistung war bei den Kreuzungen höher bei niedriger SD. Der Fettgehalt der Milch war über alle Weidehöhen von den Dimjos erhöht, während sich der Proteingehalt verringerte, was vermutlich eine Reaktion auf die veränderte Futterzusammensetzung war. Auf Kosten von Gehzeiten erhöhten sich die Liegezeiten bei den Weidehöhen. Hohe SD zwang die Tiere länger zu Gehen und zu Liegen, aber senkte die Stehzeiten im Vergleich zu niedriger SD. Dimjos waren, auch bei niedriger SD, den Yaks nicht überlegen in der Leistung bei Weiden oberhalb von 4000 m. Allerdings produzierten sie höhere Milchmengen bei niedrigen SD Gehalten, im Vergleich zu hohen SD Gehalten.

In der dritten Studie (2011), wurden zwei Genotypen Kreuzungen, Dimjos und Urangs, und reinrassigen Yaks verglichen. Jede genotypische Gruppe mit 6 multiparen laktierenden Tieren wurde auf ihre Fähigkeit zur Anpassung an hohe Höhenlage analysiert. Die erste Anpassung wurde im hochalpinen Gebiet (4700 m) im August beurteilt und die zweite Anpassung bei mittlerer Höhenlage (3000 m) im Oktober. Der experimentelle Zeitraum betrug 12 Tage auf der Hochalp und 14 Tage in mittlerer Höhenlage. Darin enthalten waren die ersten 6 bis 8 Tage für die Adaptation und die folgenden 6 Tage für die Messperiode auf jeder Höhenstufe. Jede Gruppe von Genotyp wurde auf beiden Höhenlagen auf die allgemeine Leistung, physiologischen Parametern (Atemfrequenz, rektale Temperatur und Herzfrequenz), Blutwerte (Blutzucker, Laktat und Hämoglobin) und Aktivitätsmuster untersucht. Die Dimjos wiesen durchgehend höhere Milchleistung und höherer Gehalt an Milchfett auf als die Urangs und ebenso eine höhere, tägliche Ausbeute von wichtigen Milchbestandteilen im Vergleich zu den Yaks und Urangs. Da von der Laktation beeinflusst, sanken die Tageserträge von Milchfett und Eiweiß von hohem auf mittleres Volumen, blieben aber am höchsten für Dimjos. Die Milchleistung der Dimjos war im Vergleich zu den Urangs im Einklang zu den metabolischen Blutwerten und den physiologischen Parametern auf Kosten der entsprechenden Aktivitäten. Im Vergleich zu Yaks, waren Dimjos auch nicht so gut geeignet wie Yaks in großen Höhen. Sie waren aber deutlich besser als Urangs von den physiologischen und metabolischen Parametern her gesehen. Dimjos erzeugten auch die höchste Milchleistung im Vergleich zu Yaks und Urangs in mittleren Höhen mit ähnlichem Fettgehalt.

Die Ergebnisse des Projekts zeigen die Bedeutung von Yaks und Kreuzungen mit Rindern als Lebensgrundlage für transhumant-Kleinbauern des Himalaya-Gebirges. Um eine höhere Milchproduktion zu erzielen eignen sich Dimjokreuzungen am besten bei niedriger Besatzdichte in den beschränkten Flächen wie in der KCA von Nepal, wo Landexpansion für die Beweidung unmöglich ist. Darüber hinaus eigneten sich Dimjos besser als Urangs für hohe Höhenlagen, was sich in einer höheren Milchleistung wie auch Milchfettgehalt und in den physiologischen und metabolischen Parametern zeigte. Die Aktivitätsmuster von Dimjos waren ähnlich zu denen der Yaks und Urangs, aber die Urangs waren auf der Hochalp deutlich gestresster als Yaks. Demnach sind Yaks der am besten angepasste Tiergenotyp für die Hochalp im Vergleich zu allen anderen Kreuzungen. Im Hinblick auf die zu Verfügung stehende Milchmenge haben die Dimjokreuzungen einen weiteren Vorteil gegenüber den Yaks, da sie eine längere Laktationsperiode haben und die Haltungsform ohne Kälber, während bei den Yaks fast die Hälfte der Milch durch die Kälber verbraucht wird.

Chapter 1

General Introduction

Most of the global increase in ruminant meat and milk production (about 40% since the mid 1970's) has been achieved by mixed and landless production systems and much less so in pastoral systems, as the global grassland area has been increased only by 4% (Bouwman et al., 2005). Rangelands are important natural resources for livestock grazing, as livestock grazing is the most land-use system present on earth (Kauffmann and Pyke, 2001). Besides their fragile nature, the world's mountains cover about 25% of the global land area and are inhabited by 26% of the world's populations (Diaz et al., 2003), and are the reservoir of important natural resources eg. water and biodiversity (Price, 1998) required to sustain the human generations. In the Hindu Kush-Himalayan (HKH) region, almost 60% of the total land is covered by rangeland (ICIMOD, 2013). However, in Nepal, only 11% of the total land is covered by rangeland (FAOSTAT, 2011), most of which is situated in the mountainous regions which is since recently claimed as to be overgrazed (Devkota et al., 2008).

Nepal is an agrarian mountainous country where more than 66% of the population are still dependent upon the agriculture based livelihood (FAO, 2005), and one third of the agriculture gross domestic product (AGDP) is contributed by the livestock sector. The livestock component is the main source of income of the majority of households in the mountains of Nepal and will remain as such for the upcoming future (Sharma, 2008); where there is very limited scope for crop production due to poor arable lands (CBS, 2001/02),. It is almost impossible to develop the off-farm income opportunities for short term in Nepalese mountains due to the remoteness and thus improvement of existing livestock production systems is a sustainable way of livelihood. Nepal is a country rich in ecological niches and has been divided into three physiographic regions i.e. mountains, hills and the terrai covering 17%, 68% and 15% of the total land area of Nepal and these areas also host 17 different domestic livestock species (Wilson, 1997). By this way, geographical and biological diversity has also led Nepalese farmers to develop diversified farming systems, where the crop and livestock farming are integrated in general. Out of the 17 domestic livestock species, the yaks and their crossbreds are native of the Himalayan mountains and are managed under transhumant systems to sustain the livelihood of the herders (Wilson, 1997).

Transhumant pastoral system in high altitude northern Nepal is the dominant livestock production systems, in which system the livestock species are moved along high altitude pastures in summer and again returned to low land mixed forest areas in winter (Pariyar, 2008; Dong et al., 2009b).The high Himalayan Mountains of northern Nepal have been thriving this traditional grazing systems since many years, although hardly few innovative attempts have been made in the last decades in order to promote the transhumant pastoral production and, thereby, to improve the herder's livelihood. Overgrazing in Nepal is reported mainly from alpine areas of Himalayas due to very poor pasture carrying capacity (Devkota et al., 2008). In Nepal, almost 68% of the high mountain lands are covered by protected areas (Shrestha et al., 2010), and further expansion of grazing land is restricted. Rangelands are important natural resources of the mountainous regions of northern Nepal; however, a poor understanding of the social dimensions of rangeland utility has limited their proper management and sustainable development (Dong et al., 2009a). In Nepal, rangelands are treated as common property resources, and recently this caused conflicts between the stakeholders (Aryal et al., 2013). The sustainable management of rangelands could have direct implications both on biological diversity and on the livelihood of the mountain people (Bhattarai and Upadhyay, 2013).

Scope of the doctoral project

Yak-cattle crossbreeding is an indigenous practice in the Himalayan mountains of Nepal. The history of cross-breeding yaks and cattle is not exactly known in the case of Nepal, whereas this tradition is believed to exist since more than 3000 years in China (Zhang, 2000). Yaks are found in between 3000 m -5000m (Sherchand and Karki, 1996) in Nepal, and also reported as they can go upto 6000 m in summer(Wiener et al., 2003), while the crossbreds are better suitable than yaks in grazing on rangelands located at lower elevations and in mixed forest vegetation during winter (Dong et al., 2009b). The yak-cattle crossbreds which are mainly produced from Tibetan cattle bull, *B. taurus* and female yak (nak; *B. grunniens*) are called Dimjo chauries, those of yak with local hill cattle (zebu type, *B. indicus*) are called Urang chauries. The females are primarily used for milk production. The male crossbreds produced from either of the above traditional crossbreeding are infertile and used as pack animals (Joshi, 1982). A research project focusing on the mountain livestock grazing systems in the Nepalese mountains, as detailed as carried out here, has never been performed before in Nepal. Previous studies were focused mainly on anthropological perspectives other than the biological point of view of rangelands research. The earlier studies lack the application of precise methods, and outputs were limited concerning relationships of the rangeland's productivity with various factors of influence on behavioral, physiological and performance of dairy yaks and different kinds of crossbreds used to be herded across different pasture sites and altitudes. So far, documentation is limited in case of transhumant systems especially from the eastern Himalayan region of Nepal, where data on herbage availability and animal performance should be related to ensure a sustainable utilization. In the present project, socio-economic characteristics of yak and crossbred herding sites are investigated in combination with biological methods to better understand the local transhumance system. The output of the present research could be helpful for, and validated by, other yaks and crossbreds rearing based on pastoral systems in high-altitude dominated areas.

Research hypotheses

The research project was carried out on the following hypotheses:

Hypothesis 1: Livelihood of mountain yaks and yak cattle crossbred herders can be improved by improving grazing management practices

Hypothesis 2: Optimum stocking rate can be derived for sustainable milk production with yaks and yak crossbreds in the transhumance system across various pasture sites.

Hypothesis 3: Behavior of yak crossbreds differs between altitudes and types of crossbred genotypes.

Hypothesis 4: Criteria for a sustainable grazing systems can be established once when the socioeconomic characteristics of yaks and chauries herding and biological efficiency (stocking rate and altitude suitability of crossbreds) are determined.

Goal

The overall goal of the doctoral project was to gather the primary information on the transhumant yaks and their crossbreds system so as it would stimulate the strategy fordevelopment of economically and ecologically viable options for the increase of milk production by showing the best practices for grazing Himalayan mountain rangelands in terms of selection of ideal genotypes and sustainable forms of use of rangelands to be adopted by the herders.

Purpose

To provide sound information about the ideal stocking rate management and the utility of the respective best crossbred genotype in relation to yaks at different altitudes along the commonly used transhumance routes.

Specific Objectives

- To document the general performance of yaks and their crossbreds at different pasture sites along transhumant routes in the eastern Himalayan mountains of Nepal
- To characterize the biomass productivity and ecological characteristics of the experimental pastures at different altitudinal levels (sites) that are commonly used by the herding communities in the Kanchenjunga Conservation Area (KCA) of Nepal
- To record the behavioral, physiological, and metabolic efficiency of different yak-cattle crossbreds in relation to locally available purebred yaks during summer grazing at very high altitude.
- To determine the key figures for the identification of a suitable crossbred type for milk production under the condition of very high altitude summer grazing in comparison to locally available purebred yaks.
- To describe the best practice of grazing considering stocking rate, and criteria relevant for higher milk yield and the selection of high-altitude tolerant crossbred genotype.

Chapter 2

Literature Review

Evolution, origin and distribution of yaks

The domestic yak (*Bos grunniens*) is a multipurpose animal (Rhode et al., 2007) of the high altitude Asia and a member of Bovidae family. It can tolerate up to -40 ºC temperature and is inhabiting a high altitude range between 3000-6000 m a. s.l. in general(Wiener et al., 2003). The data for divergence lineages of yaks from wild yak and cattle are not consistent in the available literature. Hartl et al. (1988) already confirmed that yaks were the divergent bovines from *Bos primigenius*. Estimated divergence times by Hiendleder et al. (2008) indicated that the *B. taurus* and *B. indicus* cattle lineages separated 1.7–2.0 million years ago from *B. primigenius*, whilst the divergence time between yak and cattle (*Bos taurus*) was 0.57–1.53 miilion years ago and between yak and the American bison (*Bison bison*) was 0.39–1.04 miilion years ago (Ritz et al., 2001). However, in reports of Tu et al. (2002), the divergence times between the ancestor of *B. grunniens* and the ancestor of *B. taurus* or *B. indicus* were about 1.2–2.2 and 1.01–2.02 million years ago (MYA), respectively. For Maiwa yaks, Gu et al. (2007) found that Maiwa yak(*B. grunniens*) one of the yak breeds of China are the sister groups of cattle/zebu(*Bos taurus/ B. indicus*) and had the divergence time of 4.38-5.32 million years ago. Yaks have been first domesticated from their wild descent by the Quing peoples since more than 4000 years for domestic use in China (Wiener, 2003). Almost 95% of the world's yak population is to be found in China. Yak is distributed across central Asia (former territories close to Russia) and south Asia, Mongolia, China and Tibet, Mongolia, Russia in majority and some nontraditional environments in Europe and Americas also(Wiener et al., 2003). Nepal has only a small share of global yak and crossbreds population estimated around 95,400 yaks together with crossbreds (CBS, 2001/02), but it is still the important source of livelihood in the Nepalese Himalaya mountains.

Yak-cattle crossbreeding systems in Nepal

Yak-cattle crossbreeding is a traditional practice in the yak rearing high altitude pastoral areas of Asia (Qi et al., 2009). The yaks are used to crossbreeding with cattle in traditional yak rearing areas of the Himalayan Mountains of Nepal. Joshi (1982) compiled the plethora of local terms used in yak-cattle crossbreeding and reciprocal backcrosses especially in the Nepalese Himalaya and from other yak-cattle crossbred herding areas in Asia. In Nepal, there are mainly two types of female F1 crosses reared, and this mainly for milk production: Dimjo and Urang chauries (Joshi, 1982). The Dimjo chauries are mostly produced by crossing male Tibetan humpless cattle bulls (*Bos taurus*) and female yaks, whilst the Urang types are mostly produced by crossing male yaks and female Nepalese hill cattle, *Bos indicus* (Palmieri, 1987; Joshi, 1982; Joshi et al., 1994; Dong et al., 2009b). The Tibetan humpless cattle bulls (Dong et al. 2009b) are sometimes called *Zo-lang*

(Joshi et al. 1994), *Joolang* in the eastern mountains of Nepal (Joshi, 1982), and or *Lang* by Tibetans and *Langdzolang* by Nepalese herders in Everest region (Palmieri, 1987).

The primary purpose of producting females by crossbreeding (the so called chauries) is for milk production (Dong et al., 2009b; Narang and Raman, 1994). The respective males are called either Dimzo or Urang Zhopkyos in Nepal (Joshi, 1982) and are infertile (Zawadowsky, 1931; Phillips et al., 1946; Joshi, 1982; Xiaolin et al., 2004; Qi et al., 2009; Palmieri, 1987; Dong et al., 2009b). The gene introgression from male crossbreds is thus impossible and used for pack purposes (Joshi, 1982). According to Wiener et al. (2003), yak-cattle crossbreeding is a long tradition in China (more than 3000 years) mainly with *Bos taurus* and some crossbreeding is also popular in northern India, Nepal and Bhutan, hybridizing yaks with *Bos indicus* cattle (Wiener et al., 2003).

Joshi et al. (1994) reported the annual calving of crossbreds as a benefit over the biennial calving of female yaks (naks). Especially the gestation period is comparatively shorter in naks (258 days) as compared to the F1 crossbreds (Joshi et al., 1994; Joshi, 1982). However, naks could also calf each year under better pasture conditions. As compared to yaks, yak-cattle crosses utilize much wider elevational ranges than yaks and are becoming increasingly important for milk production (Joshi et al., 1994; Dong et al., 2009b).

Importance of yaks and their crossbreds in Nepal

Yak and chauri milk is traditionally processed to valuable products (Thapa, 1997) in Nepal, among which butter fat and Churpi cheese (a type of very hard cheese made from whey proteins) are the main products of the Himalayan herders. Nepal was one of the first countries in Asia to establish a cheese industry and the first country in the world to produce yak cheese before the 1980's (Thapa, 1997). However, in earlier reports of Joshi et al. (1994), there were only nine yak cheese factories in Nepal with an average annual production of 990 metric tons of cheese and 30 metric tons of butter per year. Thapa (1997) reported that in the late 1990's this was increased to 20 yak cheese factories across the five yaks and their crossbreds rearing districts of Nepal.

Yaks and their crossbred's population and trends in Nepal

The population dynamics of yaks and their crossbreds in Nepal is difficult to assess due to difficulties in population nomenclature, and additionally because of the mixing of yaks with their crosbreds and mixing of both yaks and their crossbreds with cattle population. Joshi (1982) reported that there were more than 26'000 yaks and their crossbreds within 21 districts of Nepal, among which 2/3 of the population were crossbreds. The available information indicated that there was a quick rise of this population after 1991/1992, going from 58'600 to 95'400(CBS, 2001/02), i.e., an increase of 62.9%, whilst the corresponding households having this kind of livestock was increased by 57.8% from 9’000 to 14’200 households CBS (2001/2002). The yaks and their crossbreds population in Nepal have been considered by as to be in declining trend due to restriction of pastures in the nature protection areas at high altitude Joshi (2001), and the shift from herders to tourism and other ways of living (Joshi, 2003).

Possible benefits of yak cattle crossbreeding: Feed efficiency in harsh environments

The rumen of the yak has a special rumen micro-flora that might produce less methane as compared to cattle (Huang et al., 2012). Accordingly, yaks have been shown to emit comparably low amounts of methane to the environment; however, this is rather a result of their small body size and not so much of a specific type of digestion facilitating low methane emission per unit of feed (Ding et al., 2010). Likewise, the flux of major greenhouse gases from yak dung is below the environmental threshold level indicated by IPCC (Lin et al., 2009).

Yaks express particularly high N use efficiency (Long et al., 2009). This could also be the reason why yaks can utilize low quality forages at harsh and high altitude conditions. Yaks have low maintenance protein requirements as well (Xue et al., 1994). Xue et al. (1994) and Guo et al. (2012a) also reported that there were no significant effect of dietary protein on urinary excretion of N in yaks and proportionately the N retention in yaks increases with the increase in the dietary N level and the urinary excretion as well, however, Guo et al. (2012a) did not find an increase of fecal N with an increase in dietary N level. Zhang et al. (2012) reported that the N retention linearly increased with the increase in N content of the diet when yaks were offered poor quality forages. In another experiment, Wang et al. (2011) found that yaks have higher proportionate nitrogen retention in their body as compared to cattle (*Bos taurus*). The yaks have low purine derivative excretion as compared to cattle and their cattle- yak crossbreds, the cattle yak crossbreds had lower purine derivative excretion as compared to cattle (Long et al., 2009). Long et al. (2004) found that the purine derivative excretion, an indicator of rumen microbial protein synthesis, was significantly elevated with the increase of dietary N level in yaks.

Yak milk has higher protein content than cattle (Joshi et al., 1982). He et al. (2011) reported similar milk casein content in yak and cattle milk. Yak milk casein has the property of free radical scavenging and anti-inflammatory activity (Mao et al., 2011).

Likewise yaks can best digest and utilize the low quality roughages which is possible due to special enzymes produced in the rumen, even those needed to digest the very poor quality amorphous and crystalline cellulose types (Bao et al., 2011). Yaks have relatively smaller stomach, larger chest with larger lungs and heart (Wiener et al., 2003). The vascular wall of the *rete mirabile* of yak brain is thin and large in diameter, which might help yaks to bear hypoxia by cooling its brain to slow the metabolism of the brain (Ding et al., 2007). Still, yaks have more or less similar anatomical features of eyes to that of other bovines (Shao et al., 2008). The yaks have developed a special morphology and thus efficiency of the tongue compared to that of cattle which allows them to graze the short vegetation (Shao et al., 2010).

High altitude adaptation: Scientific implications

The high altitude hypoxic adaptation is a synergistic mechanism of several biological processes in living organisms. For high altitude induced changes in living beings, Richalet (2007) proposed three steps of adaptation processes, i.e. cultural (changes in behavior), physiological (changes in body vital processes) and genetic (inherent character) processes. As examples, the high altitude adaptation (Fig. 2.1) and its physiological mechanisms in man have been shown in Fig. (2.2) and consequences associated to hypoxic conditions at high altitude have been shown in Fig. (2.3).

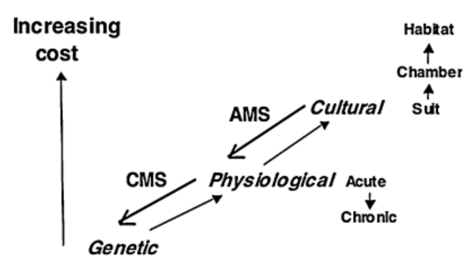


Fig. 2.1. The cost of high altitude adaptation in human, CMS (chronic mountain sickness) and AMS (acute mountain sickness) adapted from Richalet (2007)

Genetic factors have been discussed as a permanently developed high altitude adaptation mechanism (Richalet, 2007). Genetic merits have obviously been achieved in high altitude grazing animals like yaks, llamas, pikas (Richalet, 2007). There is an evolutionary development of hypoxia inducible factors in yaks (Wang et al., 2006), which might involve the transcription of genes involved in regulation of oxygen homeostasis even at hypoxic conditions (Dolt et al., 2007). The positively selected and rapidly evolving genes in the yak lineage are also found to be significantly enriched in functional categories and pathways related to hypoxia and nutrition metabolism (Qiu et al., 2012).

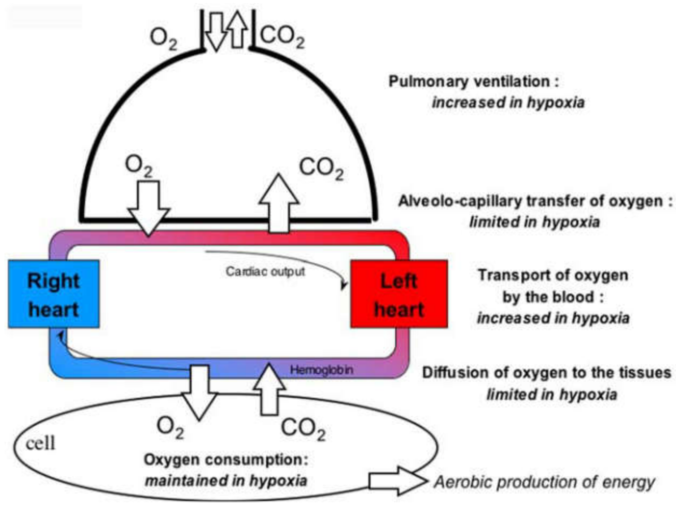


Fig. 2.2. Hypothetical physiological mechanisms in man during high altitude hypoxia (adapted from Richalet, 2007)

Kuang et al. (2010) reported that yaks muscles contain three variants of lactate dehahydrogenase-1(LDH-1) enzymes, with the highest LDH activity and the lowest malate dehydrogenase (MDH) activity, which might help yaks to regulate the metabolic processes at high altitude. Zheng et al. (2008) found that yak skeletal muscle has a higher kinetic of LDH-4 for pyruvate release than that of cattle, and considered this as a basis of molecular adaptation of yaks to high altitude hypoxic conditions. Reynafarje et al. (1975) found that high altitude (4200 m) adapted llamas and alpacas can have six times more LDH and two times more glucose-6-phosphate dehydrogenase as compared to man. In high altitude grazing sheep in the Swiss Alps, plasma vitamin-D concentration, bone mineral content, and specific alkaline phosphatase enzymes were found to be elevated recently (Liesegang et al., 2013). Hochachka et al. (1982) summarized that there is increased tendency of oxidative enzymes in some high altitude camelids. Study carried out by Parraguez et al. (2013) showed that there is a suppression of Insulin like growth factor-I (IGF-I) and IGF-II expression and an increased hypoxia inducible factor (HIF-1α) and expression of the vascular endothelial growth factor (VEGF) in sheep at high altitude mediated by hypoxia.

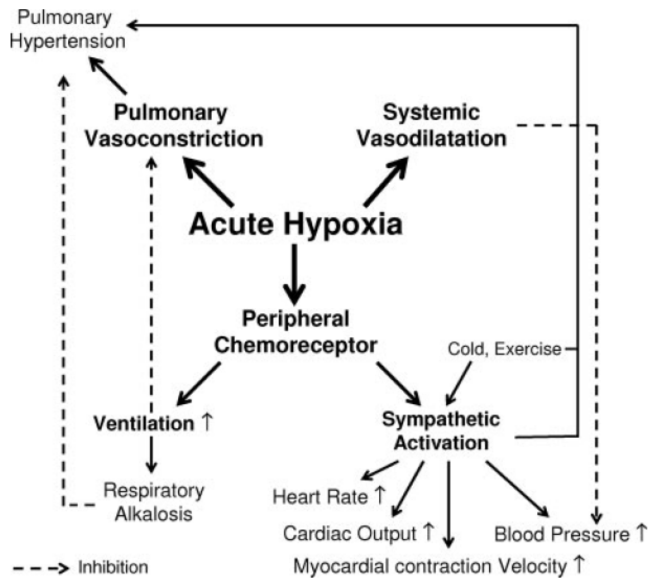


Fig. 2.3. Physiological effects of high altitude hypoxia on systemic and pulmonary circulation (adapted from Bärtsch et al., 2007)

Review of implications from high altitude grazing experiments

Physico-chemical adaptation

The increase of hemoglobin concentration in blood at high altitude has been repeatedly reported in many vertebrates (Zemp et al., 1989a; Pourouchottamane et al., 2004; wang et al., 2013). In vertebrates with high-altitude habitat, adaptive changes in blood-O_2 affinity may be mediated by modifications of hemoglobin structure (Storz et al., 2010). Multiple forms of hemoglobin appear in blood of cattle (Grimes et al., 1957) and especially in yaks. There are two forms of fetal hemoglobin (F1 and F2) and two to four other major types of adult hemoglobin (Weber et al., 1988). At given oxygen tension, fetal hemoglobin takes up and releases more oxygen than other forms of hemoglobin, as its oxygen dissociation curve is steeper (Metcalfe et al., 1967). In yaks, the fetal hemoglobin persists throughout life (Sarkar et al., 1999b). At birth, the fetal hemoglobin in newly born female yak calves could represent up to 61% and it declines with age to 42% at 10 to 11 years of age (Sarkar et al., 1999a). In Holstein and Guernsey cattle, the fetal hemoglobin could vary from 40-100% at birth and is later completely replaced by adult hemoglobin (Grimes et al., 1958), when age is progressing. Sarkar et al. (1999a) described that fetal hemoglobin makes up only up to 7.5% of total hemoglobin in the hill cattle of India. Fetal hemoglobin increases around the date of parturition in yaks and slowly declines one week after parturition (Sarkar et al., 1999b) and stays on a general level of 40-45% of the total hemoglobin for a yak kept at 3000 m a.s.l. This might be the reason why even the young calves could have more hemoglobin after birth. Reynafarje et al. (1975) observed a proportion of 55% of fetal hemoglobin in alpacas when measured at 4200 m. The short-term altitudinal adaptation predominantly involves adjustments of hemoglobin in allosteric interactions with the cellular effectors i.e. organic phosphates, protein and chloride (Weber, 2007); while long-term adaptation typically involves changes in the structure of the hemoglobin molecules inherited (Weber et al., 1988). In yaks, the higher affinity of hemoglobin to oxygen is caused by the substitution of some amino acids i.e. alanine at the 135 position of the β^{11}-chain mostly (Lalthantluanga et al., 1985).

Sakai et al. (2003) found a low hematocrit and a significant attenuation of pulmonary vasoconstriction in blue sheep (*Pseudois nayaur*) at high altitude. The blood amino acids might play a vital role in coping with the hypoxic environment. Among them L-arginine could mediate nitrous oxide through the enzymatic procedure of nitrous oxide synsthase isoenzymes (Moncada et al.,1991).The positive effect of augmenting nitrous oxide as a potent vasodilator in pulmonary circulation at normal and hypoxic conditions has been reported in sheep (Fineman et al., 1991; Koizumi et al., 2004) and yaks (Ishizaki et al., 2005) respectively. The pulmonary resistance increases with age at altitude in calves (Will et al., 1975). Ruan et al. (2004) indicated that the endogenous production of nitrous oxide mediates the role to cope the hypoxic environment in sheep.

Basic physiological changes

The basic physiological indicators such as heart rate, respiration rate and body temperature are a sign of stress and comfort in cattle, and could equally be applied to study the altitude effects in other bovines. At simulated high altitude conditions, these basic vitals have been reported to be increased in the European dairy cattle (Hays et al., 1978; Hays and Bianca, 1976; Hays and Bianca, 1975; Hays, 1976), while the heart rate also decreased after adaptation in cattle (Hays et al., 1978a, 1978b). Younger animals are relatively more stressed at high altitude than the mature ones (Bianca and Hays, 1975). At high altitude exposure up to 4000 m, the rectal temperature decreased in goats, but respiration rate and heart rate were increased (Bianca and Kunz, 1978). Krishnan et al. (2009b) reported that Indian yaks had higher rectal temperature, respiration rate and heart rate in summer than in winter when measured at 2750 m. The yak heart has special patterns of microvasculature that could be promising to adapt better to their environment especially with increasing of age (He et al., 2010).

Changes in physiological state of animals at high altitude

High altitude exposure alters vital body processes in response to hypoxia. Ge et al. (2012) reported for the Tibetan highlanders living at 4500 a.s.l. that there is tendency of increased anaerobic glucose metabolism over the fatty acid oxidation, especially controlled by the genetic factors. In athletes exposed to high altitude, increased blood level of hemoglobin was also reported (Saunders et al., 2009). Woorons et al. (2010) found that men with exercise under hypoxic condition had elevated blood lactate.

High altitude sojourn increased the blood hemoglobin (Zemp et al., 1989b, Hays et al., 1978a; Hays and Bianca, 1976), hematocrit (Bianca and Hays, 1975; Hays and Bianca, 1976), and decreased blood levels of insulin (Zemp et al., 1989b). The decreased in blood glucose may be mediated by the decline of blood insulin level at high altitude (Zemp et al., 1989b).There is a tendency of increased blood erythrocyte number and blood specific gravity (Hays et al., 1978a), viscosity (Bianca and Hays, 1975), blood pH (Hays and Bianca, 1976), leucocyte number, blood clotting time and prothrombin number (Hays and Bianca, 1976) at high altitude exposure of cattle, but this is associated with a decreased thrombocyte number (Hays and Bianca, 1976). Zemp et al. (1989a) reported a decline of ketone bodies (here: β-hydroxybutyrate) in the blood of dairy cattle at high altitude; however, at a similar altitude, increased blood level of β-hydroxybutyrate, lower blood glucose (Leiber et al., 2004), and increased blood cortisol during transportation to high altitude (Hays et al., 1975; Kreuzer et al., 1998).

Effects of high altitude on performance

The potential effects of high altitude exposure of European cattle on production and performance and product quality have been reported from many studies. During high altitude sojourn, the dry matter intake of dairy cattle have been reported to increase by Christen et al., (1996); however, in reports by Berry et al. (2001), Leiber et al. (2004, 2006) and Bianca and Hays (1975), the daily intake has been found to be decreased during the high altitude grazing. This, and the increased net energy requirements (Leiber et al., 2006; Christen et al., 1996) explain the following changes found in dairy cattle: High altitude grazing decreases body weight (Bianca and Hays, 1975; Christen et al., 1996; Kreuzer et al., 1998), milk yield (Zemp et al., 1989a; Christen et al, 1996, Kreuzer et al., 1998; Berry et al., 2001; Leiber et al., 2006), milk protein content (Berry et al., 2001; Leiber et al., 2004, 2005, 2006) and milk lactose content (Zemp et al., 1989a). However, the altitude exposure increases the milk fat percentage (Zemp et al., 1989a; Leiber et al., 2006). In some experiments with dairy cattle, the long term exposure to high altitude might have resulted in an increased tolerance in terms of milk traits in dairy cattle (Bartl et al., 2009; Qiao et al., 2012).

Morphological and anatomical features of high altitude adaptation

In general, the pulmonary hypertension at chronic hypoxia varies according to the animal species (Ge et al., 1998; Sakai et al., 2003), age and gender (Rhodes, 2005). In cattle, the exposure to high altitude induces the pulmonary hypertension (Will et al., 1962). Anand et al. (1986) reported that the pulmonary arterial resistance in Himalayan cattle was significantly lower than that of yaks, and yak-cattle crossbreds were similar to the yaks in this respect. The pulmonary arteries of yaks are thin walled and can bear the high pulmonary arterial pressure (Durmowicz et al., 1993), but the arterial perssure also increased at high altitude (Anand et al, 1986). Harris et al. (1982) found that a significantly higher pulmonary arterial pressure of llama, alpaca and guanacos inhabiting high altitude areas compared to those born at low altitudes.

Basic quantitative genetic approaches: Perspective for genotype performance

Maternal lineages

A maternal effect is any influence, other than the contribution resulting from nuclear genes, that the dam has on the phenotype of her progeny (Huizinga et al.,1986), or, the causal in uence of the maternal genotype or phenotype on the offspring phenotype (Wolf and Wade, 2009). As described above, there are yak-cattle crossbred which have cattle or yak dams and the cattle from different origins. Therefore, maternal effects may play an important role for several traits. Growth rate in animals is controlled by quantitative polygenetic traits which are moderately heritable and controlled by prenatal and postnatal maternal lineages (Sellier, 2000). Increasing the average coef cient of inbreeding in a population is also known to result in lower growth rate (Sellier, 2000). Boettcher et al. (1996) reported that the maternal lineages are associated to significant differences in fat content and milk energy concentration of cattle. In Holstein Friesian cattle, the maternal lineage accounted for 5.2, 4.1, and 10.5% of phenotypic variation of pre-adjusted records of milk yield, fat yield, and fat percentage, respectively; however, the effect was non-significant for milk yield but significant for fat percentage (Schutz et al., 1992). Huizinga et al. (1986) showed that the cytoplasmic origin (maternal linage) accounted for maximal 10% and 13%, respectively, of the phenotypic variation milk production and reproduction of cattle. The cytoplasmic effects are mainly mediated in milk production other than in body weight (Tess et al., 1987).

