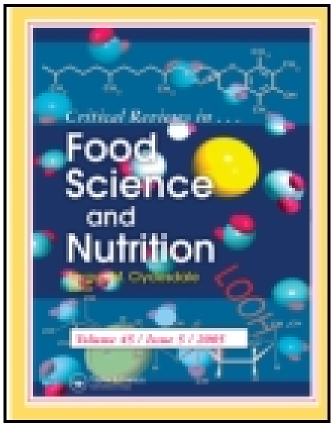

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Importance of Functional Ingredients in Yak Milk-Derived Food on Health of Tibetan Nomads Living Under High-Altitude Stress: A Review

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Importance of Functional Ingredients in Yak Milk-Derived Food on Health of Tibetan Nomads Living Under High-Altitude Stress: A Review

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Tibetan nomads have lived since ancient times in the unique and harsh environment of the Qinghai-Tibetan Plateau with average altitudes over 4000 m. These people have been able to live and multiply healthily over numerous generations under the extreme stress of high-altitude environment, including cold, hypoxia, and strong ultraviolet radiation, and with a simple diet devoid of vegetables and fruits for most of the year. Their survival depends heavily on yak milk, and its products comprise the main portion of their daily diet. In this review, yak milk and its derived products are examined in detail and compared with milk from other ruminant species. Yak milk products seem to be particularly rich in functional and bioactive components, which may play a role in maintaining the health status of Tibetan nomads. This includes particular profiles of amino acids and fatty acids, and high levels of antioxidant vitamins, specific enzymes, and bacteria with probiotic activity (yoghurt is the main food). Based on that, it is proposed that the Tibetan nomads have developed a nutritional mechanism adapted to cope with the specific challenges posed by the environment of the world's highest plateau. Systematic studies are required to demonstrate this in a more mechanistic way.

Keywords Yak milk, bioactive components, high altitude, oxidative stress, nutritional adaption, hypoxia

INTRODUCTION

Tibetan nomads are renowned for having made a living on 'the roof of the world', the Qinghai-Tibetan Plateau, by raising yaks (*Bos grunniens*) since ancient times. Archaeological evidence indicates human occupation of the Tibetan plateau as early as 25,000 to 50,000 years ago (An, 1982) which is earlier than any other high-altitude population (Aldenderfer, 1999). Tibetans could therefore represent the population most adapted to hypoxic conditions. Yaks, domesticated 8000–12,000 years ago (Guo, 2006), fulfill an important function in the Tibetans' life and in developing the prosperity of the people in the vast mountainous regions, where no other agricultural activities exist. Tibetan nomads use yaks for various purposes as they provide milk, meat, transportation, and fur and hide for clothing and shelter, as well as dried dung for fuel (Wiener, 2002). Still the main production purpose is milk (Dong et al., 2003). Although the global milk production from yak is insignificant compared with that produced by dairy cattle and other ruminants, it contributes 15% to Chinese milk consumption (Long, 1994) and is preferentially consumed by the Tibetan nomads (Beall and Goldstein, 1993).

It has been reported that metabolic adaptation to heat, cold, and high-altitude exposure may, in some instances, be accompanied by changes in nutrient requirements (Simon-Schnass, 1992). Energy expenditure, and vitamin and mineral

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requirements are increased under all three environmental conditions; moreover, dietary antioxidants are considered beneficial to reduce the increased oxidative stress associated with cold and high-altitude environments [hypoxia and ultraviolet (UV) radiation] (Askew, 1995; Owen and Johns, 2002). The body's metabolic response to cold and hypoxia can be either augmented by proper nutrition or impaired by inadequate nutrition (Askew, 1994). The composition of the diet of Tibetan nomads is usually quite simple. Besides baked Tibetan barley meal (known locally as *Zanba*), yak milk and milk products comprise the main portion of Tibetan pastoralists' daily food intake (Beall and Goldstein, 1993), and have been major sources of nutrients for Tibetan nomads for centuries. It was reported that Tibetan nomads do not consume vegetables or fruits for almost eight months of the year, or even throughout the year, yet they show no obvious signs of vitamin or mineral deficiency (Goldstein and Beall, 1987). This raises the question of how Tibetans are able to maintain their health under these extremely stressful conditions while consuming a diet of such a simple composition. It is likely that yak dairy products have played a vital role in maintaining the health of Tibetans in this hypoxic environment.