Boettcher et al. (1996) also reported, based on cattle records from Iowa and North Carolina, USA, that maternal lineage accounted for 2.7% of the variance in fat percentage but for overall milk traits it was <1.2% of the variation. Gibson et al. (1997) found that the cytoplasmic genetic variation in cattle performance is within the range of 0-5%.

Genetic divergence

The known significant genetic divergence between the taurine and zebu cattle might be attributed to geographical segregation, and variation in temperature and weather conditions (Cai et al., 2010). This might play a significant role in variation of performance traits in different kinds of yak cattle crossbreds, too.

Heterosis effects

Dairy cattle crossbreeding practices are an old tradition (Sørensen et al., 2008). Crossbreeding has the advantage of heterosis (Freyer et al., 2008), resulting from the specific combining abilities (reviewed by Sørensen et al., 2008). In general, heterosis has a favorable significant effect on milk, fat and protein corrected milk yield, and calving interval, but may also have unfavorable effects, i.e., a high somatic cell count (Haas et al., 2013). The heterosis effect can be especially used to upgrade the milk production efficiency of low milk producing cattle (Penasa et al, 2010). Samdup et al. (2010) reported that local cattle crossbreds with high yielding dairy cows have potential to produce 2.4-4.6 times higher milk yield than the original local cows in Bhutan.

Yak and yellow cattle (*Bos taurus*) crossbreeding has the potential for heterosis in milk production of up to 52.9% and 5.6% for butter fat production (Wang et al, 1994a). However, in case of body weight, Wang et al. (1994b) found that the birth weight and daily gain is parent (breed) specific in crossing with yak when crossed with European breeds of taurine origin. According to Zhang (2000), crossbreds of *B. grunniens* and *B. taurus* (Chinese yellow cattle) might attain about 50% more body weight than pure yaks at 17 months of age. It has to be kept in mind that the profit by heterosis is mainly be found in the F1 generation, but as the males from yak-cattle crossbreeding are infertile, this breeding practice builds exclusively on F1 anyway.

Nutritional benefits of milk and milk products originating from high altitude

Increased proportions of n-3 polyunsaturated fatty acids have been found in the milk fat of dairy cattle breeds of the European origin during alpine sojourn (Leiber et al., 2005). Yaks have similar milk casein content (at about 60%) to that of cattle (Sheng et al., 2008). Yak milk products seem to be particularly rich in functional and bioactive components mainly amino acids, fatty acids, antioxidant vitamins and specific enzymes (Guo et al., 2012b). In Nepalese yak, the content of conjugated linoleic acids was reported to be 2.5% of the total fatty acid (Neupaney et al., 2003) in milk, thus being higher by 2.3% compared to fatty acids in Cheddar cheese; at the same time, the proportion of saturated fatty acids is lower (Or-Rashid et al.,2008) . In the study by He et al. (2013), the conjugated linoleic acid content of Maiwa yak milk was higher during the warm season and for the multiparous yaks as compared to primiparous yaks. The elevated conjugated linoleic acid content in milk and milk products has been reported beneficial for the prevention of diabetes, cancer and other cardiovascular diseases (Shingfield et al., 2012).

Chapter 3

Livestock production systems in Himalayan Mountains: the case of the Kanchenjunga Conservation Area in Nepal[1]

[1]Based on: S.R. Barsila, N.R. Devkota and S.Marquardt, manuscript on preparation for Agricultural Systems.

Abstract

Livestock husbandry is one of the main sources of livelihood of the people in the Himalayan Mountains of Nepal. Of special importance are yaks (*Bos grunniens*) that are kept in high altitude regions of >3000 m a.s.l., as well as crossbreds of yaks with cattle (locally called chauries) are kept at lower altitudinal ranges at. In order to get information on the importance of bovine livestock production systems in the remote region of the Kanchenjunga Conservation Area (KCA) of Nepal, a household survey was conducted in February and March 2010. The households (HHs) were grouped in 4 study sites according to their altitude (i.e., high: 2400-4200 m) and low: (1400-2000m) and along either the eastern or western main trekking route) crossing–KCA. Semi-structured questionnaires were elaborated and 192 HHs keeping bovine livestock were included for data analysis. Overall, farming had a contribution of 19.8% and was contributing to household income in 80-98% of the HHs, with the exception of the study site situated at the western higher altitude, where no farming activities were reported. At western high altitude, the highest share of livestock husbandry to total income was reported (55%). Yaks and their crossbreds-were prevalent mostly at high altitude sites, and were most important with regard to HH income. Different from the western sites, 76 and 81% of the HHs situated in the eastern part mentioned tourism as a source of income at high and lower altitude, respectively. The average households landholding was 5.5 ropanis (0.3 ha), whilst the average arable land ownership was only 3.5 ropani (0. 2 ha) across the survey sites. Total bovine population per household was higher in the high altitude (P<0.001) and in the western route (P=0.007). 32-38% of the HHs kept cattle except at the western high altitude (no cattle at all), while yaks are mostly kept at high altitude (100% and 70% of households having yak in western and eastern part, respectively). Yak-cattle crossbreds were kept by >75% of the HHs, with the exception of only 5% HHs keeping crossbreds in the lower western study site. Almost 66% of all respondents stated that they did not notice changes in overall pasture conditions, and 64% of them reported the depredation of livestock by wildlife as biggest concern. The positive attitude of the respondents with regard to their willingness to rangeland improvement would be an asset for future development.

Introduction

Livestock is an integral part of the mixed crop-livestock farming systems in of Nepal (FAO, 2005, 2011). The contribution of livestock to the subsistent livelihood is even higher in the mountainous areas of in Nepal (Tulachan and Neupane, 1999) due to limited arable land available for farming. In the high altitude mountain areas, transhumant pastoralism is a common mode of livestock keeping (Dong et al., 2009b) and is dependent upon the utilization of the rangeland ecosystem along an altitudinal gradient (Dong et al., 2009b). In the Kanchenjunga Conservation Area (KCA) of Nepal, being diverse itself in altitude (1200-8596 m) and the agro-ecology, livestock keeping systems (bovines) with different domestic animals are common. At lower mountains, farmers are mainly permanent settlers and practice the stall feeding or sedentary system and the livelihood is dominated by mixed-crop livestock farming, while yaks and different yak-cattle crossbreds, mostly kept in transhumance, at altitudes above 3000 and 2000 m a.s.l., respectively. Although of high importance for the rural livelihood, the characteristics of the bovine production systems at different agro-ecological zones of KCA are poorly documented. However, the KCA has also potential for mountain tourism. Tourism is mainly dominated in the eastern region of KCA, where the world's third tallest peak, the Mt. Kanchenjunga is situated. The western route is mainly used for traditional transport and trading to and from Tibet, while the eastern route is popular for mountain trekking and expeditions. Increasing tourism and the possibility of labor within the touristic sector might have changed the socio-economic structures in the more touristic regions (i.e. eastern part).The KCA is among the first conservation area in the world managed by council of local people in a vision to decentralize the system of nature conservation and development with greater equity among the local residents (Parker and Thapa, 2012). After the declaration of conservation area in 1997, conflicts have been arising due to livestock depredation by wildlife (Ikeda, 2004) and the public expectation expectation with regard to receiving support from KCA also increased (Mueller-Boeker and Kollmair, 2000). Bovine livestock farming, and especially yak and their crossbreds herding are means of livelihood of most of the people in KCA (Kharel, 1999) for which the natural resources dependency is reported to be very high for sustaining livelihood (Parker and Thapa, 2012). The aim of the survey was to document the current status of the bovine livestock production systems in different parts and altitudes of KCA and the attitude of respondents on the rangeland situations and its improvement in the KCA The present study was carried out in order to answer the following hypotheses:

1. Livestock (bovine) husbandry has a major contribution to the livelihood of the people living within KCA in both, western and eastern part, and probably a higher importance at higher altitudes with limited options for farming due to climatic constraints.

2. The household subsistence based on tourism and labors differ according to the distribution of livestock (bovine) species across the altitude and closeness to touristic attractive sites.
3. Livestock (bovine) keepers are aware about the importance of rangeland and pasture conditions and changes in natural resources across KCA.

Methodology

Study site selection

Selection of Kanchenjunga Conservation Area (KCA)

The Kanchenjunga Conservation Area (KCA) is located in north-eastern Nepal with a total size of 2035 square kilometers and covers 60% land area of the Taplejung district (Fig. 3.1). It borders India in the east and China in the north (Kharel, 1999) and covers low (1200 m) to high mountainous areas, with the highest peak being the Mt. Kanchenjunga, of 8586 m a.s.l. (Parker and Thapa, 2011). The KCA was established in 1992 as protection area in order to conserve especially the mountain biodiversity. The KCA not only contains important wildlife speies to be protected but also human settlements existing since past. Four village development committees (VDCs), out of 50 VDCs of Taplejung district of Nepal (District Profile, 2008), namely Tapethok, Yamphudin, Lelep and Olangchung Gola (Parker and Thapa, 2011), with a total of 975 households are situated inside its borders (Lelep VDC: 457; Olangchung Gola VDC: 66; Yamphudin VDC: 147 and Tapethok VDC: 305 households (District profile, 2008). Olangchung Gola and Lelep are dominated by the Sherpa ethnic groups with their own native language (Sherpa), whilst Tapethok is dominated by theLimbu ethnic group speaking the Limbu language. Yamphudin is a mixed village of Sherpas (at high altitudes), Rai, Limbu and other communities speaking their native languages and the majority speaks also Nepali (see Table 3.1). The information was taken with the help of a field guide speaking all of the local langudges.

Selection of study sites within KCA

At first, a short consultative discussion meeting was organized at the district headquarter (Phungling, Taplejung) together with local authorities, i.e. District Agriculture Office (DAO), District Livestock Office (DLSO) and authorities from KCA, at 26th of January, 2010. The meeting was organized in support of the KCA management council at the KCA contact office, Phungling Taplejung. The primary objective of the meeting was to gather information on the livestock production systems within KCA, to identify areas of yak and crossbred keeping and to get information on the research and development activities of the local authorities inside KCA.

Information on locations of settlements at different altitude along the two main trekking routes (i.e., east and west) of KCA was obtained in consultation of the local authorities, and the altitude of various settlements within different village development committees were listed in a map. The western route goes from Taplejung in direction to Olangchung Gola and Yangma crossing Lelep in its half. The eastern route leads from Taplejung by crossing Yamphudin and then Ghunsa towards Mt. Kanchenjunga. The eastern route is mostly used by foreign tourists for trekking and mountaineering; while the western route links Tibet and Phungling of Taplejung and is use for trade and business rather than for touristic purpose. The western route has a length of around 90 km (from Phungling, Taplejung to Olangchung Gola). The eastern route has a length of approx. 200 km. Four clusters of settlements were defined as the 4 study sites covering the main part of KCA, distributed in higher and lower mountain areas (further on called 'high' and 'low') and along either the eastern or western route (further on called 'east' and 'west', see Table 3.1). Additionally, information on the total number of households in the different settlements of KCA was obtained from local statistical data (District Profile, 2008). The current number of households of the respective settlements were further additionally asked from the local people met at the village centers upon arrival to the respective settlement, one day before the surveys started (Table 3.1). The information was taken with the help of a field guide speaking most of local languages.

Table 3.1. Overview about the households (n=192) selected for the survey in different settlements of KCA, separated by altitude (high and low) and direction (east and west)

Site	Settlement	Altitude (m)	Local language	Household numbers		Main livelihood	
				Total[2]	[3]Analyzed	Bovines	Mixed
High altitude (2000-4200 m)							
West(Olangchung Gola VDC)							
	Olangchung Gola	3200	Sherpa	54	19	18	1

Yangma	4200	Sherpa	9	6	6	
Subtotal				25		
East (Lelep VDC)						
Ghunsa	3300	Sherpa	42	24		24
Gyabla	2800	Sherpa	15	11		11
Phale	2900-3000	Sherpa	25	17	1	16
Bhote-gaon[1]	2400-2800	Sherpa, others	50	30		30
Subtotal				82		
Lower altitude (<2000 m)						
West (Tapethok VDC)						
Dada-gaon	1500-1800	Limbu	25	8		8
Hellok	1500-1600	Limbu	45	9		9
Tapethok	1500	Limbu	40	31		31
Illadanda	2000	Sherpa, Rai	11	2		2
Kabran-thok	1500	Limbu	25	1		1
Lapsetar	1400-1600	Limbu	10	3		3
Margem	1500	Limbu	25	7		7
Lelep	1600	Sherpa	40	2		2
Gahiri-gaon	1500	Limbu	15	1		1
Subtotal				64		
East (Yamphudin VDC)						
Sawa	1700	Mixed[4]	25	2		2
Sammethum	1400-1600	Mixed[4]	10	6		6
Neppu	1600	Mixed[4]	21	10		10
Nakluwa	1500-1600	Mixed[4]	12	3		3
Subtotal				21		

[1] This settlement belongs administratively to Yamphudin VDC, but was included here due to its location of >2000 m a.s.l along the eastern route.
[2]Information from local respondents, data collected informally one day before conducting the survey at the respective settlement.
[3]Subtotal of households used for data analysis
[4]Mixed: Nepali, Sherpa, Rai, Limbu, and others.

Household survey

Preparation of questionnaires

The questionnaires were developed in English in January 2010 and later on translated into Nepali. The questionnaire covered questions on household characteristics, land-use and bovine livestock production system, income resources, milk products, household, herd composition and characteristics of transhumant bovine livestock production system and some qualitative questions regarding the attitudes of respondents on usages of the pastures included in transhumant routes used by the herders across high altitude KCA (Table 3.2). The questionnaires were first subjected to pretesting with involving four former transhumant livestock herders from the KCA region also present at the consultative discussion meeting in Taplejung and modified according to the feedback received.

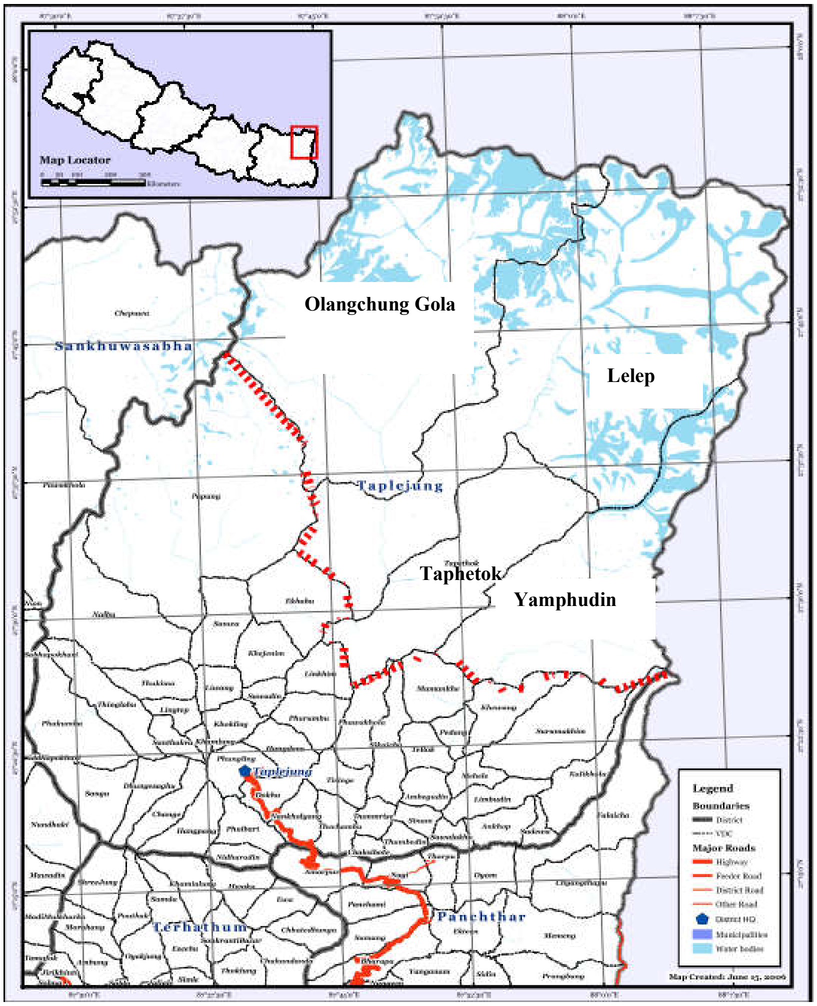


Fig.3.1. Map of the Taplejung district of Nepal showing Kanchenjunga Conservation Area covering 4 villages named Olangchung Gola, Lelep, Tapethok and Yamphudin (adaptaed from http://www.undp.org./resources/map)

Table 3.2. Categories of information surveyed and structure of the questionnaire

Groups	Descriptors	Data information	Remarks
1.Household information	General household information	Numeric and categorical data. a. Education: 1=primary, 2=secondary, 3= higher sec., 4= university b. Legal status: 1=single, 2= married, 3= widow, 4= divorced;	Questions asked to age, education, legal status and gender of respondents (total dataset used)

		c. Gender:1=male, 2=female	
2. Household income resources	Ways of daily subsistence	Numeric data, average percentage contributions by major income resources such as agriculture, livestock, jobs, varia (labor) and tourism.	Questions asked on income generated from different sources with additional focus on yaks and their crossbreds (based on available respondents willing to reply and those having the respective type of livestock)
3. Land and bovine species ownerships	Per capita household ownerships of bovine species and land category	Numeric data, major bovines, small ruminants and other domestic animal species, category of land owned available at households	Questions asked to general herd structures i.e. male female, dairy animals and calves/kids, and breeds or type of yak-cattle crossbreds per household (based on available respondents willing to reply)
4. Bovine products	Milk and butter-fat	Numeric data. a. Average daily milk yield of one animal (mid parity, healthy and regular lactating individuals) b. Average butter production, consumption and marketing	Questions asked on milk and butter yields of cattle, yaks and crossbreds, (based on available respondents having milking animals)
5. Transhumant movement	Year round cycle	General information of grazing routes(Route, campsites and number of sub-pastures within route	Questions asked to the general herd movement cycle across altitude and pastures (based on respondents practicing transhumance)
6. Rangeland usages	General questions related to transhumance	Categorical data. a. Concerned about pasture deterioration:1=yes, 2=no b. Current problems?:1= Loss of biodiversity, 2=increasing landslide,3=Increased domestic & wildlife populations, 4= others; c. Use of pasture differently from childhood?:1=yes, 2= no (described in text only); d. Current situation of pasture: 1=same, 2=good, 3= better, 4=worsened (described in text only); e. Attempts to improve pasture production?: 1=yes, 2=no (described in texts only)	Questions asked to the sustainability of various aspects of the transhumant system and current situation of rangelands (based on respondents practicing transhumance)
7. Trend of household income		f. Range/pasture improvement needed?: 1= Yes, 2= No, 1=Increasing, 2= Decreasing	Questions asked on the trend of family income as compared to previous years (based on available respondents willing to reply)

Criteria of settlement selection

Within each of the 4 study sites, a total number of 60 households each was targeted, but finally a set of 192 households having bovines were included in data analysis. The study sites contained unequal number of settlements. The study site Olangchung Gola (west/high) only has 2 settlements. However, the aim was to cumulate the households surveyed not only in one settlement, but distribute them over several, if available. The survey started at Tapethok VDC (east/low) at Tapethok. From there on, other settlements were visited based on easy accessibility (i.e.close to the route respective).Only settlements having more than 10 households were included for survey purpose.

Criteria of household selection

After settlement selection, the HHs for survey were randomly chosen based on the nearest distance from the settlement center (usually the tea shops/markets where people gather mostly). Only households based on bovine livestock systems (i.e., households having either exclusively bovines, i.e., cattle, yaks, yak-cattle crossbreds or buffaloes, which is mostly the case at high altitude or have bovines and additionally farming or other means of livelihood) were included in the survey. In case of the study site at high altitude along western route, only households having exclusively bovines (cattle, yaks, crossbreds or buffaloes) were included, the others (bovines/other means of livelihood) were excluded. Only the respondents (i.e. household owners, both genders were accepted) who were willing to provide their household information voluntarily were interviewed. In case that a household owner was not willing to participate or unavailable, a switch was made randomly to the next household of the closer distance.

The survey conducted at the study site at low altitude along the eastern route (low/west) was realized at the following dates: Tapethok (Tapethok (4th-12th February, 2010), Hellok, Kabranthok, Margem, Dandagaon, and Lelep (6th March, 2010) and Illadanda (5th March, 2010), the latter administratively belonging to Lelep VDC but included to this study site because located along the western route and being at low altitude. The second study site (high/west, Olangchung Gola VDC) was surveyed on 20th-28th February 2010 including the settlements Olangchung Gola and Yangma. At the third study site (high/east, detail in table 1) the survey was realized on the following dates: Gyabla (6th-7th March), Phale (8th-9th March 2010), Ghunsa (9th-13th March, 2010), Bhotegaon (16th-26th March), the latter administratively belonging to Yamphudin VDC but included to this study site because located along the eastern route and being at high altitude. The last study site (low/east in Yamphudin VDC) was assessed between 15th-24th March including the settlements Samethum, Nakluwa, Sawa, Neppu, Sano Neppu, and Nerdu. The household numbers of each of settlement has been given in Table 1. Altogether 192 households covering 20% of the total HHs of 957 of KCA (District Profile, 2008) were included.

Data entry and analysis

Data were analyzed using SPSS (version 18), for some basic of livestock systems either numeric or categorical data. The quantitative data were analyzed with altitude (A, i.e., high or low), route (R, i.e., east or west) and their interaction as fixed effects following the GLM for univariate ANOVA given by

$$Y= A_i+R_j+AR_{ij}+\mathcal{E}_{ijk.}$$

P<0.1 was used as significant level for comparing the parameters. Percentage data was calculated for each study site (by altitude and route respectively, i.e. east/high, west/high, east/low and west/low). The categorical data were analyzed by Chi-square test. The percentage of respondents per site calculated later from the number of repondents answered to each question and the total respondents respectively at each site.

Results

Demographic features

The average age of the respondents was 43 years, among which 96% were males and 89% were married. There were only 3.1% of respondents having university education and most of them left school at secondary education (47.4%) followed by those having upto higher secondary education level (26.1%). The average family size was 6 with 4 children per household. The detail of demographic features of the respondents across the survey sites has been presented in Table 3.3.

Table 3.3. Characterization of respondents (%, household/study site numbers in brackets) for gender, legal status and educational status across the survey sites. For age of the respondents, family size and number of children, the arithmetic means and standard error of means are displayed

Parameters	High Altitude	Low Altitude	Total

	East (n=82)	West (n=25)	Subtotal n=107	East n=21	West n=64	Subtotal n=85	n=192
Age	39.9±1.2	46.4±2.7	41.6±1.1	43.3±2.5	46.2±1.4	45.5±1.2	43.3±0.84
No. of children	3.3±0.2	3.6±0.3	3.4±0.1	3.9±0.5	4.2±0.2	1.1±0.2	3.7±0.12
Family size	5.6±0.2	5.7±0..4	5.6±0.2	6.1±0.5	6.5±0.2	6.4±0.2	6.0±0.13
Gender							
Male	95 (78)	96 (24)	95 (102)	100 (21)	95 (61)	96.5 (82)	96 (184)
female	5 (4)	41 (1)	4.7 (5)	-	5 (3	3.5(3)	4 (8)
Legal status							
single	2.4 (2)	16 (4)	5.6(6)	0	14.0 (9)	10.6 (9)	8 (15)
married	92.8 (76)	80 (20)	89.7 (96)	100 (21)	84.4 (54)	88.2 (75)	89 (171)
widow	2.4 (2)	4 (1)	2.8(3)	0	1.6 (1)	1.2 (1.)	2 (4)
divorced	2.4 (2)	0	1.9(2)	0	0	0	1 (2)
Educational status							
Primary	30.5 (25)	60 (15)	37.4 (40)	0	7.8 (5)	5.9 (5)	23 (45)
Secondary	48.8 (40)	28 (7)	43.9 (47)	42.8 (9)	54.7 (35)	51.8 (44)	47 (91)
Higher sec.	18.3 (15)	12 (3)	16.8 (18)	52.4 (11)	32.8 (21)	37.6 (32)	26 (50)
University	2.4 (2)	0	1.9 (2)	4.8 (1)	4.7 (3)	4.7 (3)	4 (6)

Income distribution of households across survey sites

The major income resources across the survey sites have been summarized in Table 3.4. Apart from the western high altitude site, farming had an income contribution to 80-98% of the HHs and was reported to provide there on average a share of 19.8% of HH income. The contribution of livestock husbandry (all kinds of livestock included) to HH income (reported to be on average of 30.8%) has been mentioned by 90.6% of total HH surveyed and was highest (P<0.001) at high altitude with an overall share of 42% to total income on an average. Yaks and yak-cattle crossbreds had a contribution to HH income for 56-96% of the HHs at high altitude, and, in case of the income provided by yaks, also to almost 25% (n=5) of the HHs situated at the eastern lower altitude, for which the contribution to the income was mentioned as to be 65%. There was no contribution of yaks to HH income at the low/west study site. The crossbreds had an average contribution of 26.9% to the income of on average 39.6% of HHs in the survey sites and was the highest for high altitude (*P*=0.066) at the western route (*P*<0.001)(Table 4). Labor (all kind of jobs and off-farm activities) contributed to HH income with a proportion of 42-53% and 80-95% to total income along the eastern and western route, respectively. The contribution of labor was highest at low altitude (*P*=0.01) western site (*P*<0.001). Tourism was a source of income for almost 76% and 81% of the

HHs surveyed along the eastern route, at high and low altitude, with a perceived income contribution of almost 60 and 50%, respectively, but contributed to HH income to only about 4% and 16% of the HHs at the western route (see Table 3.4).

Table 3.4. Major share of household income (in % of total households/study site) and the respective contribution (in % of all households with the respective activity contributing to household income) at the survey sites by the activities "farming", "livestock husbandry" (further divided by income generated by yaks and/or yak-cattle crossbreds), "labor" (i.e., jobs and varia) and "tourism"

Activities		High altitude (n=107)			Low altitude (n=85)			Total (n=192)		SEM[4]	*P*-values[2]	
		East (n=82)	West (n=25)		East (n=21)	West (n=64)					A	R
Farming	% of total HHs[5]	80.5	0		95.2	98.4		77.6				
	%Contribution	16.3	0		21.3	21.9		19.8		1.1	0.11	0.84
Livestock	% of total HHs	92.7	100		71.4	90.6		90.6				
	Contribution	29.1	55.0		32.3	6.7		30.8		2.5	<0.001	0.978
Yak[1]	*% of total HHs*[5]	57.3	96		23.8	0		39.6 (76)				
	Contribution	20.7	38.5		65.0	0		41.4		4.9	0.002	0.016
Crossbreds[1]	*% of total HHs*[5]	65.9	56		38.1	0		39.6 (76)				
	Contribution	22.9	52.1		5.6	0		26.9		3.8	0.066	<0.001
[3]Labor	% of total HHs[5]	42.7	80		52.4	95.3		66.2				
	Contribution	35.4	45.3		35.0	71.5		46.8		2.5	0.011	<0.001
Tourism	% of total HHs[5]	75.6	4		80.9	15.6		46.9 (90)				
	Contribution	57.9	40.0		47.6	21.0		41.6		6.9		

[1] Only based on households (HHs) having either yaks or yak-cattle crossbreds.
[2]A=Altitude, R=Route (analysis not performed for tourism due to low number of respondent at west/ high involved in tourism).
[3]Including off-farm jobs and varia, only mean and SEM shown for tourism.
[4] Standard error of mean (SEM) given for grand mean across the sites.
[5] Calculated separately for each site based on total number of respondents responded.

Land ownerships

The total average land holding per HH was 5.5 ropani (0.28 ha, n=168), and was of similar size across the survey sites. However, at the western high altitude site, only 2 HHs reported to have proper land, which they bought at lower altitudes for agricultural purposes but with no irrigated land. The average size of the cultivated land was 3.5 ropani (0.18 ha)/HH (n=133). Across study sites, 109 HH owned rain-fed land with average sizes of 3.5 ropani (0.18 ha)/HHs, with sizes being, higher (P=0.003) for the HHs situated at the eastern route. The irrigated land was owned by 68 HHs (1.9 ropani or almost 0.09 ha/HH, agro-forest (farm-forest) by 102 HHs (land size 4.5 ropani or 0.23ha/ HH) and fallow-land by 65 HHs (2 ropani or 0.10 ha/HH). The detail of categories of land ownerships at the study sites have been reported in Table 3.5.

Table 3.5. Percentage of households having land ownership and total land area per household having land properties (in ropani, 1 ropani is about 0.05 ha), further separated by size of land per land category (values in parentheses indicated number of respondents). Some households had land falling in more than one category

Parameters	High altitude (n=100)		Low altitude (n=92)		Total	SEM	*P*-values[3]	
	East (n=82)	West (n=25)	East (n=21)	West (n=64)	n=192		Altitude	Route
Households having land property (%)	98.7%	8%	100%	100%				
[1]Total land per household	7.7	1.8	7.3	5.3	5.5 (168)	1.2	0.529	0.108
Cultivated [2]	5.2 (57)	1.8 (2)	4.7 (15)	2.8 (59)	3.5 (133)	6	0.820	0.032
Rainfed	6.3 (38)	1.75 (2)	4.5 (15)	1.6 (54)	3.6 (109)	0.6	0.413	0.003
Irrigated	2.5 (23)	-	1.3 (3)	1.9 (42)	1.9 (68)	0.34	0.238	0.583
Agro-foresty	6.7 (40)	-	4.5 (14)	2.4 (48)	4.5 (102)	0.61	0.191	0.205
Fallow	1.9 (25)	-	2.6 (7)	2.1(33)	2.2 (65)	0.31	0.418	0.479

[1]Total land calculated as sum of rainfed, irrigated, agroforestry and fallow land
[2] Cultivated land calculated as the sum of rainfed+irrigated land
[3] *P*-values for Altitude × Route interaction for total land were and 0.553 for rainfed land only, not shown for others.

Livestock ownerships

All HHs surveyed kept bovines, as this was part of the HHs selection criteria. However, the bovine species differed across the altitude and routes (Table 3.6). The average number of bovines per HH was more than three times higher (10 at low and 36 for high altitude; $P<0.001$) in the high mountains and basically very high at the eastern part ($P=0.007$). Overall, 50% HHs kept cattle in general, but no cattel were reported for the high altitude western study sites. Between 30-40 HHs keept cattle in the east, almost all HHs at the western low altitude site.with the exception of the western site at high altitude were no cattle kept at all. Only 7 households kept cattle in transhumance, all located in the eastern sites. Female cattle constituted more than half of the total cattle population surveyed (Table 3.6). At high altitude, 70 and 100% of the HHs kept yaks in the eastern and western high altitude part with average herd sizes of 17 and 49 yaks/HH respectively, whereas only 24 and 5% of the HHs at lower altitude kept yaks (40 and 5 yaks/HH in eastern and western part, respectively). Yak-cattle crossbreds where kept by 84% and76% of the HH situated in the higher altitude, both east and west, and by 81% in the eastern lower altitude. Only 5% of the HHs situated in the western lower altitude kept crossbreds. On average, the HHs keeping crossbreds had herd sizes of about 16 and 21 animals/HH at high altitude in the eastern and western part, respectively, but only 8 and 6 animals/HH in the corresponding sites at the lower altitude (Table 3.6).

Table 3.6. Share of households (HHs) keeping cattle, yaks or yak-cattle crossbreds (in % of total households/study site) and herd structure and average number of bovines per household, separated in cattle, yaks and yak-cattle crossbreds (F1), buffalo, Bhelang and pamu), In brackets, the household numbers given.

Parameters	High Altitude		Low Altitude		Total	SEM	*P*-values		
	East (n=82)	West (n=25)	East (n=21)	West (n=64)	Mean[2] n=192		A	R	A×R
Bovine									
No. of bovines /household	27.1	65.8	19.5	7.1	29.9 (192)	2.4	<0.001	0.007	<0.001

Cattle Toal	183 (27)	0	66 (8)	333 (61)	582 (96)				
% HHs keeping cattle	32.9	0	38.0	95.3	50				
No. of cattle/HH	6.8	0	8.25	5.46	6.83	0.7	0.439	0.118	-
Herd structure of cattle (in % of total cattle numbers per study site)									
% Calf	8.7 (6)	0	10.6 (4)	17.7	14. (47)				
%Male	16.9 (13)	0	24.2 (7)	30.9 (49)	25.8 (69)				
%Female	60.1 (23)	0	36.4 (6)	51.4 (51)	52.4 (80)				
%Transhumant.[1]	14.2 (5)	0	28.8 (2)	0	7.7 (7)				
Yaks									
Total yaks	952 (57)	1233 (25)	202(5)	15(3)	2402				
% HHs keeping yaks	69.5	100	23.8	4.7	46.9				
No. of yaks/HH	16.7	49.3	40.4	5	27.9	5.9	0.385	0.906	0.005
Herd structure of yaks (in % of total yaks per study site)									
% Calf	18. (14)	32.77 (22)	31.7 (4)	0	26.6 (40)				
%Male	47.3 (56)	17.27 (25)	22.3 (5)	100(3)	30.1 (89)				
%Female	34.7 (22)	49.96 (16)	46.0 (4)	0	43.3 (42)				
Yak-cattle crossbreds (F1)									
Crossbreds Total	1076 (69)	394 (19)	142 (17)	19 (3)	1631				
%HHs keeping crossbreds	84.2	76	80.9	4.7	56.3 (108)				
No of crossbreds/ HH	15.6	20.7	8.4	6.3	12.8 (108)	3.5	0.122	0.823	0.607
Herd structure of crossbreds (in % of total crossbreds per study site)									
% Calf	21.8 (26)	10.7 (5)	34.5 (13)	0	19.9 (44)				
%Male	18.5 (38)	31.7 (7)	31.7 (11)	15.8 (1)	22.8 (57)				
%Female	59.8 (55)	57.6 (11)	33.8 (12)	84.2 (2)	57.3 (80)				
%Dimjos	36 (40)	100 (19)	0	100 (3)	48. (62)				
%Urangs	65 (29)		100 (17)		52 (46)				
[1]Others									
Buffalo	0	0	0	1.7 (51)	1.7 (51)	0.1			
Pamu (F_2)	4 (2)	4.3 (4)	0	0	4.1 (6)	1.4			
Bhelang	1 (2)	2 (1)	0	0	1.3 (3)				

% Households keeping respective livestock calculated from total Households per group.
[1]Mean number of holdings by given number of households presented, values in parentheses indicated number of respondents.
[2]Grand mean across all four sites

There were mainly two types of crossbred found in the study area. Cattle-yak crossbreds of the F1 generation are locally called Dimjos, while yak-cattle crossbreds are named Urangs. All HHs keeping crossbreds at the western route, both at high and low altitude, kept exclusively crossbreds of the Dimjo type. However, the crossbreds kept at the eastern lower altitude were all of the Urang type. At the eastern high altitude site, the proportion of households keeping crossbreds was almost 60/40 of Dimjo to Urang crossbreds (Table 3.6). The composition of the different bovine herds (in relative numbers per study site) are shown in Table 6.

Milk and butter yield of cattle, yaks and crossbreds

The average milk production potential of mid parity, healthy cattle and yaks as perceived by the respondents has been represented in Table (3.7). As the information on milk yield for the crossbreds was found not to be confidently replied by the herders, this data was not included in the analysis. Hill cattle were stated unavailable at western high altitude sites. Although several HHs kept cattle at the eastern high altitude site, only 5 HHs gave information on average daily milk yields of their animals. The average daily milk yield of cattle was reported as on average being 1.7 kg at eastern high and western lower altitude, and as 2.0 kg at the eastern lower altitude, respectively, although the latter information was obtained from only 2 HHs. Daily yields of yak milk were reported to be between 1.3 and 1.4 kg by the HHs keeping yaks in three of the study sites. Only 3 HHs of the western lower altitude reported to keep yaks (Table 3.6), but no information on milk production was obtained. The price for 1 kg of cattle milk was reported to be on average between 34 and 40 NRs (nearly 0.5 USD), while the price of yak milk stated during the time of survey was more than double, with on average 95 NRs/kg (1.25 USD). Butter yield per animal and lactation was stated as to be 7 and 13 kg at the eastern highlands and the western lowlands, respectively, while 21, 20 and 19 kg/animal/lactation were reported for yaks (average values from eastern and western highlands and eastern lowlands, respectively). The yields for butter of yak-cattle crossbreds were reported to be between 29 and 35 kg/animal/lactation (Table 3.7). The average butter yield of crossbreds was 31 kg across the survey sites as given by the respondents (n=71).

Table 3.7. Average milk and butter yields in kg and prices per kg in Nepalese Rupees (1USD=75Nepalese rupees; NRs.) as stated by the respondents keeping the respective bovine species/type, separated for yak, yak-cattle crossbreds (F_1) and hill cattle (*Bos indicus*), mean and SEM presented.

Animals	Parameters	High altitude (n=107)		Low altitude (n=85)		Total	SEM
		East (n=82)	West (n=25)	East (n=21)	West (n=64)	(n=192)	
[2]Cattle	Average daily milk yield (in kg)	1.7 (5)	-	2 (2)	1.7 (59)	1.8 (66)	0.11

	Milk price per kg (NRs.)	40 (4)	-	35 (1)	34.4 (59)	36.5 (64)	4.3
	Butter yield kg/animal/lactation	6.96 (23)	-	-	13.2 (13)	10.1 (36)	0.5
Yak	Average daily milk yield (kg)	1.3 (16)	1.4 (15)	1.4 (4)	-	1.4 (35)	0.05
	Milk price kg (NRs.)	94.3 (7)	95 (2)	-	-	94.6 (9)	17.8
	Butter yield (kg/animal)	20.6 (17)	20 (14)	18.7(3)	-	19.8 (34)	0.6
F1-Crossbreds[1]	Butter yield (kg/animal)	30.9 (48)	29.2 (10)	30.5 (11)	35 (2)	31.4 (71)	0.7

[1] No information on milk yield available due to lacking of reliable confident
[2] Only mentioned hill cattle (*B. indicus*)

Perception of respondents regarding the rangeland situation at KCA

The respondents were asked for their perception with regard to rangeland conditions, which is presented in Table 8. All HHs surveyed replied to this question, with the exception of the HHs surveyed at the western/low altitude. Here, only 4 out of 64 HHs responded and thus were included in data analysis. The livelihood of people living at the western low altitude is more dependent on farming and especially focused on the high value crops such as cardamom rather than livestock keeping. Most of the respondents were not concerned about the rangeland conditions, as stated by an average of 59-84% of the respondents surveyed in the eastern and western highlands and eastern lowlands. Asked about the problems they are challenged with regard to rangelands, depredation of domestic animals by wildlife had been mentioned by 55-76% (P=0.04) based on proportion of respondents per site. In total respondents (n=132), domestic animal depredation was followed by the loss of biodiversity (21% out of 132 respondents) and landslide (15% out of 132 respondents) were mentioned as second and third most perceived challenges faced by the respondents. Asked if there is a need for rangeland improvement, the majority of the respondents (between 78-96% across the respondents of all sites) responded positively (yes, P=0.03). The detail of the questions asked to the attitude of respondents regarding the rangeland situation of KCA have been presented in Table 3.8.

Table 3.8. Attitude of the respondents using pastures to pasture situation along the transhumant routes in KCA, percentage of total respondents per study site is given (*P*-value given for comparison of responses for each question)

Questions	Response	High altitude		Low altitude		[2]Total
		East (n=82)	West (n=25)	East (n=21)	West (n=64)	(n=192)
Respondents (in % per study site) concerned about rangeland conditions (df=3)						
	n	82	25	21	4	132
	Yes	41 (34)	16 (4)	29 (6)	25 (1)	34(45)
	No	59 (48)	84 (21)	71 (15)	75 (3)	66 (87)
[3]*P*- value of total comparison						*P*=0.11
Respondents (in % per study site) perceiving problems or changes in pasture use (df=6)						
	n	82	25	21	4	132
	Loss of biodiversity	25 (21)	24 (6)	5 (1)	0	21 (28)
	Landslide	20 (16)	0	19 (4)	0	15 (20)
	[1]Predation	55 (45)	76 (19)	76 (16)	3 (4)	64 (94)
[3]*P*- value of total comparison						*P*=0.04
Respondents (in % per study site) stating need for rangeland improvement (df=3)						
	n	82	25	21	5	133
	Yes	78 (64)	96 (24)	95 (20)	60 (3)	83 (111)
	No	22 (18)	4 (1)	5 (1)	40 (2)	17 (22)
[3]*P*- value of total comparison						*P*=0.03

[1]Domestic animlas preyed by wildlives.
[2]Total across the sites for the given response
[3]*P*-value as given by the χ^2 statistics for given degrees of freedom for comparison of responses in total respectively.

Discussion

General background

Nepal is categorized as least developed country, ranked 142nd out of 177 countries of the world in the Human Development Index (HDI; UNDP, 2008). The poverty level within the country is highest in the mountainous region as compared to the rest of the country (CBS, 2005).The poverty indices for KCA separately are unknown. However, Taplejung district is one of the poorest districts within the country ranked 36th out of 75 districts by HDI. Likewise, the district has only 47.3% adult literacy rate and 2.7 mean year of school education as compared to 36.1% adult literacy of Nepalese mountainous region and 2.5 years of school education of total eastern mountainous region of Nepal (District profile, 2008). In the present study, however a larger proportion of respondents stated to have secondary education and below. Taplejung district has also very poor Income Index (0.177) as compared national average of 0.229 (District profile, 2008). Agriculture contributes almost one third of GDP, while the livestock sector contributes almost 1/3rd of the agriculture gross domestic product (AGDP) of Nepal (FAO, 2005).

The aim of the household survey was to characterize the bovine livestock husbandry of different parts and altitudes of KCA as an example to represent the livestock production system within Himalayan Mountains of Nepal. The KCA is heterogeneous in nature, and thus includes different altitudinal ranges and ethnic groups. While at the high altitude areas, Sherpas are settling, the lower altitudes are inhabited by several different ethnical groups with different cultures and languages. However, all HHs surveyed relied to a large part on mixed crop-livestock systems (agriculture and livestock).

Household income contribution from bovines and others

Farming seems to be an equally important activity as livestock husbandry within the KCA, especially in the lower parts, as >95% of the HHs from the lower altitude included in the survey stated farming to be a source of livelihood. Also, about 81% of the HHs situated in the eastern highlands mentioned farming as a source of income. In contrary, none of the HHs included at western high altitude study site were involved in farming activities, but exclusively in livestock husbandry. The reason is that KCA has only 2% arable lands (Parker and Thapa, 2012), and this is distributed mainly to the eastern and low western regions mostly utilized for cardamom production. Most of the respondents surveyed at east high altitude had owned abandoned land as left from their relatives(migrated) as agroforestry land that they mostly for use for grazing. The average household land holding in the survey sites (0.3 ha) was found almost 4 times smaller than the average landholding (1.16 ha) across the mountains of Nepal (reviewed by Maltsoglou and Tanuguchi, 2004) or almost 3.4 times smaller than the average land size/HH of the Taplejug district of Nepal (CBS, 2001).

Management of yaks and their crosbreds

There was a significant rise of the yaks and chauries population from 1991/92 to 2001/02 (CBS 2001/02) across the country. CBS (2001/02) showed that almost 2 animals/HH, and some 60% of these bovines are kept at high altitude with an average of almost 10 heads of yaks and crossbreds in mountanins (high altitude) and about 40% in the hills(low altitudes) with an average of almost 5 heads/HH (low altitudes). The total population of yaks and their crossbreds recorded in the present study, i.e. 2402 and 1631heads of animals, respectively summing up the animal numbers as stated by the 192 HHs included, is more or less similar to the information provided by Shaha (2000) for the whole Taplejung district. Shaha et al. (2000) concluded a total number of 4036 yaks and crossbreds in the Taplejung district. According to MOAD (2011/2012), there is no change in the number of yaks and theircrossbreds across KCA were. As a large number of HHs keeping yaks and their crossbreds across KCA was surveyed in the present study, the total population would hardly be > 5000 heads in the whole Taplejung district, because the KCA is covering the higher altitudinal ranges of the Taplejung district, where these genotypes are kept. However, in the MOAD (2011/2012) report, a total number of 2890 yaks and their crossbreds were listed for the Taplejung district.

The HHs included in the present survey mentioned bigger herd size of yaks and their crossbreds on average 28 yaks/90 HHs and 13 crossbreds /108 HHs respectively as compared to that mentioned in CBS (2001/02). Livestock is of special importance for the livelihood of people living in high altitude mountain areas where no or very marginal arable land resources are available, as it was the case for the study site situated at the high altitude western region of KCA (no HHs involved in farming activities). Yaks and their crossbreds with cattle were reported as multipurpose animals (Wiener et al., 2003; Joshi, 1982; Rhode et al., 2007) in the Himalayan Mountains. However, their basic support to livelihood would differ across the 4 study sites due to difference in household holding of these animals.

General herd movement and management

While only a small number of cattle from the eastern site was reported to be kept in transhumance, all yaks and yak-cattle crossbreds belonging to the HHs surveyed in the present study were kept in transhumance. The altitudinal range covered, the animal species used and reasons of transhumant herding have been already discussed by Dong et al. (2009b), Gurung and McVeigh, (2000); Sherchand and Karki, (1996) and Pande (2004) in different high altitude areas of Nepal, that are similar to the transhumant system surveyed in the present study too.

Transhumance is a direct response to cold temperatures, shortage of forage, and the search for livelihood opportunities in the high altitude mountainous areas (Moktan et al., 2008). In the Himalayan mountains, transhumant systems are characterized by the seasonal movement of grazing livestock across different pastures from lower pasture sites to high altitude pastures in summer and vice versa in winter. Thus, the transhumant system has the potential to make use of seasonal herbage on offer across an altitudinal gradient (Dong et al., 2009b). Yaks and their crossbreds are traditionally used in transhumance in Nepal. The crossbreds have the potential to utilize the vegetation even at lower altitudes than yaks (Joshi, 1982), especially in winter. While yaks are not kept below 3000 m a.s.l. in the study area, crossbreds are even grazing on pastures as low as 2000 m. Dimjos can go upto 4500m around August, while the Urangs can graze high pastures of 4200m.

The benefit of crossbreds in transhumance is thus also that they can better utilize the pasture sites too low to be used by yaks and those that are too high in altitude for keeping cattle (Joshi et al., 1994). Thus the altitudinal distribution also has an influence on the distribution of bovines in the Nepalese Himalayan Mountains. According to information obtained from herders of the western high altitude study site, the high altitude stay of crossbreds of the urang type are rather shorter than that of Dimjo types (maximum one month in July - August at 4000-4200 m). In the lower altitude sites included in the present survey, there was an abundance of sedentary grazing of cattle and buffalo. Also yaks and their crossbreds were reported to be kept at the lower altitude study sites, however, they grazed at higher altitude pastures and followed the same pattern of movement cycle of the yaks and their crossbreds kept of the HHs situated at the high altitude study sites. This is due to the migration of high altitude herders to low altitudes and because some people of low altitude to keep yaks for trading purposes to and from Tibet.

The larger cattle population, mainly of the common hill cattle breed (*B. indicus*) at the eastern parts of KCA and use of some of them in transhumance would make it possible to produce Urang type crossbreds when crossed with male yaks. In the higher altitude parts of KCA, so called Bhelang bulls (*Bos taurus*), are available.Bhelang is a Bos taurus genotype (Joshi, 1982). They are crossed with female yaks in order to produce the Dimjo type crossbreds. The Dimjo crossbreds were found in both western and eastern high altitude sites, although they are the only type of crossbred produced in the western high altitude part of KCA. The availability of Bhelang bulls is often dependent upon the barter trade and cash and carry agreement in between the Tibetan and Nepalese herders, which is the historical cross-border trading remained still existent.

Milk and butter production

The average milk production of yaks as stated by the respondents in this study is almost two times smaller (4 kg/day) than reported by Joshi (1982) for Nepalese yak. Compared to the data reviewed by Dong et al. (2007), the local yaks at the study sites produced two times less than several yak breeds(2.5 and 2.7 kg/day) of China. However, the milk yields reported in the present study (1-1.4 kg/day on an average) were close to those mentioned for Datong yaks from Qinghai, and even higher as those reported for some other yak breeds of Tibet and China (reviewed by Dong et al., 2007). The herder's response to butter yield as found in the present study was higher as compared to the yields reported by Joshi et al. (1994), namely 10-15 kg cheese and 10-15 kg butter, respectively. In the herder's experience, hard cheese (so called churpi cheese) could be produced in amounts of almost 50-60% to that of butter ,which further increases the income generated from animals (pers. comm., Mr. Chungdak Sherpa, crossbred herder of Olangchung Gola, Nepal). The butter yields, as stated by the respondents of the present study, were almost 50% higher as obtained from crossbreds as that of yaks, which could be due to the early parturient stage (already starting in March-April) and longer lactation period of crossbreds (260 days as compared to 180 days as compared to yaks, respectively,(Joshi et al., 1994). The price for butter was reported as to be in between 4-5 USD (1 USD= 75 Nepalese Rupees) per kg during the time of survey realization, and was almost similar for yaks and their crossbreds and for butter and churpi-cheese (pers. comm., Mr. Chungdak Sherpa, Olangchung Gola, Nepal. Unlike some differences in herd movement between the yaks and their crossbreds across altitude in transhumance pattern, there is similarity in the value of butter. Thus, the net return from crossbreds can be expected, due to longer lactation compared to yaks (Joshi et al., 1994), which signifies a major advantage of crossbreds rearing in KCA.

Influence of tourism in KCA

Nepal has been recognized as a center of high altitude trekking and mountaineering in Asia (Stevens, 1992). Although being one of the remotest areas of Nepal, the Mt. Kanchenjunga in the eastern part of KCA, is a touristic attraction and visited by less than 800 tourists per year (Parker and Thapa, 2012). This led to the hypothesis, that tourism has a bigger importance for the livelihood of the people living in the eastern part of KCA. Indeed, about 80% of the HHs included in the survey situated along the eastern route at both, higher and lower altitudes, reported tourism as a source of income, with an average share of 50% to HH income. Only a small part of the HHs situated along the western route mentioned tourism as a source of income. However, the touristic potential of the eastern KCA region is still not fully exploited, which might be due to the remoteness of high altitude areas, long trekking routes and poor touristic infrastructure. In Khumbu region, where the Mt. Everest is close, Nepal, touristic activities already changed the economy of the local Sherpa communities of the lower altitude and adjoining Tibetans, with single HH income of upto 10000 USD per year (Stevens, 1993). The increased number of young generations working and switching to other professions (jobs and tourism) have rendered bovine livestock husbandry more abandoned due to poor net return (Shaha, 2000) since the recent past in Nepal.

Parker and Thapa (2012) reported a household income range of 201-1467 USD from livestock as when the information taken from the altitudinal range of 1380-2249 m, which covers almost the cattle rearing sites of KCA other than the large number yaks and their crossbreds rearing households across the high altitude areas. When selling butter and churpi-cheese , an average household income of 150-200 USD per yak and 200-350 USD from F_1 crossbred of Dimjo type can be expected for a mature, healthy animal of mid parity level .

Attitude of respondents to rangelands management

The KCA is a nature protection area but grazing domestic animals is allowed due to people living across the KCA. Xu et al. (2006) reported that the inadequacy of croplands influenced the biodiversity conservation and nature protection goal in the Wolong Biosphere Reserve of China because of the decrease of incentives for daily subsistence of people living inside. However, in KCA, the population is already sparse with little abundance of croplands. The KCA itself is the second biggest nature protection area in the Kanchenjunga landscape extending upto Bhutan from Nepal (Shakya and Joshi, 2008). Although mostly not concerned, most of the respondents were aware about a need to improve the pasture conditions. One possible mode of action in order to promote a sustainable way of transhumant herding, the KCA authorities should have strategies to realize a detailed inventory of rangelands and forests grazing sites, transhumant livestock species composition i.e yaks, crossbreds, sheep etc. and promote the introduction of activities for income generation opportunities in short term for instance cultivation of medicinal plants. Several respondents perceived wildlife-livestock conflicts as a problem of bovine livestock grazing. Ikeda (2004) reported the killing of 1-6 yaks by snow leopards in between 1995-2001 from the Ghunsa valley, after the conservation area declared in 1997. For the animals preyed by wildlives, a fair and justifiable insurance payment system established by KCA might be beneficial in order to make sure that no conflicts with the herders/farmers arise.

Conclusions

The present study confirmed the importance of bovine livestock husbandry in different parts and altitudes of the Kanchenjunga Conservation Area of Nepal. The western high altitude site is purely transhumance dominated whilst the other areas are dominated by transhumant-agropastoral and/or the mixed cop-livestock farming. Livestock (bovine) husbandry is of special importance in high altitude remote areas mostly not influenced by tourism and with no possibility of faming activities, such as at the western high altitude site(Olangchung Gola and Yangma. The overall high percentage of respondents not concerned about rangeland and pasture conditions might be a hint for a rather sustainable management without deterioration effects on the vegetation, or that negative impacts of grazing are not yet visible. The positive attitude of the respondents with regard to improvement of the rangelands would be a good asset for future rangeland development interventions.

Chapter 4

Effect of high altitude grazing on Nepalese pastures and stocking density on performance and activity pattern of

cattle-yak crossbreds (*Bos taurus* × *Bos grunniens*) as compared to yaks (*B. grunniens*)

Based on: S.R. Barsila, N.R. Devkota, S. Marquardt, submitted to Livestock Science.

Abstract

The present study was conducted in the Kanchenjunga Conservation Area of Nepal. Twelve lactating cattle-yak crossbreds (*Bos taurus* × *Bos grunniens*) without calves were selected based on similarity in milk yield and body weight, and, additionally, four lactating yaks (*B. grunniens*) with calves. Five experimental pasture sites (Sites 1 to 5) were selected, following an up- and downward transhumance route (3200, 4000, 4500, 4000, 2600 m a.s.l.). Four and six (the latter at Sites 2 to 4 only) paddocks were established by fencing based on estimated energy requirements in relation to initial pasture biomass. Crossbreds were maintained in groups of two (low stocking density (SD) and four animals per paddock (high SD). Yaks were only included at low SD and Sites 2 to 4. Each treatment was replicated per site. Body weight was measured at the start and the end of 9 d of grazing per site. Herbage samples as consumed by the animals were collected and analyzed for chemical composition. Milk yield was recorded and milk composition was analyzed daily by a portable milk analyzer. Milk consumed by the yak calves was determined by the weigh-suckle-weigh method. Pedometers were used to measure the activity pattern of two crossbreds per paddock at Sites 2 to 4. At similar body weight change, the crossbreds produced overall 29% less milk at high than at low SD, but 49% more per m^2 of pasture area. Milk composition was not affected by SD. Milk fat increased with time from 5.4 to 7.1% whereas milk protein decreased from 4.2 to 3.3%. Compared to yaks, crossbreds were on average about 1 month longer in lactation, were heavier but did not produce overall more energy-corrected milk except at Site 2. Although BW change was overall not significantly different between the genotypes, there was a genotype by site interaction. The yaks gained weight at the highest altitude while the crossbreds lost weight. At high SD, less time was spent standing and more time lying and walking. As time spent at around 4000 m (Sites 2 to 4) progressed, lying time increased and walking time decreased. It could be concluded that high SD reduced individual milk yield and forced animals to spend more time to search feed which suggests a situation of overstocking. Performance of the crossbreds was not superior to that of the yaks, and the yaks seemed to have had an advantage at high altitude.

Introduction

The use of F1-crossbreds of yaks and cattle is frequent in the yak keeping high altitude areas of Asia (Qi et al., 2009). In the Nepalese Himalaya, both yaks and crossbreds are managed under traditional transhumant systems (Joshi, 1982), where they are moved along with seasonal herbage growth across a large altitudinal range (Dong et al., 2009b). The crossbreds are more suitable for the exploitation of lower altitude pastures compared to purebred yaks and have an advantage in milk yield (MY) because of the basically higher yield of cattle and due to heterosis (Wang et al., 1994a). Furthermore, and different from yak husbandry, the calf is removed from the dam after the colostrum period. Milk and milk products of yaks and crossbreds are the main sources of livelihood of the herders in the Himalayan yak keeping areas (Guo et al., 2012a; Joshi, 1982). However, rangeland productivity is declining due to overgrazing as has been reported for other mountainous areas as well (Dickhoefer et al., 2010; Mishra et al., 2001). There is awareness about the need to extend or establish additional protection areas in the Nepalese Himalayan region (Shrestha et al., 2010). Additionally, in overgrazed rangelands unpalatable shrubs cover increasing proportions of the area (Bauer, 1990), which would further restrict the land available for livestock grazing and thus promotes overgrazing. The implementation of sustainable stocking densities (SD) often fails because of the lack of important information, for instance on pasture characteristics, which substantially differ in transhumance systems because of variations in vegetation type, altitude and climate.

The present experiment was conducted to quantify performance and activity pattern of cattle-yak crossbreds under different stocking densities along a transhumant route starting from 3200 m up to 4500 m a.s.l. and then descending to 2600 m. Additionally, the performance of the crossbreds was compared with that of purebred yaks at the three high altitude pasture sites.

Materials and methods

Experimental sites and climate recordings

A traditional transhumant route used by herders of the community of Olangchung Gola, Taplejung district, was selected for the experiment. The route is situated within the Kanchenjunga Conservation Area in the Eastern Himalayan Mountains of Nepal. Five pasture sites (Sites 1 to 5) were selected at different altitudes (Table 4.1) along the transhumant route and were preliminarily fenced always 2 weeks before the respective measurement periods started in order to protect the areas from being grazed. All five sites were facing a North-East aspect. Although Sites 2 and 4 were established at the same area, different sites were fenced which were close by but separated by a small ridge. Sites 1 to 3 (upward movement) were grazed in spring and summer, while Sites 4 and 5 (downwards movement) were used in autumn. A portable weather station was mounted at each of the 5 sites. Temperature (measured at 1300 h), minimum temperature during the night (measured at 0630 h), relative humidity and daily precipitation (measured at 0630 h) were recorded during the respective measurement periods (Table 4.2).

Table 4.1. Characterization of pasture sites and experimental paddock sizes used

Site	Dates of measurement	Local pasture names	Altitude (m a.s.l.)	Actual paddock size (m^2)	Stocking densities (m^2/head)[z]
1	May 19-27	Hile	3200	41×42	861 / 431
2	July 6-14	Mauma	4000	55×54	1485 / 743
3	Aug. 4-12	Mendalung	4500	50×45	1125 / 563
4	Sept. 1-9	Mauma	4000	50×42	1050 / 525
5	Oct. 30-Nov. 7	Jongim	2600	40×35	700 / 350

[z]Low / high stocking density.

Table 4.2. Climate data records in 2010 at the selected pasture sites (mean values ± standard deviations)[y]

Site	Altitude (m a.s.l.)	Temperature (°C) T_{min}[z]	T	Precipitation (mm)	Relative humidity (%)
Measurement h		0630 h	1330 h	0630 h	0630 h
1	3200	4±3	16±5	7±11	75±8
2	4000	2±1	14±1	9±7	75±5
3	4500	2±2	12±1	12±8	74±7
4	4000	1±1	12±2	4±6	78±7
5	2600	2±1	11±1	4±5	72±9

[y]The data displayed are averages per site across several days. Site 1: n=16, May 13-28; Site 2: n=25, June 26-July 20; Site 3: n=23, August 1-23; Site 4: n=16, August 28-September 12; Site 5: n=13, October 27-November 8.
[z]T_{min}: minimum temperature recorded for the period from 1330 to 0630 h.

Experimental animals

The crossbreds used in the present study were locally available *Bos taurus* × *Bos grunniens*, (♂ × ♀) crosses called Dimjo chauries in the local Sherpa language. They were locally produced at 4200 m in Yangma, Olangchung Gola. This type of crossbred is assumed to have a better high altitude tolerance than the *Bos grunniens* × *Bos indicus* crossbreds also prevalent in the study area. In total, 12 female crossbreds with four to five parities which had calved between April 7 and May 2, 2010 at 2500 to 3000 m a.s.l. were selected and allocated to two different SD, low and high. Animals of similar MY and body weights (BW) were chosen (initial BW, May 18: 201±7 and 202±12 kg and average initial MY, May 14-16: 2.0±0.20 kg and 2.1±0.27 kg of the groups assigned to low and high SD, respectively). According to the traditional practice, the calves were separated one week after parturition. The elevations of Sites 2 to 4 were high enough for yak husbandry, and thus four female yaks were additionally included. These yaks had calved between May 15 and 20, 2010, when they had been kept at an altitude of 3500 m a.s.l. The yaks had average BW of 186±4 kg and a MY (including the amount suckled by calves) of 3.3±0.8 kg as measured on May 18 and July 4/5, respectively. In compliance with traditional practice, the yaks were accompanied by their calves during the whole experiment. During winter until April 2010, the crossbreds grazed a forest area at around 2400 m a.s.l. before starting with the upward movement. The yaks used in this study were kept in a semi-open forest grazing area at about 3500 m a.s.l. during the same period of time.

Experimental design and determination of forage biomass and paddock sizes

For the crossbreds, the experiment was designed with two SD in fenced paddocks during measurement periods of 9 d per site each. The paddock sizes were calculated per site according to the assessment of current forage biomass availability and estimates on animal requirements based on actual BW and MY. For this purpose, 2 d before starting the measurements at the respective sites forage biomass availability was assessed by taking samples of the total biomass in plots of 50 × 50 cm (Site 1-5, n=12, 3, 6, 6 and 4 plots, respectively). These samples were separated into palatable (i.e., forage) and unpalatable biomass (based on the herders indigenous knowledge). Dead matter, mainly parts from plants grazed the previous year that were still covering the pasture, was also separated. Only the remaining green forage biomass was used for calculation of paddock size.

For the calculations of supply over requirements, the fresh forage biomass was assumed as having a content of 200 g dry matter/kg. Feed intake was estimated based on the requirements of animals by using the equation as stated in Wiener et al. (2003) for lactating yaks:

Dry matter intake, kg/d = $0.008 \times \text{BW, kg}^{0.52} + 1.369 \times \text{MY, kg/d}$.

Body weight and MY of the groups of animals were determined 1 d and 2 consecutive d before stocking the paddocks, respectively. Additional space was then allocated in each of the pastures depending on the estimated coverage of the area with unpalatable shrubs and stones and assumed trampling losses. Shortly before starting with the experimental periods, these paddocks were established within the previously fenced areas.

Based on these considerations, for high SD forage on offer should match the requirements of four adult crossbreds during 9 d. Low SD was defined as stocking with only two crossbreds for a similar period of time in a paddock of similar size. Both SD treatments were repeated by different paddocks per site. For the yaks, two paddocks stocked with two animals per paddock (low SD) were established at Sites 2 to 4.

Fencing was done with wooden poles and nylon ropes mounted at least at three levels. The animals were moved into the paddocks after morning milking at about 0900 h on d 1 and were released at about 1700 h on d 9. Before starting the experimental periods, the animals had been kept for 5 d in the surroundings of the respective pasture site, without entering the pre-fenced areas. In the time between the experimental periods at the different sites, the animals were kept together with a larger herd of the respective genotype and were moved along the transhumance route according to the traditional herders practice.

Recording of total biomass

The available total biomass was measured 2 d before the animals were allocated to their respective paddocks and the experiments started. Three plots of 50 × 50 cm which were randomly distributed on each preliminarily fenced paddock area were sampled by cutting the available biomass 2 cm above ground. In total, n=12 plots and n=18 plots were sampled at Sites 1 and 5 and at Sites 2 to 4, respectively. The standing biomass was also separated by functional groups and was first air dried and later dried at 60°C during 48 h in an oven, and weighed and milled instantly in order to determine the amount of air dry matter of this biomass.

Recording of plant cover and plant composition

Three 1 × 1 m sized plots were randomly selected per paddock, resulting in n=12 plots at Sites 1 and 5 and n=18 plots at Sites 2 to 4. Plant cover and composition were calculated using the Braun-Blanquet method (Bonham, 1989) 2 d before the animals were allocated to the respective paddocks.

Measurement of milk yield and composition

Hand milking into buckets was done from 0600 to 0700 h at Site 1, from 0700 to 0800 h at Sites 2, 3 and 4 and between 0830 and 0900 h at Site 5. Evening milking (only practiced in the crossbreds) took place between 1700 and 1800 h at all sites. Except on Site 1, the animals were removed from the paddocks and milked in a nearby area where the animals were tethered. The animals were milked in a random order, and the milk amounts were measured with a digital balance (Scout Pro, Ohaus, NJ, USA). For determining total MY of the yaks, at first milk let-down was facilitated by allowing the calves to suckle for 1 to 2 min for two times, then hand-milking was practiced and finally the calves were allowed to suckle again. By weighing them before and after suckling the milk consumed by the calves was determined. Keeping yaks and their calves separately for the night ensured that most of the milk was consumed in the morning. Still, the actual MY of the yaks was probably higher as calves may have suckled additional milk during the day. Milk compositional analysis was done after each milking on each day of the 9-d experimental period. The milk was filtered through a common milk sieve and analyzed in duplicate by a portable ultrasonic milk analyzer (Lactoscan SA-L, Milkotronic Limited, Nova Zagora, Bulgaria). Milk analysis was done in an aliquot of morning and evening milk considering yields in the case of the crossbreds. The contents measured in the milk were adjusted using regression equations obtained from 25 *B. taurus* milk samples of four different European breeds that had been analyzed with both the portable milk analyzer and the standard Milkoscan 4000 (Foss Electric, Hillerød, Denmark). The equations used read as follows: fat (%) corrected = 0.8912 × fat (%) + 0.1876; protein (%) corrected = 3.2221 × protein (%) – 6.5438; lactose (%) corrected = 0.1587 × lactose (%) + 4.1956. For analysis, the average of the last 3 d per experimental period was used. Energy corrected milk (ECM, kg/d) was calculated as milk (kg/d) × (0.038 × fat (g/kg) + 0.024 × protein (g/kg) + 0.017 × lactose (g/kg)/3.14 (ALP, 2013).