The aims of this review are, therefore, to describe the unique characteristics of the chemical and biochemical properties of yak milk-derived food compared with milk from other ruminant species and to provide evidence that the daily consumption of substantial amounts of yak dairy products plays a vital role in maintaining the health of Tibetan nomads. Furthermore, the possible mechanisms by which these food items may contribute to the adaptation of the nomads are discussed.

HEALTH CHALLENGES CAUSED BY THE HARSH ENVIRONMENT OF THE TIBETAN PLATEAU

It is well know that the unique stress at the high altitude of Tibetan Plateaus is hypobaric hypoxia caused by the decrease in barometric pressure with increasing altitude and reduction in atmospheric oxygen concentration (Beall, 2006). Hypobaric hypoxia becomes progressively more severe with increased altitude and stresses biological systems due to the impeded supply of oxygen required for metabolism in the mitochondria. Normally, living in an environment with hypoxia and, additionally, strong UV radiation causes changes to the cellular metabolism of organisms (Aldashev et al., 2005), and the abnormal metabolism found in histocytes is caused by metabolic disorders due to the increase in oxygen free radicals in the organisms.

Jefferson et al. (2004) reported that one of the main reasons for the suffering from oxidative stress by high-altitude residents is that the exposure to high altitude could weaken enzymatic and nonenzymatic antioxidant systems. Dosek et al. (2007) described that long-term exposure to high altitude, with the associated decrease in oxygen pressure, can result in oxidative/reductive stress, enhanced generation of reactive oxygen and nitrogen species, and related oxidative damage to lipids, proteins, and DNA. The severity of this metabolic challenge is related to the degree of altitude. Oxidative stress is one of the main causative factors for some common diseases experienced by high-altitude residents, such as premature senility, high-altitude brain edema, high-altitude pulmonary edema, and high-altitude erythrocytosis (Beckman et al., 1990), and is also considered to be associated with other diseases such as atherosclerosis (Ursini et al., 1998), carcinogenesis (Gasche et al., 2001), neurodegenerative diseases (Beal, 1995), coronary heart disease (CHD), stroke, and rheumatoid arthritis (Negri et al., 1991; Keli et al., 1996). Environmental factors such as hypoxia and exposure to UV light and cold together aggravate the above-mentioned diseases (Askew, 2002). The increased UV radiation experienced at high altitude is responsible also for other challenges (Simon-Schnass, 1994, 1996), which can result in eye damage and skin cancer. Although the Tibetan nomads are usually dressed with a minimum of skin exposure, their faces and hands are mostly exposed. As suggested by Fuchs and Packer (1991), UV-B and UV-A rays have enough energy to penetrate the dermis and even subcutaneous tissues.

LONG-TERM METABOLIC ADAPTION STRATEGIES OF INHABITANTS OF THE TIBETAN PLATEAU

Despite the constraints outlined above, the ethnic group of the Tibetan seems to have survived quite healthily on the world's highest plateau for numerous generations. This suggests that they have developed some unique adaptive mechanisms. The Tibetans rarely suffer from high-altitude sickness, and their eyesight and skin remain mostly uninjured. There is evidence for genetic adaptation (Simonson et al., 2010) as well as unique features of heart and pulmonary circulation in healthy Tibetan nomads compared with people living at sea level (Bärtsch and Gibbs, 2007; Penaloza and Stella, 2007). Compared with the latter, Tibetans have greater arterial oxygen saturation at rest and during exercise, and show less loss of aerobic performance with increasing altitude (Wu and Kayser, 2006). The Tibetan people also have a greater hypoxic and hypercapnic ventilatory responsiveness, larger lungs, and a greater lung diffusing capacity; moreover, their arterial oxygen and blood hemoglobin concentration is lower than in lowland inhabitants and high Andean populations living at similar altitudes (Ge et al., 1994; Beall et al., 1998; Beall, 2006, 2007). It was also reported that Tibetans develop only minimal hypoxic pulmonary hypertension and have higher levels of exhaled nitric oxide than lowlanders or high-altitude Andeans dwellers (Wu and Kayser, 2006). Several of the above findings are even occurring in Tibetans born at low altitude when exposed for the first time to high-altitude once adult (Wu and Kayser, 2006).