Measurement of body weight

Body weight (BW) was assessed for adults and calves by a digital balance (BH-300X, Aditsan, New Delhi, India, accuracy of ± 0.02 kg) covered by a wooden plate of a size of 200 × 50 ×5 cm. Adults were weighed after morning milking 1 d before the start of each experimental period and after evening milking on d 9. Body weight change was calculated as: initial BW minus final BW/9 d.

Recording of activity pattern

Times spent walking, standing and lying as well as the number of steps were recorded on Sites 2 to 4 in always the same two crossbreds per paddock (n=8) by pedometers (IceTag 3D, IceRobotics Ltd., Edinburgh, UK). The pedometers were fixed on the right hind leg. The pedometers were always fixed in the morning of d 1 during the milking procedure and detached when the animals were released from the paddocks after finishing the respective experimental period. As the animals were released at the evening of d 9, complete data sets were only available for d 1 to d 8 (n=8). Data were downloaded after each experimental period and evaluated by the corresponding software (IceTag Analyser 2008, IceRobotics Ltd., UK). Analysis was done per minute following Aharoni et al. (2009) by considering the activity as either standing or lying according to the highest proportional share (i.e. >50%/min). Standing was further separated into walking (>3 steps/min) or standing (≤3 steps/min). In order to account for the times needed for gathering of the animals and for milking both in the morning and evening, a total of 122 min had to be removed from the data set for each daily record. This resulted in always 539 min of time allocated to daytime (0900-1700 h = 480 min of the first day + 0800-0859h = 59 min of the following day), and 779 min of nighttime (1800 – 0659 h) and 1318 min of total time evaluated per day and animal. The mean of 8 d per animal was calculated and used for analysis.

Laboratory analysis

Herbage samples were transported to the laboratory of the Institute of Agriculture and Animal Science, Rampur, Nepal. There the samples were first oven dried at 60 °C for 48 h, instantly weighed and then ground to pass through a 0.75 mm mesh size of a Thomas mill. Part of these ground samples were transported to Switzerland and analyzed for proximate contents following standard procedures (AOAC, 1997; Van Soest et al., 1991). Dry matter and total ash were assessed on an automatic thermogravimetric determinator (TGA-500, Leco, St. Joseph, MI, USA: AOAC index no. 942.05). Nitrogen was determined with a C/N analyzer (Analysator CN-2000, Leco, St.Joseph, MI, USA; AOAC 977.02). The contents of crude protein (CP) were calculated as 6.25 × N. Contents of neutral detergent fiber, acid detergent fiber and acid detergent lignin were assessed on a Fibertec System M (Tecator 1020 Hot Extraction, Höganäs, Sweden). The methods were based on Van Soest et al. (1991), data were corrected for ash content and, in the case of neutral detergent fiber, α-amylase and sodium sulfite was used.

Statistical analysis

The Mixed procedure of SAS (version 9.3) was used to perform analysis of variance. For MY, milk composition, BW and behavior data, a model was applied with data of the crossbreds only in order to determine site (S) and SD effects. This Model 1 reads:

$Y = S_i + SD_j + S \times SD_{ij} + \varepsilon_{ijk}$ (1)

where S and SD as well as their interaction were treated as fixed effects. Site was treated as repeated variable, animal (replicate) nested within SD was set as subject and paddock as random effect. For MY, the last 3 d were averaged, and the initial individual data on MY measured before the start of the experiment (May 14 (evening)/15 (morning) and 15 (evening)/16 (morning), averaged) were treated as covariates.

Model 2 compared the two genotypes for daily MY and milk composition at Sites 2 to 4 with low SD only. It reads as follows:

$Y = S_i + G_j + S \times G_{ij} + \varepsilon_{ijk}$ (2)

where, different from Model 1, G = genotype is included instead of SD. Both S and G were treated as fixed effects, S was treated as repeated variable, and animal (replicate) nested within genotype was considered as subject. Paddock was set as a random effect. Again, the data obtained on the last 3 d were averaged for MY and the MY measured shortly before starting the experimental period at Site 2 (i.e., July 4 and 5) was used as covariate.

The day-to-day variation in the MY data obtained in the crossbreds was additionally analyzed with Model 3, reading:

$Y = SD_i + D_j + SD \times D_{ij} + \varepsilon_{ijk}$ (3)

where, D (day) and SD as well as their interaction were included as fixed effects, day as repeated variable with animal (nested within SD) as subject and paddock was considered as a random effect. No covariate was included for the MY data.

The botanical composition was analyzed with Model 4 treating pasture site as single fixed effect and paddock as replicate:

$Y= S_i + \varepsilon_{ij}$ (4)

The plots used for biomass cutting (three plots per paddock) were averaged per paddock, resulting in n=4 (Sites 1 and 5) and n=6 (Sites 2, 3 and 4).

Multiple comparisons among means were performed with Tukey's method considering $P<0.05$ as significant. The chemical composition of the herbage selected by the experimental animals and the climate data presented in the tables are arithmetic means. Means of variables subjected to analysis of variance and given in the tables and the figure are Least Square means.

Results

Plant cover, total biomass and chemical composition of the herbage selected

In the total of 78 sampling plots across four different altitudes (Site 2 and 4 were situated on the same altitudinal level by using different pasture areas), 96 different vascular plant species were recorded (not including two unknown Pteridophyta), whereof 69 could be determined to species level and 27 to genus level. The highest number of different plant species was recorded at the highest altitude (Table 4.3). Total available biomass was highest ($P<0.05$) at Site 2 (Table 4.4). Herbs made up the highest (>90%, $P<0.05$) share of total biomass at Site 1. Poaceae and Cyperaceae together contributed more than 50% of forage biomass on Sites 2 to 5. Poaceae alone made up about half of the total biomass at Site 5, whereas they not even accounted for 10% at Site 1 (Table 4.4). The nutritional composition of the herbage as selected by the animals is displayed in Table 5. The crude protein content in the selected herbage was high at Site 1 and decreased over time, with the sharpest decline occurring at Site 5. The contents of cellulose and hemicellulose of the herbage selected increased when progressing from Site 1 to Site 5, but this pattern was not reflected in the lignin contents8(see Table 4.5).

Table 4.3. Plant cover (in %, mean and range across sampling areas of 1 × 1 m) of the most abundant (>5%) plant species in Site 1-5 during the respective experimental period

Site	Plant cover (%)		Plant species	
	Category	Range	Species	Family
Site 1	n=31 different vascular plant species (n=12 sampling plots)			
	>20	-	-	-
	<20-15	4-55	*Anemone rivularis*[fl]	Ranunculaceae
	<15-10	2-25	*Selinum candollei*	Apiaceae
		3-20	*Lactuca* sp.	Asteraceae
	<10-5	0-45	*Sambucus* sp.	Caprifoliaceae
		0-30	*Bistorta amplexicaulis*	Polygonaceae
		2-10	Unidentified mosses	
Site 2	n=46 different vascular plant species (n=18 sampling plots)			
	>20	3-30	*Ranunculus hirtellus*[fl]	Ranunculaceae
	<20-15	10-30	*Poa himalayana*	Poaceae

		8-25	*Rumex nepalensis*	Polygonaceae
	<15-10	2-30	*Kobresia nepalensis*	Cyperaceae
	<10-5	0-25	*Potentilla griffithii*	Rosaceae
Site 3	n=50 different vascular plant species (n=18 sampling plots)			
	>20	20-45	*Kobresia nepalensis*	Cyperaceae
	<20-15	-	-	-
	<15-10	-	-	-
	<10-5	0-15	*Poa himalayana*[fl, fr]	Poaceae
		0-20	*Bistorta vivipara*	Polygonaceae
		0-15	*Ranunculus hirtellus*[fl]	Ranunculaceae
Site 4	n=44 different vascular plant species (n=18 sampling plots)			
	>20	-	-	-
	<20-15	5-30	*Kobresia nepalensis*	Cyperaceae
		2-30	*Ranunculus hirtellus*[fl]	Ranunculaceae
		10-25	*Poa himalayana*[fl]	Poaceae
		0-25	*Potentilla griffithii*[fl, fr]	Rosaceae
	<15-10	2-25	*Bistorta vivipara*[fl, fr]	Polygonaceae
	<10-5	-	-	-
Site 5	n=31 different vascular plant species (n=12 sampling plots)			
	>20	-	-	-
	<20-15	-	-	-
	<15-10	5-20	*Potentilla peduncularis*[dr]	Rosaceae
	<10-5	0-20	*Poa annua*[dr]	Poaceae
		0-20	*Rumex nepalensis*[dr]	Polygonaceae
		0-20	*Deschampsia caespitosa*[dr]	Poaceae
		0-15	*Koeleria cristata*[dr]	Poaceae
		0-20	*Agropyron* sp.[dr]	Poaceae

[fl]flowering, [fr]fruiting, [dr]drying and withering

Table 4.4. Total biomass (air-dry matter) and dead biomass (as measured in the field) of different functional groups per pasture site, recorded before starting the respective experimental measurements (Sites 1 and 5: 12 cuttings in n=4 paddocks; Sites 2-4: 18 cuttings in n=6 paddocks)[y]

Functional group[y]	Site					SEM	*P*-value
	1	2	3	4	5		

Biomass (g/m^2)							
Total air-dry weight	107^{c}	231^{a}	122^{bc}	199^{ab}	96^{c}	20.0	<0.001
Functional groups^{y}							
Poaceae (%)	6^{b}	34^{a}	31^{a}	36^{a}	51^{a}	5.5	<0.001
Cyperaceae (%)	<1^{b}	22^{a}	27^{a}	24^{a}	16^{ab}	3.7	<0.001
Herbs (%)	92^{a}	43^{b}	39^{b}	40^{b}	34^{b}	4.6	<0.001

$^{a-c}$Means within the same row without a common superscript differ (*P*<0.05).
^{y}Remainder to 100% are 'others' (ferns, small shrubs, mosses) which are not shown.

Table 4.5. Chemical composition (g/kg dry matter) of the forage selected by the experimental animals. Values are means of samples pooled over 7 d of sampling with two samples per paddock (A, B), resulting in n=8 for Sites 1 and 5 and n=12 for Sites 2, 3 and 4.

Site	Organic matter	Crude protein	Neutral detergent fiber	Acid detergent fiber^{x}	Acid detergent lignin^{x}	Hemicellulose^{y}	Cellulose^{z}
1	881	260	452	312	94	140	218
2	813	218	550	373	139	177	234
3	916	190	581	338	87	243	251
4	902	196	597	363	106	234	257
5	917	91	690	423	85	268	338

^{x}A and B samples per paddock and site were pooled before analysis resulting in n=2.
^{y}Hemicellulose= neutral detergent fiber – acid detergent fiber.
^{z}Cellulose= acid detergent fiber – acid detergent lignin.

Performance of the animals

There were various effects of site, SD and genotype in the traits describing performance of the animals (Table 4.6). In the crossbreds, only site had an effect (*P*<0.05) on initial BW, while it remained unaffected (*P*>0.1) by SD. Across SD, BW increased significantly from Sites 1 to 3, and remained unchanged compared to Site 3 at Sites 4 and 5. There was daily BW gain at Sites 1 and 2 and at Site 4, whereas there was a BW loss at Sites 3 and 5.

Across SD, MY was initially maintained (Fig. 4.1). It then decreased from the transition to Site 3 onwards. A SD being twice as high as the low SD led to massive reductions (*P*<0.05) in MY. For the individual sites, the difference accounted for declines of 18, 33, 25, 34 and 39% compared to the crossbreds kept at low SD. The 'per site' analysis (Figure 4.1) showed a significant effect (*P*<0.05) of SD from Site 2 onwards, while there was only a trend (*P*=0.08) for the effect of SD at Site 1. Still the milk production per unit of pasture area available per animal (see Table 1) was higher with high SD on average of all sites (Table 6). Site, but not SD, had an effect on the contents of fat, protein and lactose in the milk of the crossbreds. Across SD, milk fat content at first increased (*P*<0.05) from Site 1 to Sites 2 and 3 where this level was maintained (*P*>0.05), and increased again (*P*<0.05) at Site 4 remaining similar at Site 5 (*P*>0.05, data not shown in table). Across SD, protein content decreased from Site 1 to 2 (*P*<0.05), was then maintained

(*P*>0.05) and decreased (*P*<0.05) again on Site 5 (data not shown). Across SD, lactose content was highest on Site 1 and lowest on Site 4 (*P*<0.05). Taken into considerations the concomitant decline in MY, protein and lactose yields massively decreased with time (*P*<0.05). The same trend was also found for fat yield, meaning that the decline in MY was slightly overriding the concomitant increase in fat content, especially when moving to Site 5. As there was no effect (*P*>0.1) of SD on milk gross constituents, this resulted in daily yields that were lower with high SD compared to low SD similarly to total MY (Fig. 4.1).

In comparison to yaks, crossbreds were overall heavier (*P*<0.05). The genotype difference in BW change was not significant; however, there was a large variability in the data due to the BW loss of the crossbreds at Site 3 and a significant interaction of site and genotype. While the crossbreds lost 653 g BW/d at Site 3, which was different (*P*<0.05) from the BW gain of 897 g/d at Site 2, the yaks showed no difference in BW change comparing Site 2 and 3 (728 and 836 g/d, respectively, data not shown in table). Comparing the initial BW of yaks and crossbreds measured at Sites 2 and 4, the crossbreds gained 26 kg across the time, while the yaks increased their BW by 49 kg, with no initial BW differences between the genotypes any more (*P*>0.05) at Site 4 (255 and 235 kg in crossbreds and yaks, respectively, data not shown).

Genotype also had no effect on either MY or ECM yield (Table 4.6). However, there was an interaction of site and genotype with an initially higher (*P*<0.05) ECM yield in the crossbreds (3.97 and 3.11 kg/d in crossbreds and yaks, respectively, at Site 2, data not shown in table). Genotypes did not differ in milk fat content, but crossbreds were inferior (*P*<0.05) to yaks in protein content and lactose content. No significant differences

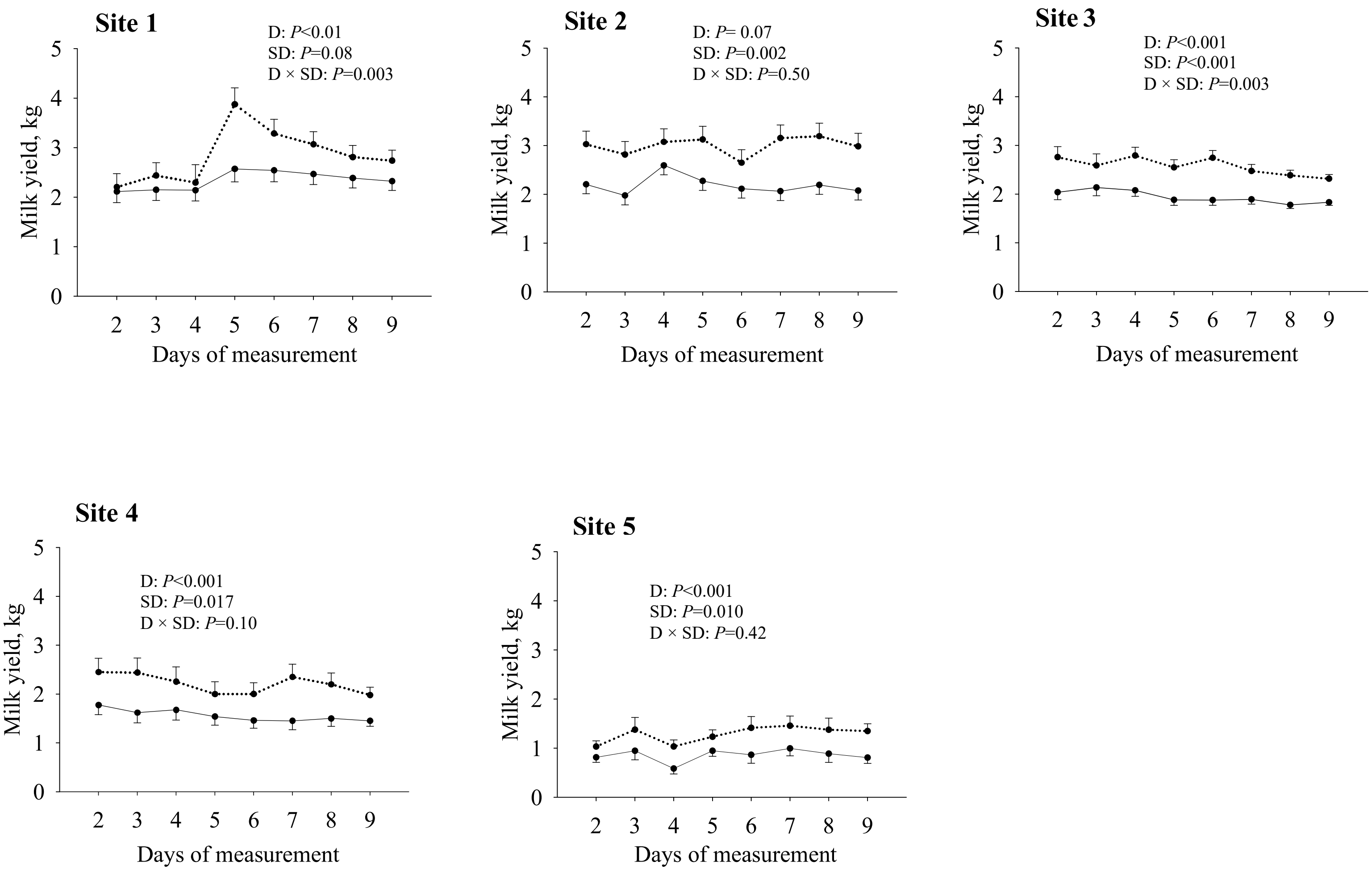


Fig. 4.1. Evolution of daily milk yield of cattle-yak crossbreds kept at two stocking densities (····◊···· low SD; —●— high SD) during the 9 d of experimental period on the five different pasture sites. Error bars represent the standard error of LS means

Table 4.6. Performance of crossbreds kept at low and high stocking densities and in comparison to yaks at the three high altitude pastures sites under low stoking density

		Site (S) and stocking density(SD) effects (crossbreds only)[x]									Site (S) and Genotype (G) effect (low SD only)[y]					
		Site						*P*-values			Genotype			*P*-values		
Traits	SD	1	2	3	4	5	SEM	S	SD	S×SD	Crossbreds	Yak[z]	SEM	G	S	G × S
Initial body weight (kg)	low	201de	229^{abc}	255^{ab}	255^{ab}	262^{ab}	7.7	<0.001	0.98	0.60	247	210	6.1	<0.001	<0.001	0.25
	high	202^{ce}	229^{bd}	261^{a}	259^{a}	251^{ab}										
Body weight change (g/d)	low	1290^{a}	897^{a}	-653^{b}	347^{ab}	-497^{b}	238.6	<0.001	0.73	0.62	197	588	220.5	0.23	0.014	<0.001
	high	673^{a}	834^{a}	-447^{b}	458^{ab}	-451^{b}										
Milk (kg/d)	low	2.90^{ab}	3.14^{a}	2.42^{b}	2.21^{bcd}	1.42^{efg}	0.15	<0.001	0.011	0.28	2.62	2.23	0.14	0.17	0.002	0.041
	high	2.38^{ab}	2.10^{bce}	1.82^{cde}	1.46^{df}	0.87^{g}										
Energy-corrected milk (ECM, kg/d)	low	3.55^{ab}	3.99^{a}	3.04^{b}	2.94^{bcd}	1.93^{efg}	0.18	<0.001	<0.001	0.13	3.30	3.16	0.05	0.08	0.023	0.006
	high	3.02^{bc}	2.73^{bce}	2.40^{cde}	2.07^{df}	1.23^{g}										
Pasture efficiency (g ECM/d and m^2)[z]	low	4.13^{bcd}	2.68^{d}	2.70^{d}	2.80^{bcd}	2.75^{bcd}	0.34	<0.001	<0.001	0.014	2.71	2.66	0.04	0.32	0.003	0.012
	high	7.00^{a}	3.68^{c}	4.27^{b}	3.93^{bcd}	3.50^{bcd}										
Fat (g/d)	low	153^{abc}	182^{a}	139^{b}	144^{bcd}	99^{ef}	8.67	<0.001	<0.001	0.10	155	142	3.90	0.037	0.14	0.002
	high	131^{bcde}	125^{bcde}	112^{cde}	103de	62^{f}										
Protein (g/d)	low	119^{ab}	123^{a}	92^{bcd}	80^{cde}	45^{fg}	5.66	<0.001	<0.001	0.22	98	107	3.58	0.08	0.0004	0.08
	high	101^{abc}	84^{cd}	71^{def}	55^{ef}	30^{g}										
Lactose (g/d)	low	142^{ab}	153^{a}	118^{bcd}	107^{cde}	69^{fgh}	7.73	<0.001	<0.001	0.22	126	114	3.33	0.023	0.0006	0.031
	high	119^{abc}	104^{cdf}	90^{def}	72^{eg}	44^{h}										
Fat (%)	low	5.31^{de}	5.88^{bcde}	5.81^{cde}	6.62^{ab}	7.12^{a}	0.16	<0.001	0.24	0.20	6.10	6.25	0.17	0.55	<0.001	0.019
	high	5.48^{e}	5.99^{bcd}	6.12^{bc}	7.06^{a}	7.05^{a}										
Protein (%)	low	4.16^{ab}	3.92^{abc}	3.85^{abc}	3.65^{bcd}	3.26^{de}	0.12	<0.001	0.56	1.00	3.81	4.68	0.05	<0.001	0.21	0.047
	high	4.22^{a}	3.98^{ab}	3.90^{ab}	3.75^{bd}	3.38^{ce}										
Lactose (%)	low	4.95^{ab}	4.92^{bcd}	4.92^{bcd}	4.90^{cd}	4.92^{bcd}	0.008	<0.001	0.38	0.69	4.92	4.98	0.01	<0.001	0.29	0.24
	high	4.97^{a}	4.93^{bcd}	4.92^{bcd}	4.91^{d}	4.93^{bc}										

[a-g]Means of the same variable and site × stocking density means with a common superscript do not differ significantly (P<0.05).
[w]Evaluated by Model 1.
[x]Evaluated by Model 2. Only values from low stocking density and only from Sites 2 to 4 were used.
[y]As yaks were accompanied by their calves the weigh-suckle-weigh method was applied for evaluating the milk yield (see Materials and Methods).
[z]Calculated as ECM divided by m^2/head of the respective SD per site (see Table 1).

fat content were found in the crossbreds when comparing Sites 2 and 4 (5.88 and 6.62%, respectively), but the yaks had a higher ($P<0.05$) fat content at Site 4 compared to Site 2 (7.07 and 5.26%, respectively). Yields of lactose and protein were affected ($P<0.05$) by pasture site, and lactose also by genotype, and fat amount was affected ($P<0.05$) by genotype. Overall, yaks produced 9 g/d more milk protein, but 13 and 12 g/d less fat and lactose, respectively, compared to the crossbreds.

Activity pattern of the crossbreds

During the time the crossbreds stayed at altitudes between 4000 and 4500 m a.s.l., the number of steps and walking time declined and lying time increased (both $P<0.05$), whereas standing time did not change ($P>0.1$; Table 7). High SD resulted in more steps ($P<0.05$) during the entire day and also when just considering daytime, and, in line with that, walking time increased ($P<0.05$) across the entire day. Standing time was shorter and lying time was longer ($P<0.05$) across the entire day at high SD as compared to low SD (Table 4.7).

Table 4.7. Activity pattern of the crossbreds kept with two different stocking densities (SD; low and high) at the different study sites[y]

			Site (S)				*P*-values		
Period	Activity	SD	2	3	4	SEM	S	SD	S × SD
Entire day	Number of steps	low	6188^{ab}	4458^{c}	3730^{c}	289.1	<0.001	0.008	0.74
		high	7085^{a}	4963^{bc}	4189^{c}				
	Walking (min)	low	434^{ab}	362^{bc}	289^{c}	17.8	<0.001	0.04	0.81
		high	467^{a}	369^{bc}	307^{c}				
	Standing (min)	low	483^{ab}	491^{a}	461^{ab}	20.1	0.73	<0.001	0.67
		high	400^{b}	421^{ab}	418^{ab}				
	Lying (min)	low	400^{c}	464^{bc}	568^{a}	14.5	<0.001	<0.001	0.49
		high	451^{c}	528^{ab}	593^{a}				
Daytime[z]	Number of steps	low	3402^{ab}	3023^{b}	2937^{b}	233.5	0.010	0.015	0.38
		high	4240^{a}	3691^{ab}	3168^{b}				
	Walking (min)	low	267^{ab}	249^{ab}	228^{b}	15.8	0.016	0.08	0.71
		high	304^{a}	275^{ab}	237^{ab}				
	Standing (min)	low	220^{ab}	230^{ab}	282^{a}	12.5	<0.001	<0.001	0.44
		high	183^{b}	184^{b}	273^{a}				
	Lying (min)	low	51^{ab}	60^{ab}	29^{b}	9.5	<0.001	0.56	0.28
		high	52^{ab}	79^{a}	29^{b}				
Night time[z]	Number of steps	low	2786^{a}	1436^{b}	794^{c}	118.9	<0.001	0.53	0.37
		high	2846^{a}	1272^{bc}	1021^{bc}				
	Walking (min)	low	167^{a}	113^{b}	61^{c}	9.5	<0.001	0.64	0.24
		high	164^{a}	94^{bc}	69^{c}				
	Standing (min)	low	263^{a}	262^{a}	179^{bc}	11.2	<0.001	<0.001	0.67
		high	216^{ab}	237^{a}	145^{c}				
	Lying (min)	low	349^{c}	404^{bc}	539^{a}	14.0	<0.001	0.002	0.69
		high	399^{bc}	449^{b}	565^{a}				

[a-d]Means of the same variable for high and low SD across pasture sites without a common superscript differ significantly ($P<0.05$).
[y]No data available from Sites 1 and 5.
[z]Daytime=from morning milking to evening milking+ next day daylight hours before milking (539 = 480 + 59 min, respectively); nighttime= evening milking to morning milking minus next day morning daylight hours (779 min). A period of 122 min/d used for gathering of the animals and milking was excluded.

Discussion

Biomass availability and nutritional value of the pastures depending on site

The standing biomass differed in amount and quality (phenological stage, botanical composition and nutrient composition) between the sites due to season and the site's altitude. Wang et al. (2007) reported a decline of biomass amount with increasing altitude in the Qinghai-Tibetan Plateau. However, the differences in standing biomass across sites found in the present experiment might have been primarily associated with season at the respective altitude in addition to the proportional differences in the plant functional groups. As expected, in the upward movement where the animals followed the vegetation growth, the pastures were still in the earlier stages of growth, as characterized for instance by the prevalence of herbs at Site 1. During the downward movement, vegetation matured and was fully flowering at Site 4. At Site 5, the vegetation was relatively dry and there was only the start of a certain regrowth mostly by grasses underneath the senescent material. The animals mainly selected the green parts. The increasing maturity of the vegetation was associated with a clear decline in nutritional quality of the herbage selected, as shown by the changes in CP and fiber. Several authors (Guo et al., 2012c; Mountousis et al., 2011; Roukos et al., 2011) reported a high nutritive value of the forage available at high altitude from different mountainous areas. However, in the present experiment fiber content was increasing and CP content was decreasing from Site 1 to Site 5. This illustrates that, compared to altitude; the phenological stage was the overriding factor in determining forage quality with an advancement of the maturity stage, mostly during the downward movement (Long et al., 1999; Mountousis et al., 2011). The relatively high CP content found at Site 1 could be related to the early sprouting stage in spring and maybe additionally to the low prevalence of grass species compared to the other sites. The fact that the herbage sampled by the animals is generally of better nutritional quality and thus richer in CP than that of a mixed sample of the whole sward (e.g. Wales et al., 1999), might be an additional explanation for the generally high CP values measured. Barshila and Devkota (2013) found CP values of 210 to 220 g/kg in single species of Poaceae and Cyperaceae collected in July from areas situated near pasture Sites 2 and 4 of the present study. Greenhouse studies yielded values of 250 to 300 g CP/kg (Sinclair et al., 2006) and of up to 330 g CP/kg (Rawnsley et al., 2002) in regrowth of earlier stage in temperate grasses grown under ideal conditions.

Effects of stocking density on performance in cattle-yak crossbreds

Pasture allowance or quality or both (Wales et al., 1999, Bovolenta et al., 2008), together with SD (O'Donovan & Delaby, 2008), have been repeatedly reported to influence MY and milk composition in cattle. In this respect, a higher SD typically decreases yields of total milk, fat, protein and lactose (O'Brien et al., 1999), which is consistent with the present results. The extent of the effect of a higher SD is dependent on the level of exploitation of the available biomass. Biomass had been the target for defining the paddock sizes for the high SD. Even though a certain decline in MY could have been expected simply from the reduced opportunity to choose from the vegetation when keeping the animals in fenced areas, the MY decline of about 30% with high SD is a sign that the border to overstocking had been reached or exceeded. Still, the overall milk production potential of the pastures was about 50% higher than what had been exploited with the low SD. This suggests that overstocking, if any, was not extreme. Although there was an effect of SD on MY and yield of milk constituents, no effect of SD on initial BW or BW change was detected. Thus, a partitioning towards maintenance of milk supply at cost of BW under still moderate feeding conditions as mentioned elsewhere for higher yielding breeds kept on mountainous pastures (Bovolenta et al., 2008) did not occurred in the present study with low yielding genotypes.

Effects of stocking density on activity pattern in cattle-yak crossbreds

Also the activity pattern of the animals was responding to SD. Lying time is considered as an indicator of comfort behavior. Studies in freestall barns (Krawczel et al., 2012; Fregonesi et al., 2007) revealed decreases in lying time with increases in SD above a certain level. Lin et al. (2011) found no effect on total lying time but a significant effect of SD on total standing time of sheep in Inner Mongolia. In that study, standing time was decreased at higher SD during daylight hours. These authors also found an effect of SD on time spent grazing, with an increase with higher SD. Grazing could not be separated from walking or standing (defined as < 4 steps/min) in the present study. However, consistent with the results of Lin et al. (2011), the crossbreds spent more time standing and carried out fewer steps per day at low SD at daytime. This indicated that the lower grazing competition between the individuals inside the paddock was resulting in sufficient feed on offer. Depending on the length and strength of exercise, walking can have a negative effect on MY and composition, at least on the short term (D'Hour et al., 1994). As walking in thin air requires more energy, it can be concluded that energy expenditure was higher for the animals kept in paddocks at high SD.

Effects of site on performance in cattle-yak crossbreds

Concerning MY and composition, the site effect inseparably included not only forage quality and forage allowance but also effects of altitude, and the progressing stage of lactation. Generally, increasing altitudes require more energy to cope with the low oxygen partial pressure and, often, cold climate. This typically impairs MY even at comparably lower altitudes of 2000 m a.s.l. (Leiber et al., 2006; Zemp et al., 1989). Qiao et al. (2012) reported the same in the Tibetan area for Chinese Holstein cattle kept at 1600 m a.s.l. as compared to 3600 m a.s.l. By contrast, Bartl et al. (2009) did not register a clear altitude effect on MY when moving indigenous Criollo and Brown Swiss cows from the Peruvian Andes at 3600 m a.s.l. to the lowlands, maybe as a consequence of the altitude adaptation obtained by being born at high altitude. Similarly, the genotypes investigated in the present study had an inherited altitude adaptation as they were crosses with purebred yaks (Qiu et al., 2012; Wang et al., 2006). Additionally, also the cattle-yak crossbreds used are kept at rather high altitude, and the *Bos taurus* bulls used for crossbreeding originate from high altitude areas in Tibet. As the animals of the present study moved to higher altitudes along with progressing season, the climatic differences compared to those recorded at the lower altitudes were rather low. When lactation stage advances, MY declines and contents of milk constituents increase (Ostersen et al., 1997). In low-yielding genotypes like the ones investigated in the present study, there is no pronounced MY peak in lactation but the changes outlined still take place moderately. Stage of lactation probably explains best why MY did not decline more during the upward movement but during the downward movement in the present study. The downward movement additionally included a considerable decline of forage quality (high in fiber, low in CP) which depressed energy supply and MY even further.

Concerning milk constituents, the typical increase in milk fat content with altitude (Leiber et al., 2006; Wu et al., 2009), was found when moving the animals from 3200 to 4000 m a.s.l. (from Site 1 to Site 2) but no further increase was found when moving the animals to Site 3. During the downward movement, milk fat content further increased. This latter increase was probably the result of both, progressing stage of lactation and increasing fiber content of the forage which promotes the formation of the most important precursor of milk fat, acetate, in the rumen (Storry and Sutton, 1969). Milk protein content is a good indicator of the supply with ruminally fermentable energy and a metabolic deficiency of energy and protein (Rook and Line, 1961). Accordingly, milk protein typically declines with increasing altitude (Leiber et al., 2005 and 2006) and with low forage quality (Rook and Line, 1961). However, the decline in milk protein with altitude found in the present study (from Site 1 to Site 2) was comparably low. The large decline at Site 5, where stage of lactation and lower altitude were expected to counteract such a decline, suggests that the low forage quality was the clearly overriding factor.