A proteomics study suggested that Tibetans at high altitude are protected from tissue damage induced by reactive oxygen species and possess a specific metabolic adaptation (Gelfi et al., 2004). Zhang et al. (2000) found that activities of superoxide dismutase in erythrocytes and glutathione peroxidase in plasma and plasma concentrations of vitamins E and C were significantly higher in native Tibetans than in migrants of Han Chinese (Hans) to the Tibetan Plateau. Conversely, hematocrit

Table 1 Comparison of concentrations of blood plasma variables in Tibetan and migrated Hans living at 4300 m altitude[a]

Variable	Tibetans	Hans	p-value[b]
Haematocrit (%)	51.1	58.2	<0.001
Superoxide dismutase activity in red blood cells (units/g hemoglobin)	12,731	11,571	<0.001
Malondialdehyde (μmol/L)	4.42	5.10	<0.05
Glutathione peroxidase activity (units)	137	126	<0.001
Vitamin C (μg/mL)	21.9	21.0	<0.05
Vitamin E (μg/mL)	8.55	7.77	<0.01

[a]Data taken from Zhang et al. (2000).
[b]Significance was declared at $p < 0.05$.

and plasma malondialdehyde were significantly lower in Tibetans than in Hans (Table 1). The total serum lipid profile of Tibetans would suggest a thrombogenic pattern with high proportions of palmitic acid and stearic acid and a low proportion of linoleic acid (Fujimoto et al., 1989), but findings with regard to serum phospholipids did not support this hypothesis (Pieroni and Price, 2006). Further, Owen and Johns (2002) showed that the Tibetans' serum profiles are characterized by higher high-density lipoprotein (HDL) and lower serum total cholesterol, apolipoprotein B, and lipoprotein levels compared with populations from Japan (Fujimoto et al., 1989), Korea, China, Belgium, and Nigeria (Kesteloot et al., 1990; Cobbaert and Kesteloot, 1992). This indicates the presence of a type of lipid metabolism defense mechanism against the development of atherosclerosis (Fujimoto et al., 1989), which is supported by the result from an epidemiological study comparing elderly Tibetans and Hans living either at the same altitude or in the lowlands (Yang et al., 2008). Accordingly, the prevalence of hypertriglyceridemia (5.0%) and low HDL cholesterol (3.1%) of Tibetans was lower than that found in Hans living in Tibet (22.5% and 10.7%, respectively) and in Beijing (14.7% and 8.4%, respectively; Yang et al., 2008).

These findings indicate that eating behavior must be critically important in mitigating high-altitude stress. There must also be a substantial consumption of dietary antioxidants to abate the altitude-induced oxidative challenges. Fruits and vegetables rich in antioxidant compounds would be very helpful in this respect (Owen and Johns, 2002; Hung et al., 2004; Nakamura et al., 2008), but are not commonly available in the diet of the Tibetan nomads. Instead, the dietary strategy of these people relies heavily on consumption of yak milk and milk products, with the associated high dietary fat intake. Such high intakes of fat might be considered detrimental to human health; however, Givens (2010) suggests that humans who consume large quantities of milk and dairy products are actually at a slightly lower risk of developing cardiovascular disease (CVD) than those who consume few of these foods.