Body weight changes are other indicators of energy supply. Accordingly, both the highest altitude (Site 3) and Site 5 caused a certain energy deficiency in the crossbreds, the first likely because of hypoxia (Bianca, 1976) and the last due to the low forage quality. Altitude-caused BW losses have been found repeatedly in cattle even at 2000 m a.s.l. (Zemp et al., 1989a), which indicates that the high altitude tolerance of the crossbreds was surpassed at 4500 m a.s.l. whereas fully adapted animals staying mostly at very high altitude do not show such weight losses (Bartl et al., 2009; Qiao et al., 2012) as was also shown by the genotype comparison in the present study.

Effects of site on behavior in cattle-yak crossbreds

The general site effect on number of steps taken might also be related to actual paddock sizes, having for instance the biggest size at Site 2. The trend towards increasing times spent lying and the concomitant decrease of walking from Sites 2 to 4, however, might indicate an increasing degree of comfort of the crossbreds when returning to the lower altitude on Site 4, or, more likely, an increase in the time spent ruminating due to the decrease in forage quality. The BW gain found on Site 4 as compared to Site 3 also indicates that this was a return to comfortable altitudes for this genotype.

The frequent moving from one pasture to another along an altitudinal gradient, which is characteristic for transhumant systems, may have been more stressful at high SD as it was accompanied by concomitant restrictions in forage on offer.

Effects of genotype on performance

Yaks are especially well adapted to high altitude environments characterized by hypoxic conditions, cold weather and often scarce forage on offer (see Wiener et al., 2003). He et al. (2011) reported a clearly higher MY in yak × yellow cattle crossbreds as compared to yaks, although the crossbreds in that study were advanced in lactation which also explains the similar contents of fat, protein and lactose in the milk of both genotypes. In the present experiment using *B. taurus* × *B. grunniens* crossbreds, the crossbreds were overall not clearly superior to yaks in MY, especially when considering the higher concentration of milk gross constituents by comparing genotypes on basis of ECM yield. There was an interaction of site and genotype with an initially higher ECM yield in the crossbreds. The observation that this initial difference was leveled out from Site 3 onwards, which was at the highest altitude of 4500 m, is a hint for the better adaptation of yaks to high altitude. Own unpublished results from a study carried out later in the same region in Nepal at 4700 m a.s.l. in May provided similar differences between these two genotypes in ECM yield but a higher fat content of the yak milk. The loss of BW at Site 3 in the crossbreds, but not in the yaks, is another sign for the better high altitude tolerance of the yaks compared to the crossbreds. While the crossbreds numerically lost 2.3 and 1.5% BW across the 9 d of measurement period at low and high SD on the high altitude Site 3, respectively, the yaks had gained 3.8% BW (data not shown in table).

Conclusions

The findings revealed that a high stocking density even during a short period of 9 days clearly limited the individuals' milk yield, had long-term and recurrent effects on milk yield (in the time between the experimental periods the animals were allowed to graze freely) and forced animals to spend more time walking, likely to gather enough feed. Both are signs of overstocking. Still farmers could be motivated to apply such a high stocking density because the individual milk yield loss was compensated by a concomitantly about 50% higher overall productivity per m^2 of pasture area in terms of milk yield. However, this might – on the longer term –lead to heavily damaged pastures difficult to restore. The present data could help to establish thresholds for sustainable stocking densities along transhumance routes as they also provide information on grazing pattern at various altitudes and characteristics of the swards in the high Himalayan area. Different from the assumptions, the performance of the crossbreds was overall not superior to that of the yaks at the same low stocking density. At the highest altitudinal site at 4500 m, the yaks even seemed to have an advantage to the crossbeds as shown by maintaining body weight and better ECM. It seems that the crossbreds surpassed their comfort zone at altitudes of 4000 m and beyond.

Chapter 5

Ability to adapt to high altitude of different yak crossbreds (*Bos taurus* × *B. grunniens* and *B. grunniens* × *B. indicus*)

in comparison to yaks (*B. grunniens*) grazing Himalayan pastures

Based on: S. R. Barsila, M. Kreuzer, N.R. Devkota, L. Ding and S. Marquardt; submitted to Journal of Animal Science.

Abstract

Yak-cattle crossbreds are common in the Himalaya, but it is unclear if the crossbreds inherit the adaptability to high altitude inherent to yaks. Therefore, the effect of high (4700 m) and medium (3050 m) altitude on yaks (*Bos grunniens*) and 2 types of yak-cattle crossbreds (*B. taurus* × *B. grunniens* (Dimjo) and *B. indicus* × *B. grunniens* (Urang)) was investigated in the eastern Himalayan mountains of Nepal. Six lactating multiparous females of each group were selected based on similarity of milk yield. The experimental periods lasted for 12 d and 14 d at high and medium altitude in August and October, respectively, each including an adaptation period and 6 d of measurement. Portable equipment was used to measure milk yield and composition, body weight (BW), heart and respiration rate, rectal temperature, blood indicators (in capillary blood) and movement behaviour. Data were statistically analyzed considering altitude, genotype and their interaction, and additionally daytime when variables were measured twice daily. Blood hemoglobin level was highest for yaks followed by Dimjos and Urangs. Blood glucose level was lower at high altitude (6.2 vs. 7.6 mmol/l) where it was initially higher (P<0.05) in Dimjos as compared to Urangs. Clear group differences were found for lactate at high altitude, both at the beginning and at the end, with yaks having the lowest and Urangs the highest values (P<0.05). These differences were leveled out at the end of the measurement period at medium altitude. Heart rate was higher and heart rate variability was smaller at high than at medium altitude. Respiration rate was highest in the evening and rectal temperature in the morning for all three groups at high altitude. Both were overall highest in yaks. At high altitude, the animals spent overall more time (min/24 h; P<0.05) standing (931) and less time lying (333) than at medium altitude (608 and 603, respectively), with the least altitude differences in the yaks. Only the yaks showed BW gain during the measurement period at high altitude. Yaks and Urangs lost weight between the high and the medium altitude period. Yields of milk, milk fat and milk protein declined from high to medium altitude, influenced by stage of lactation, and were highest in Dimjos. Yak milk had the highest fat content, especially at medium altitude. The present results showed that both crossbreds had a lower high altitude tolerance as the yaks, but that Dimjos were superior to Urangs.

Introduction

Yak-cattle crossbreeding is a common practice in the northern parts of Nepal (Joshi, 1982) because of the crossbred's higher milk yield compared to purebred yaks and their utility for lower altitudes (Dong et al., 2009b). These females, called Chauris (Degen et al., 2007), can be distinguished into Dimjos, the F1 offspring of male cattle (*Bos taurus* or *B. indicus)* crossed with female yaks, and Urangs, sired by yaks and the dam being cattle (Joshi, 1982). Yaks and crossbreds migrate in transhumance systems from lower to high altitude pastures in spring/summer and reversed in autumn/winter (Dong et al., 2009b). In yaks, various genetic (Qiu et al., 2012), physiological (Durmowicz et al., 1993; Kuang et al., 2010) and morphological (Shao et al., 2010) traits of high altitude adaptation are known. Also cattle have some adaptive mechanisms (Bianca and Näf, 1979; Christen et al., 1996), and long-term adaptation allows keeping cattle even at altitudes up to around 4000 m as practiced in the Andes (Bartl et al., 2009). It is, however, unclear in how far yak-cattle crossbreds inherit high altitude adaptive traits of the yaks and whether this depends on the cattle origin. The latter is likely because some crossbred types (yak bulls × *B. indicus* dams) are typically kept at lower altitudes in Nepal, whereas others (Tibetan bulls × yak dams) are commonly moved to higher altitudes.

The hypotheses tested in the present experiment were (i) that there is a difference between crossbreds and yaks in high altitude tolerance, and (ii) that, in their adaptive capacity, crossbreds differ when either both or only 1 parent is of high altitude origin and, at the same time, yaks are the dam or the sire breed. For that purpose, indicators of metabolic and behavioral adaptation as well as performance were measured in three genotypes at two altitudes.

Materials and Methods

Experimental Design

Grazing sites

The experiment was conducted at 2 pasture sites situated in the Kanchenjunga Conservation Area (KCA) of the Taplejung District in Nepal. Both pastures are traditionally used by local herders. The first site, further on called 'high altitude' was located at 4700 to 5100 m above sea level (a.s.l.) (Nawang valley; milking area: 27'44°52 N to 87'42°32 E, 4710 m a.s.l). The measurements there were realized in August 2011 (summer). The second measurement period was conducted in October/November 2011 (early winter) at 3000 to 3300 m (Dhanje pasture of Olangchung Gola; milking site: 27'40°25 N to 87'46°58 E, 3050 m). This site, further on called 'medium altitude', was situated at the lowest altitudinal level where yaks are kept in that region. The high altitude site was situated above the tree line and consisted of alpine grassland vegetation. It was free of shrubs and had a size of about 6 ha. During the experimental period, this site was only used by the 18 experimental animals. Three water sources were accessible to the animals, 2 small glacial lakes and 1 creek fed by molten ice. The medium altitude pasture was surrounded by pine forest and contained temperate to subalpine grassland vegetation with sporadic appearance of mainly unpalatable shrubs. It was thus semi-open and had a size of approx. 4 ha as measured by the Forest Office (C. Sherpa, herder, Olangchung Gola, Nepal, personal communication). There, 1 creek was available as water source. During the experimental period this site was used by the 18 experimental animals and by 20 crossbreds not included in the experiment. The vegetation on this pasture was already in a senescent stage. Most of the herbs were dry, and the grasses and legumes were of yellowish-green to brown color. However, there was still some green grass available.

Experimental animals

Six adult lactating multiparous (5th and 6th parity) females were used per group, and the same 18 animals were employed at both altitudes. One group was represented by purebred yaks (*B. grunniens*, locally called 'naks', n=6), and the other 2 groups consisted of 2 different yak-cattle crossbred types, n=6 each, namely Dimjos (*Bos taurus* (♂) × *B. grunniens* (♀)) and Urangs (*B. grunniens* (♂) × *B. indicus* (♀)). As crossbreeding of female yaks with *B. indicus* hill cattle bulls is not practiced, it was not possible to exclude maternal or cattle specific effects (*B. indicus* vs. *B. taurus*) in the present study. The experimental yaks and Dimjos were selected in mid-July 2011 from larger herds kept at grazing sites belonging to Olangchung Gola at some 4000 m a.s.l. The Urangs were selected 1 wk before selecting the other 2 genotypes from a herd kept in the Gyabla region of KCA at 3100 m. Urangs were immediately moved to Olangchung Gola. Yaks (accompanied by their calves during the entire experiment), Dimjos and Urangs (both without calves) were selected from herds consisting of 15, 24 and 23 lactating animals, respectively. The aim was to select groups with similar daily milk yield within and, in the crossbreds, also between groups. The averages measured on 2 consecutive days at the time of selection were 1.11±0.03 (without milk amounts suckled by the calves), 3.13±0.05 and 3.03±0.11 kg/d for yaks, Dimjos and Urangs, respectively. Calving times were at the beginning (Urangs), middle (Dimjos), and end of April (yaks). The Urangs from the Gyabla region are normally kept between 2000 and 4000 m. The herds, where Dimjos and yaks originated from, normally cover altitudinal ranges from 2400 to 4500 and 3500 to 5000 m, respectively, throughout the year. Animal caretaking and experimental procedures imposed onto the animals were performed meeting the 'International Guiding Principles for Biomedical Research Involving Animals' as issued by the Council for International Organizations of Medical Sciences. The animals were always kept in free range following herders' practices. Procedures imposed consisted of fixing of the measurement tools (pedometers or heart rate measurement belts) on the animals, performing measurements of respiration rate and rectal temperature, milking and blood sampling by experienced staff.

Time schedule

The up- and downward movement of the experimental animals after selection is illustrated in Fig. 5.1. The experimental periods (marked in gray) had durations of 12 d and 14 d at high and medium altitude, respectively. Both periods consisted of a time for adaptation to the respective altitude (6 d and

8 d, respectively), followed by 6 d of measurement each. Before and in between the two experimental periods the animals grazed together with other yaks or crossbreds. A number of portable electronic equipments were used. Batteries were recharged with the help of portable sun collectors.

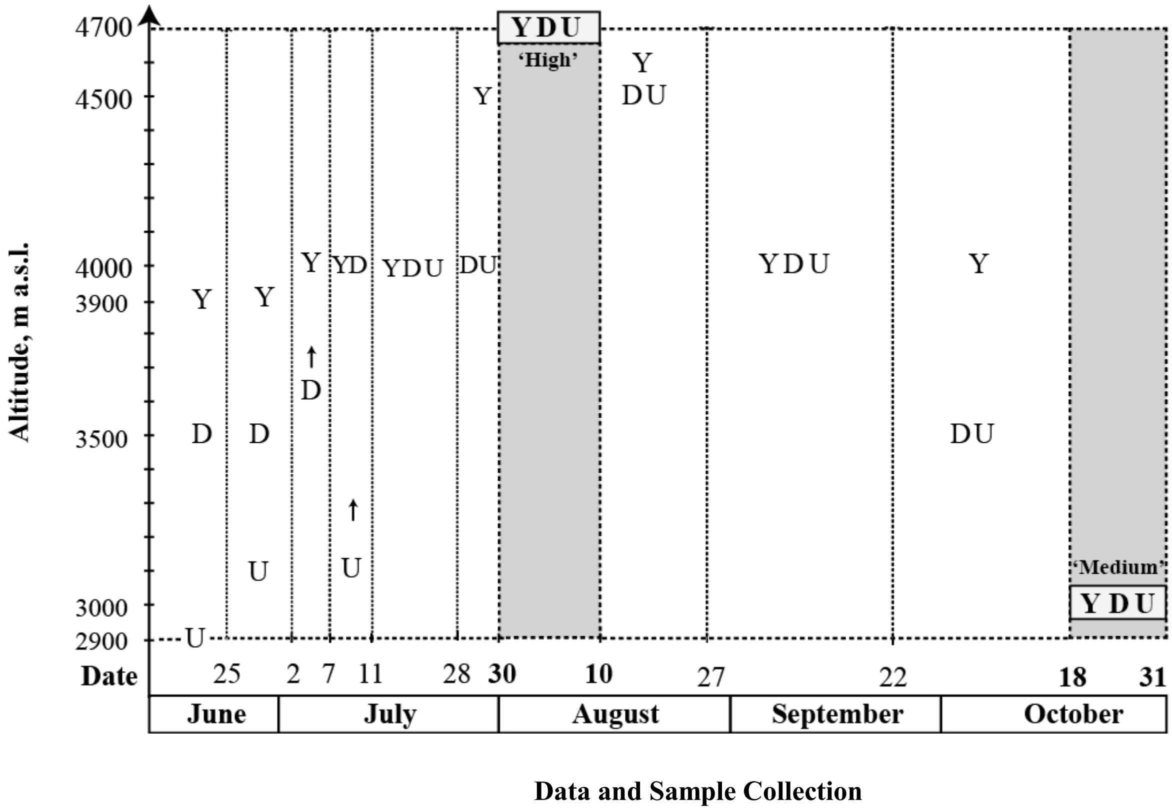


Figure 5.1. Altitude-time diagram. Grey shaded areas characterize the experimental periods each consisting of adaptation and measurement periods at high and medium altitude, respectively. Y, yak; D, Dimjo; U, Urang.

Climate recordings

A local weather station was installed near the milking area at both pasture sites on a post of 1 m height fitted with a roof. On top of the roof a rain gauge was installed. A thermometer and a hygrometer were attached to the post right underneath the roof. The climate data were recorded during the entire 12 or 14 d of experimental period at high and medium altitude, respectively. Minimum and maximum temperature and relative humidity were recorded daily at 0630 h, 1330 h and 1730 h and the lowest and highest values per day are displayed in Table 1. Precipitation was assessed once daily at 0630 h, not taking into account evaporation loss. For estimating potential thermal stress, the 'modified temperature-humidity index for yaks' (**THI**) described by Krishnan et al. (2009a) was calculated as 0.8 × ambient temperature (°C) + ((relative humidity (%)/100) × (ambient temperature (°C) 14.3)) + 46.4. According to Krishnan et al. (2009a), values >52 are out of the comfort zone for yaks resulting in heat stress. The entire day was separated into night (1730 to 0630 h), morning (0630 to 1330 h) and afternoon (1330 to 1830 h). The values for maximum temperature recorded during the respective daytime and data for relative humidity measured at 0630 h, 1330 h and 1730 h, respectively, were used for calculation of THI (Table 5.1).

Table 5.1. Climate data and temperature humidity index recorded during the adaptation and measurement periods at high and medium altitude

Site	Climate data				Temperature humidity index[5]			Observation
Period	T_{min}[1] (°C)	T_{max}[2] (°C)	H_{rel}[3] (%)	Precipitation[4] (mm)	Night	Morning	Afternoon	
Date								
High altitude site								
Adaptation								
30	–[6]	–	–	–	–	–	–	–
31	-1	14	63±13	15	41.9	57.5	45.8	Cloudy

01	0	8	64±11	20	40.2	49.3	44.8	Cloudy
02	0	9	59±16	5	38.4	51.0	47.1	Cloudy
03	-3	11	62±13	25	43.3	53.6	44.8	Cloudy
04	-3	9	62±18	5	41.4	51.2	46.2	Cloudy
05	-3	8	66±13	10	38.0	49.3	47.5	Cloudy
06	-2	11	70±13	25	40.8	53.2	48.7	Cloudy
07	-1	8	71±8	20	43.0	48.6	48.5	Cloudy
08	-3	9	70±14	15	37.4	50.4	48.7	Cloudy
09	-3	11	63±15	25	38.2	53.6	50.4	Cloudy
10	0	10	69±19	20	43.9	52.3	49.9	Cloudy
Medium altitude site								
Adaptation								
18	–	–	–	–	–	–	–	Frost /open
19	3	12	60±5	1	44.4	54.6	48.0	Frost/ open
20	2	13	61±11	5	42.3	56.0	49.7	Frost/open
21	3	14	63±14	0	43.4	57.4	51.1	Partly cloudy
22	2	12	63±16	7	44.6	54.6	49.8	Partly cloudy
23	3	13	65±14	0	46.1	56.0	50.7	Frost/open
24	4	14	65±18	0	47.4	57.4	52.3	Frost/open
25	5	15	65±15	2	49.4	58.9	52.3	Rainfall
26	6	15	63±20	2	50.7	58.8	52.5	Rainfall
27	4	11	67±13	0	47.8	53.1	50.7	Light frost
28	5	12	67±12	1	49.4	54.6	50.4	Rainfall
29	2	9	65±14	2	44.5	50.4	49.3	Rainfall
30	-1	8	62±13	1	41.9	49.0	49.7	Light snow
31	-2	9[7]	57±13	2	40.9	47.3	51.2	Snowfall

[1]Minimum temperature; data recorded at 0630 h.
[2]Maximum temperature, recorded at 1330 h.
[3]Relative humidity, mean value and standard deviation calculated from the data measured at 0630 h, 1330 h and 1730 h.
[4]Measured at 0630 h, thus mostly from the day before.
[5]Index as modified for yaks by Krishnan et al. (2009a), using T_{max} instead of ambient temperature.
[6]No data recorded.
[7]T_{max} recorded at 1730 h.

Blood sampling and analysis

Blood obtained by puncturing the ear (capillary blood) was sampled per animal and site immediately on the day of arrival at the respective altitude (i.e., d 1 of the adaptation period), and 1 d after completing the measurement period. Sampling was realized between 1100 h and 1200 h and 1200 h and 1300 h at high and medium altitude, respectively. The animals were allowed to graze before blood sampling. The samples were analyzed in duplicate immediately for hemoglobin (HemoCue Hb 201+, HemoCue AB, Ångelholm, Sweden), glucose (Accu-Chek Aviva, Roche Diagnostics, Mannheim, Germany) and lactic acid (Accutrend Plus, Roche Diagnostics, Mannheim, Germany). The point-of-care devices used were designed for the analysis of human blood. However, these or similar devices have also been used by others in livestock research (e.g., Magona et al., 2004; Fenhammar et al., 2011; Probst et al., 2013).

Heart rate and heart rate variability

Heart rate (**HR**) and heart rate variability (**HRV**) were measured as indicators of energy expenditure and general, unspecific stress imposed by the environment (altitudinal, climatic and nutritional constraints). The root mean square of successive differences in inter-beats intervals (**RMSSD**) was used as indicator of HRV (von Borell et al., 2007) as it had been already used in several studies with different ruminant species (e.g. Aschwanden et al., 2008). Data were obtained by a total of 3 Polar Equine CS600X Trotting instruments (Polar Electro Oy, Kempele, Finland). The applicability of this device for yaks had been tested in advance on a yak kept in Switzerland. The devices were fitted to 1 different animal per genotype per day. This eventually allowed obtaining 1 daily record per animal and site in the 6-d measurement periods. On the day before measurement, the animals were sheared using a portable hand-shear. Before attaching the heart belt, the animals' skin surface was moistened with common ECG gel and water in order to ensure the contact between electrodes and animal skin. Afterwards, on top of the Polar belt a moistened nylon belt was placed in order to fix the electrodes. The polar watch was put into a water-proof bag and was attached to the nylon belt. The devices were set for data recordings at 15 s intervals and activated just before the morning milking. The devices were controlled at least 3 times during daytime and restarted in case of loss of signal. The belts were removed after the evening milking, resulting in 8 to 11 h of recording. The cardiac data were analyzed using the Polar software (ProTrainer 5 Equine Edition, Version 5.35.161). The dataset from the first hour was excluded from analysis to account for the need of familiarization of the animals to the measurement tool (Mohr et al., 2002, von Borell et al., 2007). Cardiac data were initially screened for irregularities. For the remaining data, an error correction was performed to exclude artifacts by allowing only ≤ 10% errors. Bias in the HR analysis possibly occurring due to different physical activities of the experimental animals (see von Borell et al., 2007) was avoided by first synchronizing measurement of cardiac and behavior data (see below) and selecting always 5-min segments following von Borell et al. (2007). For this, at first ≥10-min segments of standing activity were identified, from which at least the first 3 min and the last min were excluded to avoid bias by previous and subsequent activities.. If the first standing period could not be used, the next one was used and analyzed as described. The first 2 standing periods each fitting to these criteria recorded in the morning (before 1200 h, average value of both periods) and afternoon (after 1200 h, averaged) were averaged and used for data analysis per animal and site for analysis. This resulted in n=6 for yaks at both altitudes, n=5 and n=4 for Dimjos, and n=6 and n=3 for Urangs at high and medium altitude, respectively.

Respiration rate and rectal temperature

During the 6-d measurement periods, respiration rate (**RR**) and rectal temperature (**RT**) were measured per animal after milking (between 0700 and 0830 h as well as 0800 and 0930 h in the morning, and 1700 and 1830 h as well as 1600 and 1730 h in the evening at high and medium altitude, respectively). For measuring RR, a common stethoscope was placed on both sides of the flank for 1 min each, and breaths/min were counted. The RT was measured for 1 min by inserting a clinical thermometer 5 to 6 cm into the rectum. The averages of 2 consecutive measurements of RR and RT were calculated for morning and evening. The 6-d averages per animal per altitude per daytime were used for statistical analysis.

Activity Behavior

The times spent standing and lying as well as the number of steps were recorded during the measurement periods at both sites using pedometers (IceTag, IceRobotics Ltd., Edinburgh, UK). In total, 9 pedometers were used and fitted to the right hind legs of 3 animals per genotype for 48 h each. This meant 2 × 2 d of measurement for the first 3 animals per genotype (d 1 and 2 as well as d 5 and 6; data later averaged) and 1× 2 d (d 3 and 4) of measurement for the remaining group members. The devices were fitted or removed just after the morning milking. The period between 1200 h of the respective first and 1200 h at the respective second day were used for data analysis (1440 min per animal and altitude). The activity records were additionally sub-divided into daytime (1200 h to 1759 h and 0700 h to 1159 h) and nighttime (1800 h to 0659 h) for analysis. As each animal was similarly exposed to milking and animal handling, these short periods of disturbance by human intervention were not excluded from the data set. No data were available for 1 Dimjo at high altitude. Records were evaluated per min (Aharoni et al., 2009) with the help of the software IceTag Analyser 2008 (IceRobotics Ltd., UK) for the times 'lying' (horizontal position) and 'standing' (vertical position) and the number of steps. In order to differentiate between 'standing' and 'walking', the activity 'standing' (as defined by the IceTag Analyser software) was assumed to have taken place when ≤ 3 steps/min were recorded. Grazing was included in both, standing and walking activities. The activity pattern per min was classified by the type of activity with the highest proportion (Bewley et al., 2010). Total times per activity per animal either during the entire 24 h or daytime or night were used for statistical analysis.

Body weight

The animals were weighed using a digital balance (model BH-300X, Aditsan, New Delhi, India) covering a weight range of up to 300 kg and having an accuracy of ± 0.02 kg. The measurements were done just after milking in the morning of d 1 of the measurement periods (initial BW) and on the evening of d 6 of the measurement period (final BW; altogether 5.5 d). The difference was used to calculate daily BW change. The animals were not fasted before weighing.

Milk yield and composition

On the last 2 d of the adaptation period and during the entire 6-d measurement periods at each site, milk yield was recorded at each milking (two times per day in the crossbreds, only in the morning in the yaks following herders' practices). For this purpose, a portable digital balance (Scout Pro, Ohaus, Pine Brooks, NJ) with a weight range of up to 4 kg and an accuracy of ± 0.1 g was used. For milking, the animals were moved to the milking area and allowed to rest without human intervention for approx. 30

min. Milking started with the first animal available. Occasionally, animals had to be collected and milked later so that it could happen that milking lasted up to 2 h. Always the same local herders performed the milking by hand after binding either the hind legs (crossbreds) or the front legs (yaks) of the animals together (herders' practice). In order to assess the milk amount suckled by the yak calves, a weigh-suckle-weigh method was applied. The calves were allowed to approach their dam for 5 min in order to stimulate milk let-down and then tied in front of the dam. After milking, calves were allowed to suckle the residual milk. This procedure underestimated total milk yield as the calves were not restricted from suckling during the rest of the daytime. However, during the nights the yak calves were separated from the dams and kept in provisional barns.

Milk was analyzed after each milking event using a portable ultrasonic milk analyzer (Lactoscan SA-L, Milkotronic Limited, Nova Zagora, Bulgaria). The measurements were done with the setting for 'cow'. Fat, protein and lactose contents were calibrated using regression equations obtained from 25 milk samples originating from 25 different European *B. taurus* breeds (6 Brown Swiss, 1 Red Holstein, 17 Holstein and 1 Jersey). These samples were analyzed both by the portable device used in the experiment and by the standard Milkoscan 4000 (Foss Electric, Hillerød, Denmark). The following regressions were used: fat adjusted = 0.891 × fat (%) + 0.188; protein adjusted = 3.222 × protein (%) – 6.544; lactose adjusted = 0.159 × lactose (%) + 4.196. The energy corrected milk (ECM, kg/d) was calculated as milk (kg/d) × (0.38 × fat % + 0.24 × protein % + 0.17 × lactose %)/3.14 (ALP, 2013). For the crossbreds, average daily contents were calculated by considering aliquots of morning and evening milk amounts.

Statistical Analysis

The Mixed procedure of SAS (SAS Institute, Carry, USA, 2009 version 9.3) and 2 different models were used for statistical analysis. Model (1) reads as follows:

$$Y_{ijk} = \mu + A_i + G_j + (A \times G)_{ij} + E(G)_{jk} + \varepsilon_{ijkl}$$

Where, A = altitude, G = Genotype, and A × G the interaction. All effects were treated as fixed. Experimental animal (E = repetition) was nested within genotype as subject and altitude was set as repeated variable. Model 1 was applied for data on milk yield and milk composition, BW, and on the behavioral and cardiac data. For HR, RMSSD and behavioral data the weighted LSmeans were calculated considering the unequal number of values when generating the averages per animal. Cardiac data were subjected to logarithmic transformation before performing the ANOVA. Tables and figures display the non-transformed LSmeans and SE. For milk yield, and milk composition, the 6-d averages per animal and altitude were used for statistical analysis. Milk yield recorded in the animals at the time of animal selection was used as co-variable. In case of the yaks, milk suckled by the calves estimated at high altitude was used for calculation of this covariable, because the weigh-suckle-weigh procedure had not been applied during yak selection.

For the analysis of blood variables, rectal temperature (RT) and respiration rate (RT), measured at 2 different daytimes at both altitudes, Model (2) was applied:

$$Y_{ijk} = \mu + A_i + G_j + T_k + (A \times G)_{ij} + (A \times T)_{ik} + (G \times T)_{jk} + (A \times G \times T)_{ijk} + E(G)_{jl} + \varepsilon_{ijklm}.$$

Model (2) is an extension of Model (1) with the introduction of T = time and all possible interactions as fixed effects. For RT and RR the 6-d averages per animal, time and altitude were used for analysis. A random effect was estimated to account for the 2 repeated within-subject factors 'altitude' and 'time' (Moser, 2004). Data are given as LSmeans and SE and raw data were used for creating the boxplots using SigmaPlot 12.2 (Systat Software Inc., San Jose, CA).

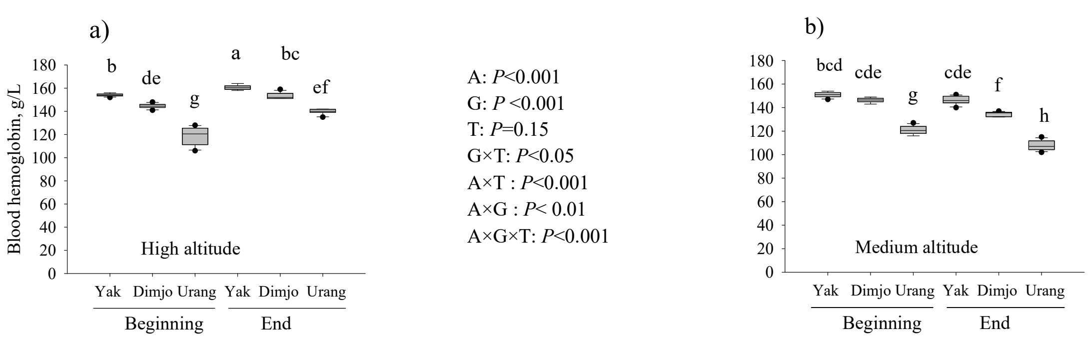
Results

Climate

During the high altitude experimental period, the sky was cloudy during most of the time. At medium altitude frost occurred on some days in the early morning (Table 5.1). Values for THI of >52.0 were found every morning of the adaptation period at medium altitude and for 2 d at high altitude, and of 3 d of the measurement periods at both altitudes. At medium altitude, THI was slightly higher than 52.0 during 3 d of the experimental period in the afternoon (Table 5.1).

Metabolic Indicators in Blood

At high altitude, yaks initially had the highest blood hemoglobin levels, followed by Dimjos, whereas Urangs had the lowest levels (Fig. 5.2a). During the 12 d of stay at high altitude, hemoglobin increased ($P<0.05$) in all 3 genotypes. At medium altitude, hemoglobin was still high in all groups ($P>0.05$ as compared to the initial values at high altitude). During the 14 d at medium altitude, it declined ($P<0.05$) in the crossbreds but not in the yaks (Fig. 5.2b). Across altitudes and times, blood hemoglobin levels were higher ($P<0.05$) in yaks than in Dimjos or Urangs (153, 145 and 122 g/L, respectively; data not shown). The initial blood glucose level at high altitude was higher in Dimjos than Urangs ($P<0.01$), with the value measured in yaks being intermediate ($P>0.05$, Fig. 2c). Glucose decreased ($P<0.05$) with time in all 3 genotypes at high altitude and was similar at the end of the measurement period. At medium altitude, glucose was initially similar between genotypes and was maintained for Dimjos and Urangs, but decreased ($P<0.05$) in the yaks at the end of the 14 d at medium altitude (Fig. 5.2d). Across all genotypes and times, glucose level was lower ($P<0.001$) at higher altitude than at medium altitude (6.2 vs. 7.6 mmol/L; data not shown). Blood lactate levels were highest ($P<0.05$) for Urangs, followed by Dimjos and then yaks at both measurement times at high altitude (Fig. 5.2e). Still, lactate decreased ($P<0.05$) with time in all 3 genotypes. At medium altitude, lactate levels were similar between Dimjos and Urangs and the level remained stable with time (Fig. 5.2f). In yaks, initial blood lactate values at medium altitude were found to be as high as for the Urangs when arriving at high altitude ($P>0.05$), but levels in yaks then declined over time to those measured in the crossbreds, but being still higher than at high altitude in the yaks.



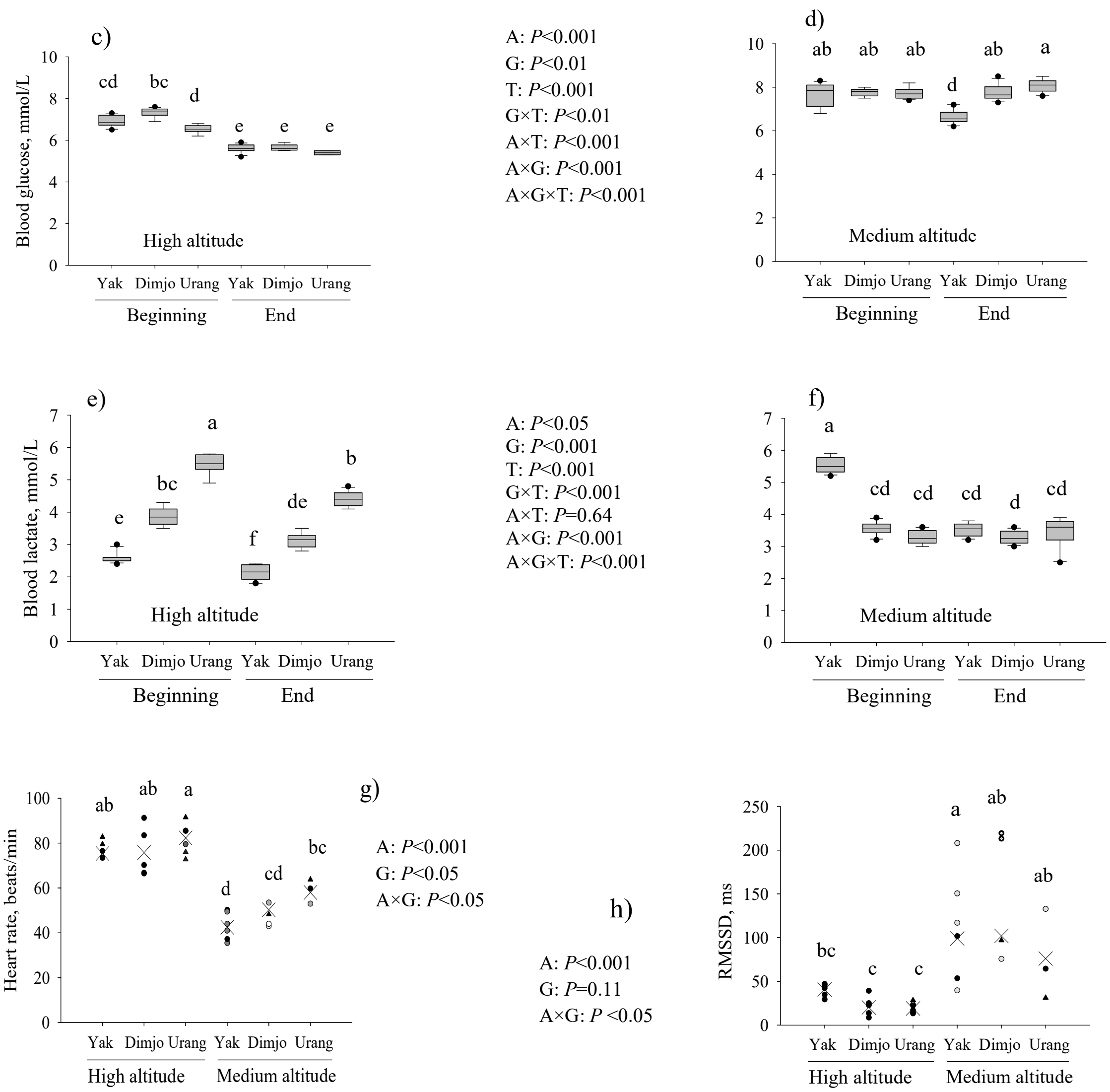


Figure 5.2. Capillary blood hemoglobin (a, b), glucose (c, d), and lactate (e, f) levels measured at the beginning of the adaptation period ('Beginning') and after the measurement period ('End') as well as heart rate (g) and root mean square of successive differences in inter-beats intervals (RMSSD) (h) during standing of the animals as measured at 4700 (high) and 3050 (medium) m a.s.l. Means (blood parameter) and weighted LSmeans (×**;** cardiac parameters, showing values for the single animals) are displayed. ●, ▲, , ○, represent data based on 4, 3, 2 and 1 measurement per animal, respectively. A, altitude; G, genotype; T, time of measurement. [a-h]LS means without a common superscript differ ($P < 0.05$) within variable.

Cardiac variables, respiration rate and rectal temperature

At high altitude, the HR was higher ($P<0.001$) than at medium altitude (78 vs. 50 beats/min, respectively; Fig. 5.2g). There was no difference ($P>0.05$) in HR among the 3 genotypes at high altitude. At medium altitude, the Urangs had the highest HR ($P<0.05$ compared to yaks). The RMSSD was lower at high altitude than at medium altitude ($P<0.001$, 27 ms and 92 ms, respectively). The between-animal variability in RMSSD at medium altitude was much higher than the genotype differences (Fig. 5.2h). The morning RR was in the range of 22 to 25 breaths/min and was similar between the genotypes and across altitudes (Table 2). In the evening, the RR measured at high altitude was higher ($P<0.05$) for all genotypes than the RR in any other measurement. It was highest ($P<0.05$) for yaks followed by Dimjos and Urangs. No corresponding difference between the genotypes was found in evening RR at medium altitude. Overall, RT was significantly higher across genotypes at high than at medium altitude (38.3 vs. 37.7 °C; data not shown). The highest RT was measured in yaks in the morning at high altitude (Table 5.2).

Activity behavior

Altitude affected ($P<0.001$) the time spent standing and lying during the entire 24 h and during the night (Table 5.3). At high altitude, overall more time was spent standing during the 24 h than at medium altitude (931 vs. 608 min), whereas the lying time was shorter (333 vs. 603 min; data not shown in Table). At high altitude, yaks spent more ($P<0.05$) time lying and less ($P<0.05$) time standing during 24 h than the Urangs. The Dimjos showed an intermediate behavior. Both crossbreds spent more ($P<0.05$) time lying at medium compared to high altitude during 24 h and at night, whereas this was not significant in the yaks. At medium altitude, no genotype differences were observed in standing and lying behavior. Most of the lying occurred during the night (72, 58 and 57 % at high altitude and 83, 88 and 81 % at the medium altitude site for yaks, Dimjos and Urangs, respectively; data not shown). Only altitude had an effect ($P<0.05$) on the time spent walking during 24 h and during the daytime. In general, the animals spent more time walking at medium altitude than at high altitude (229 vs. 176 min; data not shown).

Performance

Yaks always had a lower ($P<0.05$) BW than the 2 crossbreds (Table 5.4). The Dimjos maintained their BW throughout the experiment, whereas the yaks and Urangs had initially a lower ($P<0.05$) BW at the medium altitude as compared to initial BW measured at the high altitude site. However, during the high altitude stay, yaks gained weight whereas both crossbreds similarly lost weight ($P<0.05$ compared to yaks). Overall, milk yield and ECM were higher ($P<0.05$) at high than at medium altitude, and higher ($P<0.05$) for Dimjos than for Urangs at both altitudes. Yaks had a lower ($P<0.05$) ECM than the Dimjos at the high altitude site (being similar to the Urangs). At medium altitude, yaks had the lowest ($P<0.05$) ECM yield.

Milk yield differences were well reflected in yields of the major milk constituents. The milk fat content was always highest ($P<0.05$) in yaks followed by Dimjos and Urangs. It did not change much between altitudes for Dimjos, but increased ($P<0.05$) in yaks and Urangs from high to medium altitude, resulting in an overall altitude effect ($P<0.05$). Milk protein content declined ($P<0.05$) from high to medium altitude. There were no general group effects on milk protein content, but at medium altitude the yaks, differently from high altitude, had the lowest ($P<0.05$) protein content among the 3 genotypes (genotype × site interaction, $P<0.01$). The milk lactose content decreased ($P<0.05$) in yaks and Urangs, but not in Dimjos, from high to medium altitude (genotype × site interaction, $P<0.01$).

Table 5.2. LSmeans of respiration rate and rectal temperature measured in yaks, Dimjos and Urangs (n=6 each) at high and medium altitude separately by morning and evening measurement

	High altitude			Medium altitude				*P*-values						
Item	Yak	Dimjo	Urang	Yak	Dimjo	Urang	SE	G	A	T	G×A	G×T	A×T	G×A×T
Respiration rate (breaths/min)														
Morning	24.8[d]	24.3[de]	23.4[de]	23.2[de]	22.2[def]	22.5[def]	0.50	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Evening	51.0[a]	40.4[b]	31.6[c]	20.5[f]	20.5[f]	21.6[ef]								
Rectal temperature (°C)														
Morning	38.7[a]	38.3[b]	38.2[bcd]	38.1[de]	37.5[fg]	37.4[g]	0.03	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	0.011
Evening	38.3[bc]	38.2[cde]	38.0[e]	38.2[bcde]	37.6[f]	37.5[fg]								

[a-g]Within a variable, least square means without a common superscript differ ($P<0.05$).
G=Genotype, A=Altitude, T=Time of measurement (i.e., morning, evening).

Table 5.3. Weighted LSmeans of the activity variables measured in yaks (n=6), Dimjos =5) and Urangs (n=6) during 24 h (1200 h to 1159 h) and separated by daytime (1200 h to 1759 h plus 0700 h to 1159 h) and nighttime (1800 h to 0659 h) at high and medium altitude.

	High altitude			Medium altitude				*P*-values		
Activity (min)	Yak	Dimjo	Urang	Yak	Dimjo	Urang	SE	Genotype	Site	Genotype × site
24 h										
Standing	786^{bc}	935^{ab}	1074^{a}	615^{c}	586^{c}	624^{c}	53.4	0.073	<0.001	0.022
Walking	214	154	159	207	234	245	30.0	0.90	0.021	0.14
Lying	440^{ab}	351^{bc}	207^{c}	618^{a}	620^{a}	571^{ab}	48.0	0.040	<0.001	0.14
Steps (no.)	3004	2746	2658	2667	2779	2813	364.9	0.97	0.83	0.65
Daytime										
Standing	406^{ab}	404^{ab}	441^{a}	398^{ab}	397^{ab}	362^{b}	21.9	0.99	0.011	0.022
Walking	129	107	129	160	186	190	22.2	0.81	0.007	0.56
Lying	125	149	90	102	77	108	18.3	0.64	0.14	0.12
Steps (no.)	1856	1869	2260	2077	2105	2159	251.6	0.66	0.52	0.69
Nighttime										
Standing	380^{bc}	531^{ab}	633^{a}	217^{c}	189^{c}	262^{c}	42.7	0.009	<0.001	0.061
Walking	85	47	30	47	48	55	13.1	0.27	0.65	0.037
Lying	315^{bc}	202^{c}	117^{c}	516^{ab}	543^{a}	463^{ab}	47.0	0.036	<0.001	0.27
Steps (no.)	1148	877	398	590	674	654	171.5	0.21	0.18	0.039

$^{a-c}$ Within a row, least square means without a common superscript differ ($P<0.05$).

Table 5.4. LSmeans of the variables describing the performance measured in yaks, Dimjos and Urangs (n=6 each) at high and medium altitude

	High altitude			Medium altitude				*P*-values		
Parameter	Yak	Dimjo	Urang	Yak	Dimjo	Urang	SE	Genotype	Site	Genotype × site
BW										
Initial (kg)	244^{c}	259^{a}	256^{a}	229^{d}	258^{a}	251^{b}	1.19	<0.001	<0.001	<0.001
Change (g/d)[1]	330^{a}	-591^{bc}	-664^{bc}	-88^{ab}	-618^{bc}	-1088^{c}	126.9	<0.001	0.027	0.32
Milk yield[2] (per day)										
Absolute (kg)[3]	2.11^{ab}	2.47^{a}	2.06^{b}	0.76^{cd}	1.24^{c}	0.79^{d}	0.10	<0.001	<0.001	0.30
Energy corrected (kg)	2.78^{b}	3.48^{a}	2.60^{b}	0.91^{e}	1.81^{c}	1.13^{d}	0.05	<0.001	<0.001	0.012
Fat (g)	135^{b}	167^{a}	115^{c}	49^{e}	90^{d}	55^{e}	2.56	<0.001	<0.001	0.001
Protein (g)	81^{b}	102^{a}	83^{b}	20^{e}	48^{c}	31^{d}	1.77	<0.001	<0.001	0.20
Lactose (g)	97^{b}	126^{a}	105^{b}	30^{e}	65^{c}	42^{d}	1.76	<0.001	<0.001	0.27
Milk composition (%)										
Fat	6.91^{b}	6.56^{cd}	5.43^{e}	8.19^{a}	6.75^{bc}	6.37^{d}	0.05	<0.001	<0.001	<0.001
Protein	4.10^{a}	3.95^{a}	3.88^{ab}	3.34^{d}	3.60^{c}	3.61^{bc}	0.06	0.49	<0.001	0.011
Lactose	4.94^{a}	4.92^{ab}	4.92^{ab}	4.88^{d}	4.90^{bc}	4.89^{cd}	0.005	0.099	<0.001	0.009

[a-d]Within a row, least square means without a common superscript differ (P<0.05).
[1]Calculated from BW measured on Day 6 (evening) minus BW measured on Day 1 (morning).
[2]Yaks only milked in the morning; milk amount suckled by the calves during that time estimated by the weigh-suckle-weigh method.
[3]Using milk yield data obtained during selection of the animals as covariate.

Discussion

With increasing altitude mammals are forced to first respond with a higher RR and HR to cope with the increasingly anoxic conditions (Hock, 1970). From research with humans it is known that they respond to high altitude conditions (here: normobaric hypoxia) with an increased sympathetic activity which is manifested by a decrease in HRV and an increase in HR (Wille et al., 2012). These changes may be associated with an increase in body temperature which was seen as a sign for elevated blood circulation efforts in ruminants (Bianca and Näf, 1978). A slower increase in red blood cells and hemoglobin follows, allowing respiration and heart rate to slow down again. The response in these criteria should obviously be low when the animal's genotype is already adapted to high altitude conditions as it is known for yaks. Apart from the anoxic conditions, high altitude is often associated with cold and wind which together massively increase energy expenditure. This is indicated by low blood glucose and elevated blood lactate produced in anaerobic muscle metabolism (Kreuzer et al., 1998). The latter may also indicate stress (Mitchell et al., 1988, Apple et al., 2005). As a result of these boundary conditions also moving behavior and performance of insufficiently altitude adapted animals could be impaired.

Yaks developed special adaptive mechanisms to cope with these conditions, such as increments in heart and lung size, thus also having a proportionately larger chest than cattle (reviewed by Wiener et al., 2003). Adaptive traits of yaks related to the cold include a thick hair coat and mostly nonfunctional sweat glands, which is why high ambient temperature may be more stressful than very high altitude (Wiener et al., 2003). There were no major differences in adaptive traits between local cattle kept at high altitude and exotic breeds or crosses with them maintained at the same altitude (3600 m, Bartl et al., 2009; 2700 m, Wuletaw et al., 2011), but this might be different when comparing yaks and its crossbreds. The present study compared 2 different crossbred genotypes with yaks (Dimjos and Urangs) at 2 different altitudes in terms of productive and adaptive potential. Dimjos are commonly kept at higher altitude in the eastern Himalayan part of Nepal due to the availability of *B. taurus* bulls (Tibetan cattle, locally called Bhelang) from the nearby Tibetan area where this *B. taurus* genotype is kept at the slopes concluding the Tibetan plateau (Dong et al., 2009b). However, their actual origin is unclear (Palmieri, 1987). The Urangs are more prevalent in the lower mountains where yak bulls are crossed with the largely available *B. indicus* cows of the common hill cattle breed usually kept at 500 to 2500 m in Nepal.

Physiological responses of the genotypes to altitude

Respiration rate

Genotype differences were only observed at high altitude, where RR was generally higher in the evening than in the morning in all genotypes, this particularly in the yaks. The Dimjos were intermediate between yaks and Urangs in evening RR. This could be an indication for a more active regulation of respiration in yaks, but also Dimjos, which up-regulates their RR to cope better with the high oxygen demands at high altitude as compared to the Urangs. However, the reason for the lack of a corresponding difference in the morning remains unclear. Chetri et al. (2011) measured RR of 20 and 48 breaths/min in Dimjos at 3365 m and 1655 m, respectively, and considered the increase of RR at the lower altitude as sign of discomfort as it was below the lowest range of 2000 m used for Dimjo keeping. In the present study, yaks and crossbreds had to walk for about 1 h to the milking place in the evening, differently to the morning when the animals stayed near the milking area during the night. Ramesha et al. (2009) measured RR of yaks before (18 to 22 breaths/min) and after (43 to 57 breaths/min) walking with weight load. These values are roughly within the range of the RR measured in the present study where, however, the animals were treated equally at high and medium altitude, and were allowed to rest for 30 min before starting the measurements. This would imply that the high evening RR at 4700 m did not exclusively result from the evening walk. Bianca and Näf (1979), using partial vacuum in climate chambers to isolate the effects of altitude from those of ambient temperature, found an increase of RR with altitude alone and, additionally, a correlation of 0.49 between RR and ambient temperature. The cold-adapted yaks depend on evaporation via the upper respiratory tract to get rid of heat load (Wiener et al., 2003). In the present experiment, the threshold of the critical temperature-humidity index of 52 (Krishnan et al., 2009a) was occasionally exceeded; this, however, probably only during short periods (keeping in mind that maximum temperatures had been used for calculation) and especially at medium altitude where no elevated RR was observed in the yaks.

Body temperature

There was a downward gradient in rectal temperature being from yaks to Dimjos and Urangs at both altitudes. At high altitude in the early morning, the Urangs were observed to be shivering, with the hair erected. Rectal temperature was higher at high altitude than at medium altitude in all genotypes. This has also been shown experimentally in cattle exposed to artificial anoxic conditions equivalent to 4000 m (Bianca and Näf, 1978, 1979). Low ambient temperatures were additionally found to increase RT (Bianca and Näf, 1979). Consistent with this and the corresponding minimum ambient temperatures, RT was higher in the morning than in the evening in all three genotypes at high but not at medium altitude.

Heart rate, heart rate variability and energy expenditure

The HR was clearly higher at high than at medium altitude. Bianca and Näf (1978) as well as Hays et al. (1978) also observed a rise in HR when exposing cattle to simulated altitudes of 3500 to 4000 m as compared to 400 m. Better adapted genotypes should respond less in HR to higher altitude. Accordingly, Anand et al. (1986) at 4500 m measured HR (beats/min) of 53, 77 and 73 in yaks, local cattle and Urang-type yak-cattle crossbreds, respectively. The values measured at 4700 m in the present study fall within this range, but did not differ between yaks and crossbreds. However, consistent with Anand et al. (1986), yaks had a lower HR at medium altitude than Urangs. The HR is correlated with energy expenditure (heat production) as was shown in cattle (Han et al., 2003; Brosh, 2007; Brosh et al., 2010) and yaks (Han et al., 2002). Chinese yellow cattle (Han et al., 2003), other than yaks (Han et al., 2002), were found to increase the daily fasting heat production with increasing altitude in summer. Different from cattle, yaks may even decrease metabolism and energy expenditure in the cold winter (Han et al., 2002, 2003). Only very crude assumptions on EE can be drawn from the present data as only HR and no O_2 consumption (Brosh, 2007) was recorded, and this only for a low number of resting bouts per animal. However, the higher HR at high altitude found points to an elevated energy expenditure at 4700 m, and the lack of genotype differences in HR at 4700 m suggest that yak-cattle crossbreds might be less impaired in high altitude tolerance than what is known for cattle. Yet, the difference in HR of yaks and Urangs measured at 3000 m is consistent with Han et al. (2002, 2003). The RMSSD values measured in the present study as a variable describing HRV were generally higher than the values reported for cattle elsewhere (Mohr et al., 2002, Hagen et al., 2005), especially at medium altitude. The latter indicates a lower stress level at the lower altitude. To the authors' knowledge, no reports of RMSSD in yaks or cattle exposed to high altitude are available. No genotype differences were found for RMSSD, which however might be also related to the low number of repetitions and the large between-animal variability at medium altitude. At high altitude, RMSSD was numerically smaller in the crossbreds, especially the Urangs, than in the yaks. However, more repetitions are needed to clarify if genotype really has an influence on RMSSD depending on altitude as was indicated by the significant altitude × genotype interaction.

Metabolic energy status

Across both measurement times and genotypes, glucose was lower at high altitude which might be related to energy deficiency resulting from hypoxia (Kreuzer et al., 1998). Although not assessed by analysis, forage quality can be excluded as an explanatory factor because the vegetation was still in a favorable phenological stage at high altitude whereas maturity and frost impaired forage quality at medium altitude. Concerning lactate, exposure to high altitude may also increase blood levels (Hays et al., 1978b). Imposing different forms of stress related to animal handling (transport, slaughter: Mitchell et al., 1988; transport to a different altitude: Kreuzer et al., 1998; restraint and isolation: Apple et al., 2005) is also known to increased lactate. Thus the clear genotype differences found in blood lactate level at high altitude (Urangs > Dimjos > yaks) illustrated their different sensitivity to anoxic conditions in muscle metabolism. Levels slightly and similarly decreased in all genotypes during the 12 d of stay at 4700 m suggest a certain adaptation. At medium altitude, lactate was similar and low with exception of those from the yaks after arriving at medium altitude. The latter is difficult to explain but would suggest yaks were initially unusually stressed when moved to this altitude which is the lowest level used for yak grazing in that region.

Oxygen uptake capacity of the blood

The low oxygen partial pressure at high altitude demands either high hemoglobin content or a reduced pulmonary-arterial resistance or both. The latter was not measured in the present study, but Anand et al. (1986) actually found a lower resistance in yaks compared to local cattle at 4500 m. Consistent with the first assumption, yaks had the highest hemoglobin levels, which were lowest in the Urangs and intermediate in the Dimjos. These differences persisted throughout the entire high altitude stay, even though hemoglobin significantly increased in all 3 genotpyes as expected (Hays et al., 1978a; Claxton and Ortiz, 1996; Pourouchottamane et al., 2004). At medium altitude the high hemoglobin level was maintained with time in the yaks, whereas it declined in the crossbreds. This further confirms that yaks are well adapted to hypoxic conditions.

Influence of genotype on activity behavior at different altitudes

In the present experiment, yaks were hypothesized to be in better state of comfort than the crossbreds at high altitude. Lying time is an important indicator of animal welfare (see Phillips, 2002) and is expected to account for about 40 % of the daily activities in cows kept on pasture or in freestall barns (Sambraus, 1978). In a study by Brosh et al. (2010) in the Mediterranean area, lying time accounted for 23-30% of total time, unaffected by season. In the present study, 40 to 43 % of the daily time budget was spent for lying at medium altitude, whereas only 31, 24 and 14 % were spent lying at high altitude by yaks, Dimjos and Urangs, respectively. This was compensated by different standing times. Resting activities are also related to the animals' energy budget. During cold weather, especially at night when solar radiation is absent, lying might be advantageous as a means of sparing energy through a lower convective heat loss (Olson and Wallander, 2002). Vercoe (1973) estimated an almost 20 % higher heat production when cattle were standing as compared to lying. At high altitude, especially the Urangs spent more time standing and less time lying than the yaks. Differences between cattle breeds in lying time have been also reported elsewhere (Njoka-Njiru and Guliye, 2001; Dodzi and Muchenje, 2012). The genotype differences in standing and walking activities at high altitude were more pronounced during the night. Grazing was not separated as an activity and thus probably was covered by standing and walking activities. Therefore, it cannot be excluded that the Urangs extended their grazing time after sunset. Nevertheless, it seems that the crossbreds were in a better state of comfort at medium than at high altitude. The overall longer time spent walking at medium altitude might be related to the poor quality forage on offer needing more time for searching. Dimjos were observed to enter the forested areas surrounding the pasture site at medium altitude frequently but briefly. This behavior was less pronounced in the Urangs and not observed in the yaks which prefer open pasture.

Influence of genotype on performance at different altitudes

Milk yield and maintenance of body weight

Considering milk yield and the change in BW from high to medium altitude, as measured directly upon arrival, Dimjos were superior to Urangs. This is consistent with the physiological data. However, Urangs had calved on average about 1-2 wk earlier than Dimjos which might have slightly added to these differences. Yaks were lowest in milk yield consistent with their typically low milk yield and rather short lactation period. However, the comparison between the yaks and the crossbreds in terms of milk yield has to be made with care, as (i) they had calved later than the crossbreds and were therefore nearer to peak production and (ii) because the milk suckled by the calf from around 0900 h to about 1830 h resp. 1730 h at high and medium altitude, respectively, could not be recorded. However, as the calves were separated from the dams overnight, it is likely that a major part of the milk was consumed in the morning. The general decline in milk yield from high to medium altitude can be mainly attributed to the progressing stage of lactation and partly to the lower feed quality (higher maturity) of the vegetation at medium altitude. Starting with a lower BW than the crossbreds, yaks were able to maintain their BW during the stay at high altitude, whereas this was not the case in the crossbreds. However, when comparing initial BW at high and medium altitude, the genotype differences were not as clear, because the Dimjos were obviously able to maintain average BW best and the yaks lost most BW during the downwards movement from high to medium altitude.

Milk Composition

Consistent with the expected genotype differences, the milk fat content was higher in yaks than in both crossbreds at both altitudes. Within crossbreds, fat content was higher in Dimjos than in Urangs. Milk at medium altitude had a higher fat content than at high altitude in yaks and Urangs, though not in Dimjos. This increase was primarily due to the ongoing stage of lactation and the reduced milk yield in October, accompanied by the more mature (fibrous) forage on offer. Similar to He et al. (2011), comparing yak vs. yak × yellow cattle crossbreds, no overall genotype differences in contents of protein and lactose in milk was found. Wu et al. (2009) found roughly similar contents (%) in yak milk collected at 4300 m in July as compared to the values measured in the present study (7.14 vs. 6.91 for fat, 4.98 vs. 4.10 for protein and 4.97 vs. 4.94 for lactose, respectively). The decrease in milk protein content found in the present study when moving the animals to medium altitude indicates a severe shortage in energy and protein supply (Brun-Lafleur et al., 2010) which overrode the reduced requirements for the formation of these milk constituents because of the progressing stage of lactation. Qiao et al. (2012) found no effect of altitude on milk protein content in Chinese Holstein cows kept either at 3600 or 1600 m, but described a clear increase in milk protein with diets of higher quality.

Possible reasons for genotype differences in high altitude tolerance

The yaks were better adapted to the high altitude site than both types of crossbred. This became obvious from the results found in the physiological traits (high levels of hemoglobin, low blood lactate levels) and BW gain at 4700 m. As there was no purebred cattle group, the position of the crossbreds in the distance between the purebreds cannot be determined, but the difference between the two crossbred genotypes shows that part of the range was likely covered. Heterosis is known for yak-cattle crossbreds like that in performance (Wang et al., 1994a, 1994b), but it still has to be clarified whether traits important for altitude tolerance are also affected by heterosis. There was a clear difference in high altitude tolerance between the crossbreds. The Dimjos were superior in metabolic response to high altitude compared to the Urangs, and Dimjos almost reached the adaptive capacity of the yaks. They were also better performing than the Urangs. One likely explanation is that also the Tibetan *B. taurus* breed, kept at rather high altitudes since long, also developed adaptive traits which are inherited and thus gives the corresponding crossbreds an advantage compared to crosses with common Nepalese hill cattle. However, with the present data it was not possible to differentiate this from either maternal effects as for instance know for certain milk traits (Schutz et al., 1992) or cattle specific effects (*B. taurus* vs. *B. indicus*) or both. Clarifying the reasons for the seemingly better adaptability of Dimjos over Urangs in traits related to adaptation to altitude needs performing a specific long-term crossbreeding experiment.

This doctoral research project pointed out the ways forward to improvement of transhumant yaks and their crossbreds used for milk production in the Himalayan Mountains of Nepal. At first, the livestock production system, attitude of herders/ farmers on pasture and transhumant management were documented in the household questionnaire survey (case study). Further, two biological experiments were carried out as to show the best alternatives to increase the milk production potential of Dimjos (*Bos taurus* × *Bos grunniens*) in comparison to purebred yaks at two basic management regimes, first under stocking density management (performance study), and second the selection of altitude adapted crossbred genotypes (adaptation study) followed in a selected transhumant route commonly used by the local yaks and crossbreds herders in KCA. The performance study was simulated with the common mode of seasonal movement of herds with using five pastures across the altitudinal gradients (2600-4500m) i.e. upward and downward movement. The upward movement was realized for experiments at 3200 (May), 4000 (July) and 4500 m (August) and the downward movement again at 4000m (September) and finally at 2600 m (Oct./Nov.). No any changes were made in herder's traditional herd movement schedule across the pasture sites to represent almost the entire lactation. Different from that, the available crossbreds (Dimjo and Urangs) were compared at two different altitudes (4700 m and 3000 m) for their adaptive capacity among each other and with yaks (adaption study). The milk and body weight performance, behavioral changes and the animals' ability for metabolic and physiological adjustments at two altitudes have been compared.

Implications from the household survey

As a case study, it is well understood that KCA has a diverse groups of bovine species traditionally used for household milk production. The use of high altitude summer pastures with yaks is further overlapped by use with crossbreds mostly in between 4000-4500m. Although, rearing yaks and their crossbreds is still a viable business for these animal rearing households in KCA. In the perception of the respondents, crossbreds can produce almost the double amount of butter-fat than yaks with having similar prices (3-4 USD/kg) during the entire lactation, which is a benefit over rearing yaks. Raw milk selling was observed very occasional and the opportunistic price for yak milk was noticed 2-3 times higher than that of hill cattle. The majority of the respondents were positively viewed on rangeland improvement, a support which can definitely be an asset for future pasture development activities across the KCA. The genotypic distribution of bovines found was altitude- and site-specific. Crossbred production is a frequently applied traditional business based on the availability of the Tibetan cattle bulls (*Bos taurus*) and or hill cattle (*Bos indicus*) (Joshi, 1982), though they were recorded in small numbers only. As much of the Himalayan herders of Nepal prefer the Dimjo genotype of crossbreds (Joshi, 1982), the Dimjo holding households were also found proportionately larger than the Urangs holding households across the survey sites.

Implications from the performance study

The stocking density management is a useful and widely used tool in pasture-based dairy systems and has been negotiated for higher milk production, also without impairing the reproductive efficiency (Macdonald et al., 2008). There is also evidence of increasing stocking rate as a reason for a decreased lactation length in dairy cows (McCarthy et al., 2011). The crossbreds have a longer lactation period than the yaks and thus annually produce definitely more milk than the purebred yaks. It is clear that the low SD results in a significantly higher individual milk yield production at similar changes in body weight and no reduction in milk constituents. Milk yield per unit of pasture area has also been found less for low SD Dimjos in this study. Simialr cases have been also reported by Mayne et al. (1987); and Macdonald et al. (2008) for dairy cows. At cost of pasture damage at high SD, low SD with Dimjos is definitely an ideal system for increased milk production on per unit pasture where grazing lands are too seasonal and limited as in KCA of Nepal. High milk yield during upward movement upto 4000 m in July and maintenance of weight loss at 4500 m in August again maintained at 4000 m in September well provided the hints for the altitudinal suitability of Dimjos upto 4000 m and beyond as influenced by the lactation stage. The decreased SNF, protein and lactose content at low altitude pastures could be related to the decline of pasture nutrient density (Rook et al., 1992). It is also visible that the body weight of the crossbreds were significantly declined at the highest altitude (4500m) pasture in August and maintained at 4000 m in September. The changes in body weight of the crossbreds across the pasture sites would have certain significances on physiological traits and overall body condition and, with that, milk yield.

The crossbreds maintained at low SD for higher milk yield even were not proved better than yaks for grazing at high altitude pastures above 4000m. Milk yield and body weight of yaks were consistent and with higher milk fat and protein content across the pasture sites. But at the same time, the milk yield and body weight declined in crossbreds during upward movement from 4000-4500 m. It was further revealed that lying time at low SD was high at cost of walking as compared to high SD crossbreds. Long standing (Huzzey et al., 2005) and walking (D'Hour et al., 1994) duration has been expressed as indicators of stress in cattle, while lying time as the best indicator of cow comfort (Gibbons et al., 2012). Vegetation at high SD paddocks was likely more exploited than paddocks with low SD. This can be expected from the higher walking/number of steps at high SD. The high SD has thus surely forced to alter the foraging behavior of animals (Yoshihara et al., 2009) as a consequences of increased competition between individuals, and time needed for search of acceptable forage increased (Orr et al., 2004). However, post-grazing biomass in paddocks was not measured at all in the performance comparison of high and low density stocked crossbreds (Dimjos).

Implications from the adaptation study

The crossbreds and yaks are separately herded by the herders in general, although they could be kept together while at grazing in main season of pasture growth (July-September) at high altitudes (4000-4500 m).

The yaks are very well adapted to high altitudes, reported elsewhere due to several mechanisms behind the logic (Durmowicz et al., 1993; Kuang et al., 2010; Shao et al., 2010; Qiu et al., 2012). In the present project, the yaks also proved to be better adapted at high altitude than the crossbreds due to their superior metabolic and physiological performances and more suitable behavior and for having higher milk fat and weight gain in general.

Crossbreeding has the advantage of heterosis effects on milk production (Wang et al., 1994a). The adaptation study clearly showed the genotype differences in performance, physiologic and metabolic traits of two F_1 crossbreds (Dimjos and Urangs) in comparison to the purebred yaks. In comparison to Urangs, Dimjos better capitalized heterosis especially at high altitude as has been observed from its higher milk yield and milk fat content. The same is true for blood metabolic and physiologic state (mainly the RR and RT) of the Dimzos in comparison to Urangs. Other experiments with dairy cattle adapted to very high altitude, showed no effect of altitude on milk yield with changes in fat content in the Andes (Bartl et al., 2009) and without change in fat content in Tibet (Qiao et al., 2012), but rather the genotypic differences with the significant changes in daily milk yield and fat content viewed well in the adaptation study.