There are many reports of dietary compounds conferring specific benefits to human health. For instance, reindeer milk plays an important role in maintaining the health of the Lapps from the polar region due to its high nutrient density. Reindeer milk contains more than 20% fat, three times more protein, double the mineral content, and more ascorbic acid than cow's milk (Haraldson, 1983). The cuisine in many countries around the Mediterranean contains considerable amounts of fish, seafood, and olive oil, which are rich in n-3 fatty acids (FA), and fruits and vegetables high in antioxidants, and is thought to prevent or reduce the risk of CHD (de Lorgeril et al., 1994; Bach-Faig et al., 2011). The Greenland Inuits have lower serum triaclycerol (TAG) concentrations compared with the Danish population despite high intakes of dietary fat, because this fat is especially rich in n-3 (omega-3) FA (Dyerberg and Bang, 1982; Bjerregaard et al., 1997). Elevated TAG concentrations are associated with an increased risk of CDH (Assmann et al., 1998; Sarwar et al., 2007).

An adaptive behavior to cope with high-altitude oxidative stress has been reported for some native highland tribes in India who often eat the seeds of *Trichopus zeylanicus*, which contain bioactive components with antioxidant capacity derived from polyphenols and sulfhydyl. Consumption of these seeds has been shown to scavenge free radicals and reduce the levels of lipid peroxidation and DNA damage (Tharakan et al., 2005; Dosek et al., 2007).

PROCESSING OF YAK MILK AND THE CONSUMPTION OF YAK MILK PRODUCTS BY THE TIBETAN NOMADS

According to Dong et al. (2003), the nutritionally dense and sweet yak milk is greatly liked by Tibetans. Most fresh yak milk is processed immediately by households into a variety of indigenous products capable of being stored for a considerable time under the climatic conditions of the Qinghai-Tibetan Plateau. Products include milk, butter, cream, yoghurt, and *Qula* (Table 2). Nondairy foods include *Zanba*, made from the baked highland barley meal, occasionally supplemented by consuming Tibetan sheep and yak meat. Yak milk and butter are usually mixed with tea and drunk by the nomads every day. *Qula* is a kind of dried curd, made by adding whey to skimmed milk, followed by sun drying of the curd. *Qula* is consumed as a snack by herdsmen when tending their grazing animals, together with milk and tea or is mixed with butter and barley meal to make *Zanba* (Cai, 1992). Among all yak milk products, yoghurt is the most important and is of considerable economic and dietary importance to the people of the Qinghai-Tibetan Plateau (Cao et al., 2004; Zhang et al., 2008). Yoghurt is consumed by the locals in amounts as high as 1 to 2 kg per day (Zhang et al., 2008). Due to its limited shelf-life, yoghurt is more readily available in the warm season (from June to September) when most milk is being produced. During the cold season (from October to May), other products serve as staple foods. Yak butter can be stored for a long time without undergoing oxidation. This is facilitated by the typically low temperature at the Tibetan plateau. When yak butter is blended with vegetable oil, it is possible to further extend its shelf-life (Neupaney et al., 2003a). The generally long shelf-life is attributed to the rich content of antioxidants in yak butter and because it is mainly composed of

Table 2 Daily consumption of yak milk and yak milk products by adult Tibetan nomads[a]

	Milk	Butter	*Qula*	Yoghurt
Daily intake	100–200 mL	50–100 g	30–80 g	1000–2000 g
Mode of consumption	Drunk in tea, 3 to 8 times daily	Drunk in tea, 3 to 5 times daily	Drunk in tea or eaten with baked barley meal	Drunk directly

[a]Data from Zhang et al. (2008) and Yang et al. (2008), based on an extensive household survey in Tibet and the Qinghai Province of China.

TAG (980 g/kg total lipids), few free sterols, and phospholipids (3.2 and 2.7 g/kg, respectively), and insignificant amounts of hydrocarbons and sterol esters (Neupaney et al., 2003a). Its specific FA profile also makes yak butter harder (melting point of 41°C vs. 36°C of butter produced from cattle milk; Neupaney et al., 2003b). Such properties have also facilitated its use in a unique art from known as ‘yak butter-flower,’ which provides a decorative exposition of Tibetan Buddhism and culture.