The metabolic and physiological shifts during high altitude conditions have been well observed in the genotypes studied. The blood glucose and lactate level declined sharply at the end of measurement at high altitude; however, the blood lactate remained in the order of being highest for Urangs, intermediate to Dimzos and the least for yaks. This further proves that the yaks had a very low demand of anaerobic energy as compared to the crossbreds and better metabolic state of Dimzos over Urangs. The cyclical and rhythmic variation in respiration rate might have been an indication of differences in energy utilization pattern at high altitude conditions, but that needs further confirmation by synchronizing results with meteorological observations and by long term measurements. A high respiration rate could be associated to high oxygen intake (and lowered blood lactate at the end of measurement) at high altitude. Data showed that all genotypes were somewhat capable for aerobic energy production but persisted in the order of highest for yaks, Dimjos and Urangs respectively. The high rectal temperature in the morning could be a direct response to morning cold as there was still limited physical activity of animals during and around the time of milking.

Animal activity pattern has a major role in comfort behavior. The day time was utilized for grazing by all genotypes but rather rarely slow (few steps/walking time) at night. As the steps performed and walking time were statistically similar between the genotypes at night, discomfort is exhibited by standing and it seems that the less comfort at night affected the whole day comfort of Urangs based on observation of lying time at high altitude. The better comfort of the crossbreds at medium altitude can be concluded well from their increased lying time (Gibbons et al., 2012) at cost of standing in general.The genotype differences in lying and standing, but similarity in walking increased the demand for rest and were stressed by the hypoxia at high altitude conditions which is depicted by the longer time of Urangs for total time hours. Later, time periods across the genotypes for walking at high altitude indicated further differences in time for search of pasture. The increased walking time of crossbred at low altitude might reduce milk yield due to the need for more partition of energy towards walking (Osuji, 1974). Though the increased lying time at medium altitude is clearly due to the favorable altitude compared to the high altitude site, part of the effects could also have been due to the advancing lactation (Chaplin and Munksgaard, 2001).

The significant rise in blood glucose level at medium altitude can also be viewed as a response to the lower demand of energy and the lower production of milk lactose (Rook and Campling, 1965), or affected by the progressing stage of lactation (Denbow, 1986). However, when the lactation was advanced during medium altitude measurement period, milk fat content increased significantly for yaks and Urangs. In the latter, milk amount decreased compared to Dimjos. The Dimjos had still high milk yield at the medium altitude measurement period without much variation in fat content as compared to high altitude, and proves for more persistent fat yield as compared to Urangs. As the Urangs and yaks had limited their milk yield at medium altitude, milk fat content became significantly higher than at high altitude respectively.

Future research priorities

Future research priorities derived from the performance study

The two stocking densities investigated were determined based on assumption of the milk yield and body weight (Wiener et al., 2003) in relation to the biomass available with an assumption of a dry matter content of 200 g/kg of the pasture. However; this should be elaborated based on seasonally determined dry matter contents and contents of digestible nutrients. As soon as the phenological stage changes of the pastures across the different pasture sites during transhumance are known, a detailed pasture quality assessment trial would add value to elaborate the findings of the performance study.

The dry matter intake of dairy cattle was reported inconsistently, namely either to be increased (Christen et al., 1996) and decreased (Berry et al., 2001) in studies in the European Alps. More research is needed to estimate the herbage selection of yaks and crossbreds. This would add further benefits to estimate the dry matter intake (Ding et al., 2007) estimation at pastures along transhumant routes. So, when pasture quality and pasture selectivity are known in detail, estimates on daily dry matter intake and differences between the crossbreds kept at different stocking densities and across the pastures sites can be established in the pastures of the Himalayan mountains.

Milk fat remained the only constantly changing factor across altitude and pasture sites, but this mutually with the lactation stage and associated changes in forage quality. Energy partition studies (Brosh et al., 2010; Han et al., 2001) could provide better hints to explain the reasons for a low milk energy output at high milk fat percentage during the downward movement in the perspective with the changing lactation stage and degrading pasture quality due to ageing when animals graze at low altitude pasture sites (altitude) during the downward movement.

Future research priorities from the adaptation study

It is clear in the altitude study that Dimjos are better suited than Urangs for high altitude conditions. However, more research is needed to elaborate physiological performances of crossbreds, is ideal to express the better utility of findings from the altitude study results. As a physiological mechanism of oxygen uptake at high altitude, total hemoglobin had recorded. Further studies on blood hemoglobin morphology of the genotypes should be identified. High-altitude adapted yaks have fetal hemoglobin (Sarkar et al., 1999a) as a major hemoglobin phenotype, while it is believed to be absent in cattle (Grimes et al., 1957). This might have altered the oxygen uptake and respiratory behavior of the crossbred genotypes at high altitude as they are of two contrasting origin.

Lactate metabolism is linked to fulfill the demand of oxidative energy (Brooks, 2009). Further as a metabolic stressor, the blood level of non-esterified fatty acids (Adewuyi et al., 2005), and β-hydoxybutyrate (Leiber et al., 2004) should be assessed. When anaerobic energy is needed to meet the energy demands, there would be lowered level of free fatty acids in blood as has been discussed by Brooks (2009). As a low frequency of observations available from standing (as rest) was used to predict the heart parameters, a study with longer duration with the values based on lying (comfort) time would be helpful to further elaborate the research results.

General Conclusion

The knowledge of the socio-economic backgrounds of livestock holding and the different livestock production systems across KCA is beneficial for better dissemination of findings (Lisson et al., 2010) from the performance and adaptation studies of this doctoral project. Moreover, the managers of the KCA should provide the capacity to perform a detailed local rangeland inventory including grazing history (animal genotypes and population, pasture ecology, pasture size, time and duration of grazing, seasonal biomass production etc.) which have direct implications for future pasture developments along the transhumant routes.

It is clearly observed in the performance study that the low SD produced higher individual milk yield, fat and protein yield for Dimjos. The adjustment on stocking density maintained in this project gives an idea to maintain stocking density threshholds for future research as when when further information about pasture ecology and utilization is available, would add benefit for stocking density management. Nevertheless, crossbreds of female yaks with the Tibetan bulls (Dimjos) have an advantage other than crossbreeding yaks with female hill cattle (Urangs) of Nepal in terms of high altitude tolerance. Still, the yaks proved to be better adapted at high altitude than Dimjos, as was obvious from the better physiologic and metabolic results and is also reflected with higher milk fat content. However, the Dimjos remained very close to the yaks in behavior with the highest milk yield and milk fat even at very high altitude conditions.

In general, a suitable genetic makeup of the animals was shown to be a permanent base of high altitude adaption (Richalet, 2007), which has a direct importance for the metabolic, physiologic and behavioral efficiency of yaks, Dimjos and Urangs used in the adaptation in this project. The high altitude acclimatized economic traits of animals (Shirley et al., 2008) as likely in Dimjos is beneficial for milk yield and milk traits. One reason could be that the father is already originated from high altitude Tibetan areas, the Bhelang bull (*Bos taurus*) in comparison to the Urangs as the mother of the Urangs originated from the hills of Nepal, the hill cattle (*Bos indicus*). The biological efficiency of animals might depend on the physiological adjustment to the particular environment, which is obvious from the better indices of blood metabolic (low lactate) and physiologic profiles (high respiration rate and rectal temperature) reflected in the performance of Dimjos in comparison to Urangs. The divergence in the studies on locally available cattle and yaks could provide reliable information regarding the ecological and geographical variation in milk traits (Cai et al., 2010) for which the genotypes are traditionally used for crossbreeding. More research is needed to confirm the proportionate importance of the effects of heterosis (Freyer et al., 2008; Wang et al., 1994a, 1994b), maternal lineages effects (Huichinga et al., 1986) and altitudinal origin of the parents in crossbreds concerning milk yield and milk fat content. Recombination (de Haas et al., 2013) particularly for the efficiency of metabolic traits of crossbreds when used from different sources of origin at high altitude conditions could also be applied for prospective research.

References

Adewuyi, A.A., Gruys, E., and van Eerdenburg, F.J.C.M., 2005. Non esterified fatty acids (NEFA) in dairy cattle. A review. Vet. Quarterly, 27, 117–126.

Aharoni, Y., Henkin, Z., Ezra, A., Dolev, A., Shabtay, A., Orlov, A., Yehuda and Y., Brosh, A., 2009. Grazing behavior and energy costs of activity: a comparison between two types of cattle. J. Anim. Sci. 87, 2719–2731.

ALP (Agroscope Liebefeld-Posieux). 2013. Fütterungsempfehlungen und Nährwerttabellen für Wiederkäuer (Feeding recommendations and nutrient tables for ruminants).

http://www.agroscope.admin.ch/futtermitteldatenbank/04834/index.html?lang=de (Accessed February 21, 2013).

Anand, I.S., Harris, E., Ferrari, R., Pearce, P., and Harris, P., 1986. Pulmonary haemodynamics of the yak, cattle, and cross breeds at high altitude. Thorax, 41, 696–700.

AOAC, 1997. Official Methods of Analysis. Assoc. Off. Anal. Chem., Arlington, VA, USA.

Apple, J. K., Kegley, E. B. , Galloway, D. L. , Wistuba, T. J. , and Rakes, L. K., 2005. Duration of restraint and isolation stress as a model to study the dark-cutting condition in cattle. J. Anim. Sci. 83,1202–1214.

Aryal, A., Brunton, D., Pandit, R., Rai, R.K., Shrestha, U.B., Lama, N. and Raubenheimer, D., 2013. Rangelands, conflicts, and society in the upper Mustang region, Nepal. Mount. Res. Develop., 33, 11–18.

Aschwanden, J., Gygax, L. , Wechsler, B. and Keil, N. M., 2008. Cardiac activity in dairy goats whilst feeding side-by-side at two different distances and during social separation. Physiol. Behav. 95, 641–648.

Bao, L., Huang, Q., Chang, L., Zhou, J. and Lu, H., 2011. Screening and characterization of cellulose with endocellulase and exocellulase activity from yak rumen metagenome. J. Mol. Catal. **B**: Enzym. 73, 104–110.

Barshila, I. and Devkota, N.R., 2013. Botanical composition and herbage mass estimation in relation to quality status of Mauma Kharka (rangeland) in the Taplejung District, Nepal. Global J. Sci. Frontier Res. Agric. Vet. 13, 55–60.

Bartl, K., Gómez, C. A. , Aufdermauer, T. , Garcia, M. , Kreuzer, M. , Hess, H. D. and Wettstein, H.-R., 2009. Effect of diet type on performance and metabolic traits of Peruvian local and introduced cow types kept at 200 and 3600 m of altitude. Livest. Sci. 122, 30–38.

Bartl, K., Gómez, C.A., Aufdermauer, T., Garcia, M., Kreuzer, M., Hess, H.D., Wettstein, H.-R., 2009. Effect of diet type on performance and metabolic traits of Peruvian local and introduced cow types kept at 200 and 3600 m of altitude. Livest. Sci. 122, 30–38.

Bärtsch, P. and Gibbs, J. S. R., 2007. Effect of altitude on the heart and the lungs. Circualtion, 116, 2191–2202.

Bauer, J.J., 1990. The analysis of plant-herbivore interactions between ungulates and vegetation on alpine grasslands in the Himalayan region of Nepal. Vegetatio 90, 15–34.

Berry, N. R., Sutter, F., Bruckmaier, R. M., Blum, J.W. and Kreuzer, M., 2001. Limitations of high alpine grazing conditions for early- lactating cows: effect of energy and protein supplementation. Anim. Sci. 73, 149–162.

Bewley, J. M.,. Boyce, R. E, Hockin, J., Munksgaard, L. , Eicher, S. D. , Einstein, M. E. and Schutz, M. M., 2010. Influence of milk yield, stage of lactation, and body condition on dairy cattle lying behaviour measured using an automated activity monitoring sensor. J. Dairy Res. 77, 1–6.

Bhattarai, K.R. and Upadhyay, T. P., 2013. Rangeland management in Sagarmatha (Mount Everest) national park and buffer zone, Nepal: an ecological perspective. Mount. Res. Develop. 33, 19–28.

Bianca W., and Näf, F., 1979. Responses of cattle to the combined exposure, to diurnal temperature rhythm (-5 to 25°C) and to simulated high-altitude (4,000 m). Int. J. Biometeor. 23, 299–310.

Bianca, W. and Hays, F.L., 1975. Responses of calves to a simulated altitude of 5000 m. Int. J. Biometeor. 19, 155–165.

Bianca, W. and Kunz, P., 1978. Physiological reactions of three breeds of goats to cold, heat and high altitude. Livest. Prod. Sci. 5, 57–69.

Bianca, W., 1976. The significance of meteorology in animal production. Int. J. Biometeor. 20, 139–156.

Bianca, W., and Näf, F., 1978. Reaktionen von Rindern auf 4000 m simulierte Höhe in Abhängigkeit vom Alter. Schweiz. Arch. Tierheilk. 120, 615–630.

Boettcher, P.J., Steverink, D.W.B., Beitz, D.C., Freeman, A.E. and Mcdaniel, B.T., 1996. Multiple herd evaluation of the effects of maternal lineage on yield traits of Holstein cattle. J. Dairy Sci. 79, 655–662.

Bonham.C.D., 1989. Measurements for terrestrial vegetation. John Wiley and Sons, New York, NY, USA.

Bouwman, A.F., Van der Hoek, K.W., Eickhout, B. and Soenario, I., 2005. Exploring changes in world ruminant production systems. Agric. Sys. 84, 121–153.

Bovolenta, S., Saccà, E., Corazzin, M., Gasperi, F., Biasioli, F. and Ventura, W., 2008. Effects of stocking density and supplement level on milk production and cheese characteristics in Brown cows grazing on mountain pasture. J. Dairy Res. 75, 357–364.

Brooks, G.A., 2009. Cell-cell and intracellular lactate shuttles. J. Physiol., 587, 5591–5600.

Brosh, A. 2007. Heart rate measurements as an index of energy expenditure and energy balance in ruminants: a review. J. Anim. Sci. 85, 1213–1227.

Brosh, A., Henkin, Z., Ungar, E. D., Dolev, A., Shabtay, A., Orlov, A., Yehuda, Y. and Aharoni, Y. 2010. Energy cost of activities and locomotion of grazing cows: a repeated study in larger plots. J. Anim. Sci. 88, 315–323.

Brun-Lafleur, L., Delaby, L., Husson, F. and Faverdin, P., 2010. Predicting energy × protein interaction on milk yield and milk composition in dairy cows. J. Dairy Sci. 93, 4128–4143.

Cai, X., Chen, H. and Lei, C., 2010. Matrilineal genetic inter-introgression of *Bos taurus* and *Bos indicus* in China. Livest. Sci. 128, 12–19.

CBS (Central Bureau of Statistics), 2001/02. Agriculture monograph (Chapter 11: Livestock and poultry). Central Bureau of statistics, Kathmandu Nepal. (Retrived on 29 May, 2013 from http://cbs.gov.np/?p=419).

Central Bureau of Statistics (CBS), 2005. Poverty trends in Nepal (1995-96 and 2003-04). http://www.cbs.gov.np (accessed on 28 June, 2013).

Chaplin, S. and Munksgaard, L., 2001. Evaluation of a simple method for assessment of rising behaviour in tethered dairy cows. Anim. Sci., 72, 191–197.

Chetri, D. K., Nepali Karki, D. B. , Sah, R. and Devkota, N. R., 2011. Transhumance effect on husbandry practices and physiological attributes of chauri (yak-cattle) in Rasuwa district. Our Nature 9,128–137.

Christen, R. E., Kunz, P. L., Langhans, W., Leuenberger, H., Sutter, F. and Kreuzer, M., 1996. Productivity, requirements and efficiency of feed and nitrogen utilization of grass-fed early lactating cows exposed to high alpine conditions. J. Anim. Physiol. Anim. Nutr. 76, 22–35.

Claxton, J. R., and Ortiz. P., 1996. Haematological parameters in Brown Swiss and Holstein cattle at high altitude. Trop. Anim. Health. Prod. 28, 112–116.

D'Hour, P., Hauwuy, A., Coulon, J.B. and Garel, J.P., 1994. Walking and dairy cattle performance. Ann. Zootech. 43, 369–378.

de Haas, Y., Smolders, E.A.A., Hoorneman, J.N., Nauta, W.J. and Veerkamp, R.F., 2013. Suitability of cross-bred cows for organic farms based on cross-breeding effects on production and functional traits. Animal, 7, 655–664.

Degen, A. A., Kam, M., Pandey, S. B., Upreti, C. R., Pandey, S. and Regmi, P, 2007. Transhumant pastoralism in yak production in the lower Mustang district of Nepal. Nomadic Peoples 11, 57–85.

Denbow, C.J., Perera, K.S., Gwazdauskas, F.C., Akers, R.M., Pearson, R.E. and McGilliard, M.L., 1986. Effect of season and stage of lactation on plasma insulin and glucose following glucose injection in Holstein cattle. J. Dairy Sci., 69, 211–216.

Devkota, N.R. and Kolachhapati, M.R., 2008. Herbage harvested carrying capacity, and stocking density of selected rangelands of Rasuwa and Taplejung districts (Abstract).

Proceedings of the Fifth National Science and Technology Conference, Nov. 10–12, 2008, Kathmandu, Nepal. 25 p.

Diaz, H.F., Grosjean, M. and Graumlich, L., 2003. Climate variability and change in high elevation regions: past, present and future. Climatic Change, 59, 1–4.

Dickhoefer, U., Buerkert, A., Brinkmann, K., Schlecht and E., 2010. The role of pasture management for sustainable livestock production in semi-arid subtropical mountain regions. J. Arid Environ. 74, 962–972.

Ding, L., Long, R., Yang, Y., Xu, S. and Wang, C., 2007. Behavioural responses by yaks in different physiological states (lactating, dry or replacement heifers), when grazing natural pasture in the spring (dry and germinating) season on the Qinghai-Tibetan plateau. Appl. Behav. Sci., 108, 239–250.

Ding, X.Z., Long, R.J., Kreuzer, M., Mi, J.D. and Yang, B., 2010. Methane emissions from yak (*Bos grunniens*) steers grazing or kept indoors and fed diets with varying forage: concentrate ratio during the cold season on the Qinghai-Tibetan Plateau. Anim. Feed Sci. Tech. 162, 91–98.

Ding, Y., Shao, B. and Wang, J., 2007. The arterial supply of brain of yaks (*Bos runniens*).Annals of Anatomy. 189, 31–38.

District Profile, 2008. District profile of Taplejung district of Nepal. Secretariat of the National Planning Commission, Central Bureau of Statistics, Kathmandu, Nepal (in Nepali), 1–100, pp.

Dodzi, M. S., and Muchenje, V., 2012. Seasonal variation in time budgets and milk yield for Jersey, Friesland and crossbred cows raised in a pasture-based system. Trop. Anim. Health Prod. 44, 1395–1401.

Dolt, .K.S., Mishra, M.K., Karar, J., Baig, M.A., Ahmed, Z. and Qadar Pasha, M. A., 2007. cDNA cloning, gene organization and variant specific expression of HIF-1 α in high altitude yak (*Bos grunniens*). Gene. 386, 73–80.

Dong, S. K., Wen, L. , Zhu, L. , Lassoie, J. P. , Yan, Z. L. , Shrestha, K. K., Pariya, D. and Sharma E., 2009b. Indigenous yak and yak-cattle crossbreed management in high altitude areas of northern Nepal: a case study from Rasuwa district. Afr. J. Agric. Res. 4, 957–967.

Dong, S., Lassoie, J., Shrestha, K.K., Yan, Z., Sharma, E., and Pariya, D., 2009a. Institutional development for sustainable rangeland resource and ecosystem management in mountainous areas of northern Nepal. J. Environ. Manag. 90, 994–1003.

Dong, S., Long, R., Kang, M., 2007. Milking performance of China yak. African J. Agric. Res. 2, 52–57.

Durmowicz, A. G., Hofmeister, S., Kadyraliev, T. K. ,. Aldashev, A. A. and Stenmark, K. R., 1993. Functional and structural adaptation of the yak pulmonary circulation to residence at high altitude. J. App. Physiol. 74, 2276–2285.

FAOSTAT (FAO Statistics Division), 2011. Food and Agriculture Organization of the Unites Nations, FAOSTAT, FAO, Rome. Retrieved May 29, 2013 from http://faostat3.fao.org/home/index.html.

Fenhammar J., Andersson, A., Forestier, J., Weitzberg, E., Sollevi, A. , Hjelmqvist, H. , and Frithiof, R., 2011. Endothelin receptor A antagonism attenuates renal medullary blood flow impairment in endotoxemic pigs. PLoS ONE 6:e21534. doi:10.1371/journal.pone.0021534.

Fineman, J.R., Heyman, M.A. and Soifer, S.J., 1991. N^{ω}-nitro-L-arginine attenuates endothelium-dependent pulmonary vasodilation in lambs. Am. J. Physiol. Heart Circ. Physiol. 260: H1299-H1306.

Food and Agriculture Organization (FAO), 2005. Livestock sector brief (Nepal). Food and Agriculture Organization of the United Nations, FAO, Rome, pp. 1–18.

Food and Agriculture Organization (FAO), 2005. Livestock Sector Brief (Nepal). Food and Agriculture Organization of the United Nations, FAO, Rome, Italy1–19 , pp.

Food and Agriculture Organization (FAO), 2011. World Livestock 2011: Livestock in Food Security. Food and Agriculture Organization of the United Nations, FAO, Rome, 1–115 pp.

Fregonesi, J.A., Tucker, C.B. and Weary, D.M., 2007. Overstocking reduces lying time in dairy cows. J. Dairy Sci. 90, 3349–3354.

Freyer, G., König, S., Fischer, B., Bergfeld, U. and Cassell, B. G., 2008. Crossbreeding in dairy cattle from a German perspective of the past and today. J. Dairy Sci. 91, 3725–3743.

Ge , R.-L., Simonson, T. S.,Cooksey, R. C., Tanna, U., Qin, G., Huff,C. D., Witherspoon, D. J., Xing, J., Zhengzhong, B., Prchal, J.T., Jorde, L. B. and McClain, D. A., 2012. Metabolic insight into mechanisms of high-altitude adaptation in Tibetans. Mol. Gen. Metabol. 106, 244–247.

Gibbons, J., Medrano-Galarza, C., de Passillé, A.M. and Rushen, J., 2012. Lying laterality and the effect of IceTag data loggers on lying behaviour of dairy cows. Appl. Anim. Behav. Sci., 136, 104–107.

Gibson, J.P., Freeman, A.E. and Boettcher, P.J., 1997. Cytoplasmic and mitochondrial inheritance of economic traits in cattle. Livest. Prod. Sci. 47, 115–124.

Grimes, R. M., Duncan, C. W. and Lassiter, C. A., 1957. Occurrence of multiple hemoglobins in certain breeds of dairy cattle. J. Dairy Sci. 40, 1338–1342.

Grimes, R. M., Duncan, C. W. and Lassiter, C. A., 1958. Bovine fetal hemoglobin.I. Postnatal persistence and relation to adult hemoglobins. J. Dairy Sci. 41, 1527–1533.

Gu, Z., Zhao, X., Li, N. and Wu, C., 2007. Complete sequence of the yak (*Bos grunniens*) mitochondrial genome and its evolutionary relationship with other ruminants. Mol. Phylogen. Evol. 42, 248–255.

Guo, X. S., Zhang, Y., Zhou, J. W., Long, R.J., Xin, G.S., Qi, B., Ding, L.M. and Wang, H.C., 2012a. Nitrogen metabolism and recycling in yaks (*Bos grunniens*) offered a forage–concentrate diet differing in N concentration. Anim. Prod. Sci. 52, 287– 296.

Guo, X., Long, R., Kreuzer, M., Ding, L., Shang, Z., Zhang, Y., Yang, Y. and Cui, G., 2012b. Importance of functional ingredients in yak milk derived food on health of Tibetan nomads living under high altitude stress: A review. Crit. Rev. Food Sci. Nutr. (doi: 10.1080/10408398.2011.584134).

Guo, X.S., Ding, L.M., Long, R.J., Qi, B., Shang, Z.H., Wang, Y.P. and Cheng, X.Y., 2012c. Changes of chemical composition to high altitude results in *Kobresia littledalei* growing in alpine meadows with high feeding values for herbivores. Anim. Feed Sci. Tech. 173, 186–193.

Gurung, G. and McVeigh, C., 2000. Pastoral management and yak rearing in Manang's Nar-Phu valley. Proceedings of the third international congress on yak, 4–9 September, Lhasa, P.R. China. http://agtr.ilri.cgiar.org/documents/library/docs/yakpro (accessed on June 28, 2013).

Hagen, K., Langbein, J. , Schmied, C. , Lexer, D. and Waiblinger, S., 2005. Heart rate variability in dairy cows – influences of breed and milking system. Physiol. Behav. 85, 195–204.

Han, X.-T., Xie, A.-Y. , Bi, X.-C. , Liu, S.-J. and Hu, L.-H., 2003. Effects of altitude, ambient temperature and solar radiation on fasting heat production in yellow cattle (*Bos taurus*). Br. J. Nutr. 89, 399–407.

Han, X.-T.,. Xie, A.-Y, Bi, X.-C. , Liu, S.-J. and Hu, L.-H., 2002. Effects of high altitude and season on fasting heat production in the yak *Bos grunniens* or *Poephagus grunniens*. Br. J. Nutr. 88, 189–197.

Harris, P., Heath, D., Smith, P., Williams, D.R., Ramirez, A., Krüger, H. and Jones, D.M., 1982. Pulmonary circulation of llama at high and low altitudes. Thorax. 37, 38–45.

Hartl, G.B., Göltenboth, R., Grillitsch , M. and Willing, R.,1988. On the biochemical systematics of Bovini. Biochem. System. Ecol. 16, 575–579.

Hays , F.L., Bianca, W. and NäF, F., 1978b. Effect of exercise on young and adult cattle at low and high altitude. Int. J. Bioeteor. 22, 147–158.

Hays, F. L., Bianca, W. and Näf, F., 1978a. Effects of exposure to a simulated altitude of 3,500 m on calves and oxen. Int. J. Biometeor. 22, 135–146.

Hays, F.L. and Bianca, W., 1976. Pulmonary hypertention, blood coagulation and aspirin treatment in high altitude exposed cattle. Int. J. Biometeor. 20, 56–60.

Hays, F.L., 1976. Alp and valley cattle: exercise in cold, hot and high environments. Pfliigers Arch. (Eur. J. Physiol.), 362, 185–192.

Hays, F.L., Armbruster, H., Vetter, W. and Bianca, W., 1975. Plasma cortisol in cattle: circadian rhythm and exposure to a simulated high altitude of 5,000 m. Int. J. Biometeor. 19, 127–135.

He, S., Ma, Y., Wang, J., Li, Q., Yang, X., Tang, S. and Li, H., 2011. Milk fat chemical composition of yak breeds in China. J. Food Comp. Anal. 24, 223–230.

He, S.-H., Ma, Y., Li, Q.-M., Li, D.-H., Wang, J.Q. and Cui, Y.H., 2013. The fatty acid pro le of Chinese Maiwa yak milk in relation to season and parity. Int. J. Dairy Tech. 66, 25-30.

He, Y.Y., Yu, S.J. and Du, P., 2010. Morphological study on microvasculature of left ventricular wall in infant and adult yaks. The Anatomical Rec. 293, 1519–1526.

Hiendleder, S., Lewalski, H. and Janke, A., 2008. Complete mitochondrial genomes of *Bos taurus* and *Bos indicus* provide new insights into intra-species variation, taxonomy and domestication. Cytogen. Genome Res. 120, 150–156.

Hochachka, P.W., Stanley, C., Merkt, J. and Sumar-Kalinowski, J. 1982. Metabolic meaning of elevated levels of oxidative enzymes in high altitude adapted animals: an interpretative hypothesis. Resp. Physiol. 52, 303–313.

Hock, R.J. 1970. The physiology of high altitude. Scientific American, 222, 52–62.

Huang, X. D., Tan, H. Y, Long, R., Liang, J. B. and Wright, A.-D. G., 2012. Comparison of methanogen diversity of yak (*Bos grunniens*) and cattle (*Bos taurus*) from the Qinghai-Tibetan plateau, China. BMC Microbiol.12, 237 (DOI: 10.1186/1471-2180-12-237).

Huizinga, H.A., Korver, S., McDaniel, B.T. and Politiek, R.D., 1986. Maternal effects due to cytoplasmic inheritance in dairy cattle. Influence on milk production and reproduction traits. Livest. Prod. Sci. 15, 11–26.

Huzzey, J.M., von Kyserlingk, M.A.G., Weary, D.M., 2005. Changes in feeding, drinking, and standing behavior of dairy cows during the transition period. J. Dairy Sci. 88, 2454–2461.

ICIMOD (International Centre for Intergrated Mountain Development), 2013. Rangelands Resources Management, retrieved on 5 June, 2013 from www.icimod.org.

Ikeda, N., 2004. Economic impacts of livestock depredation by snow leopard (*Uncia uncia*) in the Kanchenjunga Conservation Area, Nepal Himalaya. Environ. Conserv. 31, 322–330.

Ishizaki, T., Koizumi, T., Ruan, Z., Wang, Z., Chen, Q. and Sakai, A., 2005. Nitric oxide inhibitor altitude-dependently elevates pulmonary arterial pressure in high-altitude adapted yaks. Resp. Physiol. Neurobiol. 146, 225–230.

Joshi, D. D. 1982. Yak and Chauri husbandry in Nepal. K. D. Joshi (Publisher), Kathmandu, Nepal.

Joshi, D. D. 2003. Yak in Nepal. *In*: Wiener, G., Jianlin, H., and R. Long, R., (eds.). The yak (2nd ed.). Food and Agriculture Organization, Regional Office for Asia and the Pacific, RAP Publication, Bangkok, Thailand. pp. 316–322.

Joshi, D. D., 1982. Yak and Chauri husbandry in Nepal. K. D. Joshi (Publisher), Kathmandu, Nepal.

Joshi, D.D., Lund, P.N., Miller, D.J. and Shrestha, S.K., 1994. In: Rongchang, Z., Jianlin, H. and Jianping, W. (eds.) .Yak production in Nepal. Yak production in central Asian highlands. Proceedings of the first international congress on yak, August 1-6; Gansu Agricultural Univesity, China. pp 105-112.

Joshi, D.D., Lund, P.N., Miller, D.J. Shrestha, S.K., 1994. In: Rongchang, Z., Jianlin, H., Jianping, W. (eds.) .Yak production in Nepal. Yak production in central Asian highlands. Proceedings of the first international congress on yak, 1-6 August; Gansu Agricultural Univesity, China, 1–112 pp.

Kauffman, J.B. and Pyke, D.A., 2001. Rangeland ecology, global livestock influences. Encycl. Biodiv. 5, 33–52.

Kharel, F.R., 1999. Status paper of Kanchenjunga Conservation Area. In Richard, C., Basnet, K., Sah, J.P., Raut, Y. (eds): Grassland ecology and management in protected areas of Nepal, Vol. III. Proceedings of a workshop on grassland ecology and management held at Royal Bardiya National Park, 15-19 March, 1999, Thakurdwara, Bardiya Nepal, 1–136 pp.

Koizumi, T., Ruan, Z., Sakai, A., Ishizaki, T., Matsumoto, T., Saitou, M., Matsuzaki, T., Kubo, K., Wang, Z., Chen, Q. and Wang, X., 2004. Contribution of nitric oxide to adaptation of tibetan sheep to high altitude. Resp. Physiol. Neurobiol.140, 189–196.

Krawczel, P.D., Klaiber, L.B., Butzler, R.E., Klaiber, L.M., Dann, H.M., Mooney, C.S. and Grant R.J., 2012. Short term increases in stocking density affect the lying and social behavior, but not the productivity, of lactating Holstein dairy cows. J. Dairy Sci. 95, 4298–4308.

Kreuzer, K., Langhans, W., Sutter, F., Christen, R.E., Leuenberger, H. and Kunz, P.L., 1998. Metabolic response of early-lactating cows exposed to transport and high altitude grazing conditions. Anim. Sci. 67, 237–248.

Krishnan, G., Ramesha, K. P., Sarkar, M., Chakravarty, P., Kataktalware, M. A. and Saravanan, B. C., 2009a. Modified temperature humidity index for yaks. Indian J. Anim. Sci. 79, 788–790.

Krishnan, G., Ramesha, K.P., Chakravarty, P., Chouhan, V.S. and Jayakumar, S., 2009b. Diurnal variation in the physiological responses of yaks. Indian J. Anim. Sci. 79, 1132–1133.

Kuang, L., Zheng, Y., Lin, Y. , Xu, Y. , Jin, S. , Li, Y. , Dong, F. and Jiang, Z., 2010. High-altitude adaptation of yak based on genetic variants and activity of lactate dehydrogenase-1. Biochem. Genet. 48, 418–427.

Lalthantluanga, R., Wiesner, H. and Braunitzer, G., 1985. Studies on yak hemoglobin (*Bos grunniens*, Bovidae): structural basis for high intrinsic oxygen affinity? Biol. Chem. 366, 63–68.

Leiber, F. , Kreuzer, M. ,, Jörg, B., Leuenberger, H. and Wettstein, H.-R., 2004. Contribution of altitude and alpine origin of forage to the in uence of alpine sojourn of cows on intake, nitrogen conversion, metabolic stress and milk synthesis. Anim.Sci.78, 451–466.

Leiber, F., Kreuzer, M., Leuenberger, and Wettstein, H.-R., 2006. Contribution of diet type and pasture conditions to the influence of high altitude grazing on intake, performance and composition and renneting properties of the milk of cows. Anim. Res. 55, 37–53.

Leiber, F., Nigg, D., Kunz, C., Scheeder, M.R.L., Wettstein, H.-R. and Kreuzer, M., 2005. Protein composition, plasmin activity and cheesemaking properties of cows' milk produced at two altitudes from hay of lowland and high-alpine origins. J. Dairy Res. 72, 65–74.

Liesegang, A., Hüttenmoser, D., Risteli, J., Leiber, F., Kreuzer, M. and Wanner, M., 2013. Influence of high-altitude on bone metabolism of sheep. J. Anim. Physiol. Anim. Nutr. 97, 58–66.

Lin, L., Dickhoefer, U., Müller, K., Wurina and Susenbeth, A. 2011. Grazing behavior of sheep at different stocking rates in the Inner Mongolian steppe, China. Appl. Anim. Behav. Sci. 129, 36–42.

Lin, X., Wang, S., Ma, X., Xu, G., Luo, C., Li, Y., Jiang, G. and Xie, Z., 2009. Fluxes of CO_2, CH_4, and N_2O in an alpine meadow affected by yak excreta on the Qinghai-Tibetan plateau during summer grazing periods. Soil Biol. Biochem. 41, 718–725.

Lisson, S., McLeod, N., McDonald, C., Corfield, J., Pengelly, B., Wirajaswadi, L., Rahman, R., Bahar, S., Padjung, R., Razak, N., Puspadi, K., D., Sutaryono, Y., Saenong, S., Panjaitan, T., Hadiawati, L., Ash, A. and Brennan, L., 2010. A participatory, farming systems approach to improving Bali cattle production in the smallholder crop–livestock systems of eastern Indonesia. Agric. Syst., 103, 486–497.

Long, R.J., Apori, S.O., Castro, F.B. and Ørskov, E.R., 1999. Feed value of native forages of the Tibetan Plateau of China. Anim. Feed Sci. Technol. 80, 101–113.

Long, R.J., Dong, S.K., Hu, Z.Z., Shi, J.J., Dong, Q.M. and Han, X.T., 2004. Digestibility, nutrient balance and urinary purine derivative excretion in dry yak cows fed oat hay at different levels of intake. Livest. Prod. Sci. 88, 27–32.

Macdonald, K.A., Penno, J.W., Lancaster, J.A.S. and Roche, J.R., 2008. Effect of stocking rate on pasture production, milk production and reproduction of dairy cows in pasture-based systems. J. Dairy Sci., 91, 2151–2163.

Magona, J. W., Walubengo, J. , Anderson, I., Olaho-Mukani, W., Jonsson, N. N., and Eisler, M. C., 2004. Portable haemoglobinometers and their potential for penside detection of anaemia in bovine disease diagnosis: a comparative evaluation. Vet. J. 168, 343–348.

Maltsouglou, I., Taniguchi, K., 2004. Poverty, livestock and household typologies in Nepal (PPLPI working paper No. 13). FAO, Rome Italy, 1–47 pp.

Mao, X.-Y., Cheng, X., Wang, X. and Wu, S.-J., 2011. Free-radical-scavenging and anti-in ammatory effect of yak milk casein before and after enzymatic hydrolysis. Food Chem. 126, 484–490.

Mayne, C.S., Newberry, R.D., Woodcock, S.C.F. and Wilkins, R.J., 1987. Effect of grazing severity on grass utilization and milk production of rotationally grazed dairy cows. Grass Forage Sci., 42, 59–72.

McCarthy, B., Delaby, L., Pierce, K.M., Journot, F., and Horan, B., 2011. Meta-analysis of the impact of stocking rate on the productivity of pasture-based milk production systems. Animal, 5, 784–794.

Metcalfe, J., Batrels, H. amd Moll, W., 1967. Gas exchange in the pregnant uterus. Physiol. Rev. 47, 782-838.

Mishra, C., Prins, H.H.T., and van Wieren, S.E., 2001. Overstocking in the trans-Himalayan rangelands of India. Environm. Conserv. 28, 279–283.

Mitchell, G., Hattingh, J., and Ganhao, M., 1988. Stress in cattle assessed after handling, after transport and after slaughter. Vet. Rec. 123, 201–205.

MOAD (Ministry of Agricultural Development), 2011/2012. Statistical Information on Nepalese Agriculture.Government of Nepal, Ministry of Agricultural Development, Agri-Business Promotion and Statistics Division, Agri Statistics Section, Singh Durbar, Kathmandu, Nepal. (http://www.moad.gov.np/download.php (accessed June 28, 2013).

Mohr, E., Langbein, J. and Nürnberg, G., 2002. Heart rate variability: a noninvasive approach to measure stress in calves and cows. Physiol. Behav. 75, 251–259.

Moktan, M.R., Norbu, L., Nirola, H., Dukpa, K., Rai, T.B. ,Dorji, R.,2008. Ecological and social aspects of transhumant herding in Bhutan. Mount. Res. Develop. 28, 41–48.

Moncada, S., Palmer, R. M. J. and Higgs, E.A., 1991. Nitric oxide: physiology, pathophasiology and pharmacology. Pharm. Rev. 43, 109–142.

Moser, E. B. 2004. Repeated measures modeling with PROC MIXED. Paper 188-29. In: SAS Institute Inc. Proc. 29th Ann. SAS Users Group Int. Conf., Cary, NC, USA.

Mountousis, I., Dotas, V., Stanogias, G., Papanikolaou, K., Roukos, Ch., and Liamadis, D., 2011. Altitudinal and seasonal variation in herbage composition and energy and protein content of grasslands on Mt Varnoudas, NW Greece. Anim. Feed Sci. Technol. 164, 174–183.

Mueller-Boker, U., Kollmair, M., 2000. Livelihood strategies and local perceptions of a new nature conservation project in Nepal. Mount. Res. Dev. 20, 324 – 331.

Narang, M. P. and Raman. 1994. Yak husbandry and research in Himachal Pradesh. *In:* Z. Ronghang, H. Jianlin and W. Jianping (eds.) Proceeding of the 1st International congress on yak held in Lanzhou, P.R. China, 4-9 September 1994. Supplement of J. Gasu Agric. Uni., P.R. China, 119–123 pp.

Neupaney, D., Kim, J.-B., Ishioroshi, M. and Samejima, K., 2003. Studies on some functional and compositional properties of yak butter lipid. Anim. Sci. J. 74, 391–397.

Njoka-Njiru, E. N., and Guliye, A. Y., 2001. Grazing behaviour of Jersey and Guernsey heifers in sub-humid tropical conditions of Kenya. Asian-Aust. J. Anim. Sci. 14, 491–495.

O'Brien, B., Dillon, P., Murphy, J.J., Mehra, R.K., Guinee, T.P., Connolly, J.F., Kelly, A. and Joyce, P., 1999. Effects of stocking density and concentrate supplementation of grazing dairy cows on milk production, composition and processing characteristics. J. Dairy Res. 66, 165–176.

O'Donovan, M. and Delaby, L., 2008. Sward characteristics, grass dry matter intake and milk production performance is affected by timing of spring grazing and subsequent stocking rate. Liv. Sci. 115, 158–168.

Olson, B. E. and Wallander, R. T., 2002. Influence of winter weather and shelter on activity patterns of beef cows. Can. J. Anim. Sci. 82, 491–501.

Orr, R.J., Rutter, S.M., Yarrow, N.H., Champion, R.A. and Rook, A.J., 2004. Changes in ingestive behaviour of yearling dairy heifers due to changes in sward state during grazing down of rotationally stocked ryegrass or white clover pastures. Appl. Anim. Behav. Sci., 87, 205–222.

Or-Rashid, M.M., Odongo, N.E., Subedi, B., Karki, P. and Mcbride, B.W., 2008. Fatty acid composition of yak (*Bos grunniens*) cheese including conjugated linoleic acid and trans-18:1 fatty acids. J. Agric. Food Chem. 56, 1654–1660.

Ostersen, S., Foldager, J. and Hermansen, J.E., 1997. Effects of stage of lactation, milk protein genotype and body condition at calving on protein composition and renneting properties of bovine milk. J. Dairy Res. 64, 207–219.

Osuji, P.O., 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. J. Range Manage. 27, 437–443.

Palmieri, R.P., 1987. Cattle hybrids among the Sherpa of Nepal. J. Cult. Geo. 7, 89–100.

Pande, R.S., 2004. Chauri production systems in upper slope areas, Sindhupalchok, Nepal. Proceedings of the International Congress on Yak, Chengdu, Sichuan, China. http://www.ivis.org (accessed on June 28, 2013).

Pariyar, D., 2008. Country Pasture/Forage Resource Profiles (Nepal). FAO Rome, Italy. www.fao.org/ag/agp/AGPC/doc/Counprof/PDF%20files/Nepal.pdf (accessed on July 1, 2013).

Parker, P. and Thapa, B., 2011. Distribution of benefits based on household participation roles in decentralized conservation within Kanchenjunga Conservation Area project Nepal. Env., Develop. Sus. (doi: 10.1007/s10668-011-9296-6).

Parker, P. and Thapa, B., 2012. Natural resources dependency and decentralized conservation within Kanchenjunga Conservation Area Project, Nepal. Environ. Manage. 49, 435–444.

Parraguez, V. H., Urqieta, B., Pérez, L., Castellaro, G., De Los Reyes, M., Torres-Rovira, L., Aguado-Martínez, A., Astiz, S. and González-Bulnes, A., 2013. Fertility in high altitude environment is compromised by luteal dysfunction: the relative role of hypoxia and oxidative stress. Reprod. Biol. Endocr. 11, 24 (doi: 10.1186/1477-7827-11-24).

Penasa, M., De Marchi, M., Dal Zotto, R., de Jong, G., Bittante, G. and Cassandro, M., 2010. Heterosis effects in a black and white dairy cattle population under different production environments. Livest. Sci. 131, 52–57.

Phillips, C. 2002. Cattle behavior and welfare. 2nd ed. Blackwell Science Ltd., Oxford, UK.

Phillips, R.W., Tolstoy, J.A. and Johnson, R.G., 1946. Yaks and yak-cattle hybrids in Asia. J. Heredity, 37, 207–215.

Pourouchottamane, R., Sarkar, M., Chatterjee, A., Saud, N., Saravanan, B. C., Kataktalware, M. A. and Bhattacharya, M., 2004. Influence of altitude on the heamato-biochemical changes in yak (*Poephagus grunniens* L.). Proceedings of the International Congress on Yak, Chengdu, Sichuan, Chin., Retrieved May 29, 2013 from www.ivis.org.

Price, M. F. 1998. Mountains: globally important ecosystems. In: Dembner (ed.). Unasylva: Moving Mountains. Retrieved 23 May, 2013 from http://www.fao.org/docrep/w9300e/w9300e00.htm#Contents.

Probst, J. K., Hillmann, E., Leiber, F., Kreuzer, M. and Neff, A.S., 2013. Influence of gentle touching applied few weeks before slaughter on avoidance distance and slaughter stress in finishing cattle. Appl. Anim. Behav. Sci. 144, 14–21.

Qi, X.B., Jianlin, H., Wang, G., Rege, J. E. O. and Hanotte, O., 2009. Assessment of cattle genetic introgression into domestic yak populations using mitochondrial and microsatellite DNA markers. Anim. Gen. 41, 242–252.

Qiao, G. H., Shao, T., Yu, C. Q., Wang, X. L., Yang, X., Zhu, X. Q. and Lu, Y., 2012. A comparative study at two different altitudes with two dietary nutrition levels on rumen fermentation and energy metabolism in Chinese Holstein cows. J. Anim. Physiol. Anim. Nutr., online early (doi:10.1111/j.1439-0396.2012.01339.x).

Qiu, Q., Zhang, G., Ma, T., et al., 2012. The yak genome and adaptation to life at high altitude. Nat. Genet. 44, 946–949+ (online first: doi:10.1038/ng.2343).

Ramesha, K. P., Pradhan, V. K., Kataktalware, M. A., Rajkhowa, J., Bora, M., Krishnan, G., Kumar, N., Saravanan, B. C., Biswas, T. K. and Bhattacharya, M., 2009. Effect of pack at high altitude on yaks (*Poephagus grunniens*). Indian J. Anim. Sci 79, 487–488.

Rawnsley, R.P., Donaghy D.J., Fulkerson, W.J. and Lane, P.A. 2002. Changes in the physiology and feed quality of cocksfoot (*Dactylis glomerata* L.) during regrowth. Grass Forage Sci. 57, 203–211.

Reynafarje, C., Faura, J., Villavicencio, D., Curaca, A., Reynafarje, B., Oyola, L., Contreras, L., Vallenas, E. and Faura, A., 1975. Oxygen transport of hemoglobin in high-altitude animals (Camelidae). J. Appl. Physiol. 38, 806–810.

Rhode, D., Madsen, D.B., Brantingham, P.J. and Dargye, T., 2007. Yaks, yak dung, and prehistoric human habitation of the Tibetan Plateau. Develop. Quaternary Sci. 9, 205–224.

Rhode, D., Madsen, D.B., Brantingham, P.J. and Dargye, T., 2007. Yaks, yak dung, and prehistoric human habitation of the Tibetan Plateau. Dev. Quaternery Sci.9, 205–224.

Rhodes, J., 2005. Comparative physiology of the hypoxic pulmonary hypertension: historical clues from Brisket disease. J. Anim. Physiol. 98, 1092–1100.

Richalet, J.-P., 2007. A proposed classi cation of environmental adaptation: the example of high altitude. Rev. Environ. Sci. Biotechnol. 6, 223–229.

Ritz, L.R., Glowatzki-Mullis, M.-L., MacHugh, D.E. and Gaillard, C., 2000. Phylogenetic analysis of the tribe *Bovini* using microsatellites. Anim. Genet. 31, 178–185.

Rook, A. J., Fisher, W. J. and Sutton, J. D. 1992. Sources of variation in yields and concentrations of milk solids in dairy cows. Anim. Prod., 54,169–173.

Rook, J.A. F. and Campling, R.C., 1965. Effect of stage and number of lactation on the yield and composition of cow's milk. J. Dairy Res., 32, 45–55.

Rook, J.A.F. and Line, C., 1961. The effect of the plane of energy nutrition of the cow on the secretion in milk of the constituents of the solids-non-fat fraction and on the concentrations of certain blood-plasma constituents. Brit. J. Nutr. 15, 109–119.

Roukos, C., Papanikolaou, K., Karalazos, A., Chatzipanagiotou., A., Mountousis, I. and Mygdalia, A. , 2011. Changes in nutritional quality of herbage botanical components on a mountain side grassland in North-West Greece. Anim. Feed Sci. Tech. 169, 24–34.

Ruan, Z., Koizumi, T., Sakai, A., Ishizaki, T. and Wang, Z., 2004. Endogenous nitric oxide and pulmonary circulation response to hypoxia in high-altitude adapted Tibetan sheep. Eur. J. Physiol. 93, 190-195.

Sakai, A., Matsumoto, T., Saitoh M., Matsuzaki, T., Koizumi, T., Ishizaki, T., Ruan, Z. H., Wang, Z. G., Chen, Q.H., Wang, X. Q., 2003. Cardiopulmonary hemodynamics of blue-sheep, *Pseudois nayaur*, as high-altitude adapted mammals. Japanese J. Physiol. 53, 377–384.

Sambraus, H. H. (Hrsg.). 1978. Nutztierethologie: Das Verhalten landwirtschaftlicher Nutztiere – eine angewandte Verhaltenskunde für die Praxis. 1st ed. Verlag Paul Parey, Berlin, Germany.

Samdup, T., Udo, H.M.J., Eilers, C.H.A.M., Ibrahin, M.N.M. and van der Zijpp, A.J., 2010. Crossbreeding and intensi cation of smallholder crop–cattle farming systems in Bhutan. Livest. Sci., 132, 126–134.

Sarkar, M., Das, D. N., and Mondal, D. B., 1999b. Fetal haemoglobin in pregnant yaks (*Poephagus grunniens* L.). The Vet. J. 158, 68–70.

Sarkar, M., Pal, R. N., Das, D.N., Mondal, D. B., Mohanty, T. K. and Pattanaik, S., 1999a. Postnatal persistence of foetal haemoglobin in yaks. Aust. Vet. J. 77, 190 p.

Saunders, P.U., Pyne, D. B. and Gore, C. J., 2009. Endurance training at high altitude. High Alt. Med. Biol. 10, 135–148.

Schutz, M. M., Freeman, A. E., Beitz, D. C. and Mayfield, J. E., 1992. The importance of maternal lineage on milk yield traits of dairy cattle. J. Dairy Sci. 75, 1331–1341.

Sellier, P., 2000. Genetically caused retarded growth in animals. Domes. Anim. Endocr. 19, 105–119.

Shaha, B.P.K., 2000. Economics of yak farming with relation to tourism in Nepal. Proceedings of the Third International Congress on yak, 4-9 September, Lhasa, P.R. China. http://agtr.ilri.cgiar.org/documents/library/docs/yakpro (accesed on June 28, 2013).

Shakya, B., Joshi, R.M., 2008. Protected areas and biodiversity conservation in the Hindu Kush-Himalayan region with special reference to the Kanchenjunga landscape. In: Chettri, N., Shakya, B., Sharma, E. (eds.): Biodiversity Conservation in the Kanchenjunga Landscape. International Centre for Mountain Research and Development, Kathmandu, Nepal.13–20 pp.

Shao, B., Long, R., Ding, Y., Wang, J., Ding, L. and Wang, H., 2010. Morphological adaptations of yak (*Bos grunniens*) tongue to the foraging environment of the Qinghai-Tibetan Plateau. J. Anim. Sci. 88, 2594–2603.

Shao, B.-P., Ding, Y.-P., Yu, S.-Y., Wang, J.-L., 2008. The arterial supply of the eye of the yak (*Bos grunniens*). Res. Vet. Sci. 84, 174–177.

Sharma, E., 2008. Developing a transboundary biodiversity conservation landscape and conservation corridors in the Kangchenjunga complex. In: Chettri, N., Shakya, B., Sharma, E.(eds.): Biodiversity Conservation in the Kanchenjunga Landscape, International Centre for Integrated Mountain Development, Kathmandu Nepal, 3–10 pp.

Sheng, Q., Li, J., Alam, M.S., Fang, X. and Guo, M., 2008. Gross composition and nutrient profiles of Chinese yak (Maiwa). Int. J. Food Sci. Technol. 43, 568–572.

Sherchand, S., Karki, N.P.S., 1996. Conservation and management of yak genetic diversity in Nepal. In: Miller, D.J., Craig, S.R. and Rana, G.M. (eds.): Proceedings of a workshop on conservation and management of yak genetic diversity, 29-31 October, Kathmandu, Nepal, 47–56 pp.

Shirley, K.L., Beckman, D.W. and Garrick, D.J., 2008. Inheritance of pulmonary arterial pressure in Angus cattle and its correlation with growth. J. Anim. Sci. 86, 815–819.

Shrestha, U. B., Shrestha, S., Chaudhary, P. and Chaudhary, R. P. 2010. How representative is the protected areas system of Nepal? Mount. Res. Develop. 30, 282 –294.

Sinclair, K., Fulkerson, W.J. and Morris, S.G., 2006. Influence of regrowth time on forage quality of pairie grass, perennial ryegrass and tall fescue under non-limiting soil nutrient and moisture conditions. Aust. J. Exp. Agric. 46, 45–51.

Singhfield, K.J., Bonnet, M. and Scollan, N.D., 2012.Recent developments in altering the fatty acid composition of ruminant-derived foods. Animal (doi: 10.1017/S1751731112001681).

Sørensen, M.K., Norberg, E., Pedersen, J. and Christensen, L. G., 2008. Crossbreeding in dairy cattle: a Danish perspective. J. Dairy Sci. 91, 4116–4128.

Stevens, S.F., 1993. Tourism, Change, and Continuity in the Mount Everest Region, Nepal. Geograph. Rev. 83, 410–427.

Storry, J.E. and Sutton, J.D., 1969. The effect of change from low-roughage to high-roughage diets on rumen fermentation, blood composition and milk fat secretion in the cow. Brit. J. Nutr. 23, 511–521.

Storz, J. F., Runck, A. M., Moriyama, H., Weber, R. E. and Fago, A., 2010. Genetic differences in hemoglobin function between highland and lowland deer mice. J. Exp. Biol. 213, 2565–2574.

Tess, M.W., Reodecha, C. and Robinson, O.W., 1987. Cytoplasmic genetic effects on preweaning growth and milk yield in Hereford cattle. J. Anim. Sci. 65, 675–684.

Thapa, T.B., 1997. Prospects of processing and marketing of yak milk based products from Nepal.In: Rongzhen, Y., Xingtai, H. and Xiaolin, L., 1997. Yak production in central Asian highlands. Proceedings of the second International Congress on yak, 1-6 September, Xining China, 12-16 pp.

Tu, Z.-C., Qiu, H. and Zhang, Y.-P., 2002. Polymorphism in Mitochondrial DNA (mtDNA) of yaks (*Bos grunniens*). Biochem. Gen. 40, 187–193.

Tulachan, P.M. and Neupane, A., 1999. Livestock in mixed farming systems of the Hindu Kush Himalayas. FAO Rome and International Centre for Mountain Development, Kathmandu Nepal. http://www.fao.org/docrep/x5862e/x5862e02.htm#P0 (accessed on June 28, 2013).

United Nations Development Program (UNDP), 2008. Human Development Reports. http://hdr.undp.org/en/reports/nationalreports (accessed on 28 June, 2013.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.

Vercoe, J. E. 1973. The energy costs of standing and lying in adult cattle. Br. J. Nutr. 30, 207–210.

von Borell, E., Langbein, J., Després, G. , Hansen, S, Leterrier, C., Marchant-Forde, J., Marchant-Forde, R., Minero, M., Mohr, E. , Prunier, A., Valance, D., and Veissier, I., 2007. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals: a review. Physiol. Behav. 92, 293–316.

Wachsmuth, N.B., Völzke, C., Prommer, N., Schmidt-Trucksäss, A., Frese, F., Spahl, O., Eastwood, A., Stray-Gundersen, J. and Schmidt, W., 2013. The effects of classic altitude training on hemoglobin mass in swimmers. Eur. J. Physiol. 113, 1199–1211.

Wales, W.J., Doyle, P.T., Stockdale, C.R. and Dellow, D.W., 1999. Effects of variations in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. Aust. J. Exp. Agric. 39, 119–130.

Wang, C.T., Long, R.J., Wang, Q.J., Ding, L.M. and Wang, M.P., 2007. Effects of altitude on plant-species diversity and productivity in an alpine meadow, Qinghai-Tibetan plateau. Aust. J. Bot. 55, 110–117.

Wang, D.P., Li, H.G., Li, Y.J., Guo, S.C., Yang, J., Qi, D.L., Jin, C. and Zhao, X.Q., 2006. Hypoxia-inducible factor 1a cDNA cloning and its mRNA and protein tissue speci c expression in domestic yak (*Bos grunniens*) from Qinghai-Tibetan plateau. Biochem. Biophys. Res. Comm. 348, 310–319.

Wang, D.P., Li, H.G., Li, Y.J., Guo, S.C., Yang, J., Qi, D.L., Jin, C. and Zhao, X.Q., 2006. Hypoxia-inducible factor 1α cDNA cloning and its mRNA and protein tissue speci c expression in domestic yak (*Bos grunniens*) from Qinghai-Tibetan plateau. Biochem. Biophy. Res. Comm. 348, 310–319.

Wang, H., Long, R., Liang, J.B., Guo, X., Ding, L. and Shang, Z., 2011. Comparison of nitrogen metabolism in yak (*Bos grunniens*) and indigenous cattle (*Bos taurus*) on the Qinghai-Tibetan Plateau. Asian- Aus. J. Anim. Sci. 24, 766 – 773.

Wang, N., Vandepitte, W. and Wu, J. C., 1994a. Crossbreeding yak (*Bos grunniens*) and yellow cattle (*Bos taurus*): simulation of a rotational system and estimation of crossbreeding means and heterosis effects. J. App. Anim. Res. 6, 1–12.

Wang, N., Vandepitte, W. and Wu, J.C., 1994b. Comparison of meat production potential of hybrids from *Bos grunniens* (yak) and six *Bos taurus* breeds: A deterministic simulation model for economic evaluation. J. Appl. Anim. Res. 5, 81–88.

Weber, R.E., 2007. High-altitude adaptations in vertebrate hemoglobins. Resp. Physiol. Neurobiol. 158, 132–142.

Weber, R.E., Lalthantluanga, R. and Braunitzer, G., 1988. Functional characterization of feta and adult yak hemoglobins: an oxygen binding cascade and its molecular basis. Archive Biochem. Biophys. 263, 199–203.

Wiener, G., Jianlin, H. and Long, R.J. (Eds.). 2003. The Yak. 2nd ed. RAP Publication 2003/06. FAO Regional Office for Asia and the Pacific. Bangkok, Thailand.

Will, D., Alexander, A.F., Reeves, J.T. and Grover, R.T., 1962. High altitude-induced pulmonary hypertension in normal cattle. Circ. Res. 10, 172-177.

Will, D.H., Hicks, J.L., Card, C.S., Reeves, J.T. and Alexander, A.F., 1975. Correlation of acute with chronic hypoxic pulmonary hypertension in cattle. J. Appl. Physiol. 38, 495–498.

Wille, M., Mairer, K., Gatterer, H., Philippe, M., Faulhaber, M. and Burtscher, M., 2012. Changes in cardiac autonomic activity during a passive 8 hour acute exposure to 5500 m normobaric hypoxia are not related to the development of acute mountain sickness. Int. J. Sports Med. 33, 186–191.

Wilson, R.T., 1997. Animal genetic resources and domestic animal diversity in Nepal. Biodiv. Conserv. 6, 233–251.

Wolf, J.B. and Wade, M., 2009.What are maternal effects (and what are they not)? Phil. Trans. R. Soc. B. 364, 1107–1115.

Woorons, X., Bourdillon, N., Vendewalle, H., Lamberto, C., Mollard, P., Richalet, J.-P. and Pichon, A., 2010. Exercise with hypoventilation induces lower muscle oxygenation and higher blood lactate concentration: role of hypoxia and hypercapnia. Eur. J. Appl. Physiol. 110, 367–377.

Wu, X.-H., Luo, Z., Yu, L., Ren, F.-Z., Han, B.-Z. and Nout, M.J.R., 2009. A survey on composition and microbiota of fresh and fermented yak milk at different Tibetan altitudes. Dairy Sci. Technol. 89, 201–209.

Wuletaw, Z., Wurzinger, M., Holt, T., Dessie, T. and Sölkner, J., 2011. Assessment of physiological adaptation of indigenous and crossbred cattle to hypoxic environment in Ethiopia. Livest. Sci. 138, 96–104.

Xiaolin, L., Zhouping, Z., Yaping, W., Jiping, Z., Kexuan, W. and Xinquan, Z., 2004. Investigation on mechanism of sterility of male hybrids between yak and cattle. Proceedings of the International Congress on Yak, Chengdu, Sichuan, China 2004, http://www.ivis.org (accessed on 5 May, 2013).

Xu, J., Chen, L., Lu, Y. and Fu, B. 2006. Local people's perceptions as decision support for protected area management in Wolong Biosphere Reserve, China. J. Environ. Manage. 78, 362–372.

Xue, B., Chai, S.T., Liu, S.J., Wang, W.B., Xie, A.Y., Hu, L.H., Zhang, X.W. and Zhao, Y.P., 1994. Study of the protein requirement of growing yak. Yak production in central Asian highlands. In: Rongchang, Z., Jianlin, H. and Jianping, W. (eds.). Proceedings of the first international congress on yak, Gansu Agricultural University, China, 1–6 August, 198–201 pp.

Yoshihara, Y., Chimeddorj, B. and Buuveibaatar, B., 2009. Heavy grazing constraints on foraging behavior of Mongolian livestock. Grassland Sci., 55, 29–35.

Zawadowsky, M.M., 1931. Zebu-yak hybrids: sterility of bulb, fertility of cows and material on the genetics of zebu-yak hybrids. J. Heredity, 22, 297–313.

Zemp, M., Blum, J.W., Leuenberger, H. and Künzi, N.,1989b. Influence of high altitude grazing on productive and physiological traits of dairy cows. II. Influence on hormones, metabolites and haematological parameters. J. Anim. Breed. Genet. 106, 289–299.

Zemp, M., Leuenberger, H., Künzi, N. and Blum, J.W., 1989a. In uence of high altitude grazing on productive and physiological traits of dairy cows. I. In uence on milk production and body weight. J. Anim. Breed. Genet. 106, 278–288.

Zhang, R.C., 2000. Interspecies hybridization between yak, *Bos taurus* and *Bos indicus* and reproduction of the hybrids. Recent advances in yak reproduction. http:// www.ivis.org (accessed on 5 May, 2013).

Zhang, Y., Zhou, J.W., Guo, X.S., Cui, G.X., Ding, L.M., Wang, H.C., Li, L.W. and Long, R.J., 2012. In uences of dietary nitrogen and non- ber carbohydrate levels on apparent digestibility, rumen fermentation and nitrogen utilization in growing yaks fed low quality forage based-diet. Livest. Sci. 147, 139–147.

Zheng ,Y., Si, X., He, Q., Jin, S., and Hong, J., 2008. Yak lactate dehydrogenase A4: purification, properties and cDNA cloning. Biosci. Biotechnol. Biochem. 72, 2448–2451.

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Barsila, S.R., Kreuzer, M., Devkota, N.R., Marquardt, S. 2013. Behavioral and physiological differences between yaks and yak crossbreds at two altitudes in Nepal. Proc. 17th meeting of the FAO-CIHEAM Mountain Pasture Network, June 2013, Torino, Italy, 117–118 (Abstr.).

Barsila, S.R., Devkota, N. R., Kreuzer, M., Marquardt, S. 2013. Welche Yak-Rind-Kreuzung ist besser an grosse Höhe angepasst? Eine vergleichende Studie physiologischer Parameter mit zwei Yak-Kreuzungen und Yaks im nepalesischen Himalaya. ETH Schriftenreihe Tierernährung Tagungsbericht, 2013 Band 36, 155–157(Abstr.).

Barsila, S.R., Devkota, N.R., Leiber, F., Kreuzer, M., Marquardt, S. 2012. Performance of yaks (*Bos grunniens*) on high altitude alpine pastures in Eastern Nepal. Proc. Soc. Nutr. Physiol. 21, 155 (Abstr.).

Barsila, S.R., Kreuzer, M., Devkota, N.R., Marquardt, S. 2012. Yaks and their crossbreds: Performance at two different altitudinal pastures in the Himalayan Mountains of Nepal. In: Feed for Health (Kreuzer, M., Lanzini, T., Liesegang, A., Bruckmaier, R. und Hess, H.D., Hrsg.), ETH Schriftenreihe zur Tierernährung, ETH Zürich, Band. 35, 159–161 (Abstr.).

Barsila, S.R., Devkota, N.R. 2012. Persistency of common fodder grasses under Melia tree based silvipastoral system. The sixth Nat. Conf. Sci. Technol., Sept. 25–27, Khumaltar, Lalitpur, Nepal (Abstr.).

Barsila, S.R., Devkota, N.R., Kreuzer, M., Marquardt, S. 2011. Effect of pasture site on milk yield and composition and body weight changes of transhumant naks (*Bos grunniens*) in Nepal. In: Zukunftsträchtige Futtermittel und Zusatzstoffe (Kreuzer, M., Lanzini, T., Wanner, M., Bruckmaier, R., Guidon, D., Hrsg.), ETH Schriftenreihe zur Tierernährung, ETH Zürich, Bd. 34, 141–144 (Abstr.).

Barsila, S.R., Devkota, N.R., Leiber, F., Kreuzer, M., Marquardt, S. 2011. Effect of pasture site and stocking density on milk yield and composition of yak-cattle crossbreds (*Bos grunniens* × *Bos taurus*) along a transhumance route of the Eastern Himalayan Mountains of Nepal. Proc. 8th Int. Symp. on the Nutrition of Herbivores (ISNH8). Advances in Animal Bioscience 2 (Part 2), 372 (Abstr.).

Barshila, I., Devkota, N. R., **Barsila, S. R.** 2011. Farmer's indigenous knowledge on adoption of fodder tree species in mid- hill farming systems of Nepal. The 6th National Convention of Nepal Animal Science Association (NASA), 25–26 September, Kathmandu, Nepal, 14–15 (Abstr.).

S. R. Barsila., Barshila, I. , Devkota, N. R. 2011. A case Study on Transhumant Migration of Baruwal Sheep and their crossbreds in the Kanchenjunga Conservation Area of Nepal. The 6th National Convention of Nepal Animal Science Association (NASA), 25–26 September, Kathmandu, Nepal, 25-26 Sept, 32–33 (Abstr.).

Barsila, S.R., Devkota, N.R. 2008. Nutritive value of common forages under shade at IAAS Livestock Farm, Rampur. In: Proc. 5th Nat. Sci. and Technol. Conf., 10–13, November, Kathmandu Nepal (Abstr.).

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