ROLE OF YAK DAIRY PRODUCTS IN COVERING DAILY NUTRIENT REQUIREMENTS AND MAINTAINING HEALTH OF THE NOMADS

There is evidence from the literature that yak milk has unique properties that make it particularly useful in meeting the nutritional requirements and sustaining the health of the Tibetan nomads. It could be hypothesized that the particular composition of yak milk reflects the animals’ ability to survive at such high altitudes with its nutritional stress during long cold winters. The animals have responded by developing unique mechanisms for accumulating metabolites, differing from those of other domestic ruminants. In general, yak milk has a higher nutrient density than milk from dairy cattle. Total milk solids, fat, and protein concentrations are almost twofold higher than the levels found in Holstein cattle, which are globally the most prominent milk-producing genotype (Table 3). Compared with cattle milk-based yoghurt, yoghurt made from yak milk is also richer in these nutrients (Table 4). The daily consumption of 1 kg of yak yoghurt provides 68% of the protein, 62.5% of the fat, 69% of the potassium, and 38% of the zinc (Zhang et al., 2008) required to meet the Chinese Dietary Reference Intakes (DRIs) for adults (Chinese Nutrition Society, 2000). The amount of calcium, phosphorous, and magnesium consumed with this amount of yak yoghurt would also meet the Chinese DRIs for each of these elements.

Energy Supply

By consuming large amounts of yak milk and butter, Tibetan nomads are able to derive sufficient energy to cope with elevated requirements in high-altitude environment (Askew, 1995). Tibetan nomads, who generally consume yak butter, are known to be very strong mountain climbers with fewer reported health problems (Neupaney et al., 2003a).

Protein and Amino Acid Supply

Like in dairy cattle, the major protein in yak milk is casein, accounting for over 60% of total proteins present (Sheng et al., 2008). A recent study by Mao et al. (2007) suggested that there were some active casein peptides in yak milk that exhibit an inhibitory activity against the angiotensin-I-converting enzyme. This would suggest that yak milk casein provides a natural antihypertensive component, with potential future commercial value in the field of functional foods. Sheng et al. (2008) reported that, like in cattle milk protein, glutamic acid is the most abundant amino acid in yak milk protein (Csapó-Kiss et al., 1995). This amino acid is an important excitatory neurotransmitter and also plays a vital role in the metabolism of sugars and fats (Garattini, 2000). Additionally, yak milk protein has a higher proportion of total essential amino acid than cattle milk (464 vs. 432 g/kg protein, respectively). Yak milk protein is especially richer in methionine than that of dairy cows (31 vs. 18 g/kg protein, respectively; Csapó-Kiss et al., 1995; Sheng et al., 2008). Methionine breakdown products are known to act as endogenous antioxidants by scavenging various oxidizing molecules (Levine et al., 1996). Therefore, the extra methionine may increase the antioxidant potential of the diet of the Tibetan nomads.

Saturated Fatty Acids

The saturated fatty acids (SFA) consumed with milk and milk products are a matter of concern for human health. A high consumption of especially the short- and medium-chain SFA is considered to increase the risk of developing CVD (Nakamura et al., 2003). Similar to milk fat of other ruminant species grazing high alpine pastures (Bianchi et al., 2003; Zeppa et al., 2003; Leiber et al., 2005), the proportion of these two classes of FA is clearly lower in milk and milk products originating from yak compared with products originating from more conventional feeding systems (Tuo, 2006; Or-Rashid et al., 2008). The total concentration of the SFA as a whole is also markedly lower in yak milk fat than in other ruminants’ milk fat (Table 5). Similar

Table 3 Comparison of composition of the milk from yak and Holstein cows (g/kg)

	Total solids	Fat	Protein	Lactose	Ash	Reference
Yak	157–184	55–86	42–64	33–58	4–9	Silk et al. (2006)
Holstein cattle	114–120	25–35	30–35	45–50	7	Bett et al. (2004); Martimez et al. (1991); Khorasani et al. (2001)

Table 4 Comparison of the composition of yoghurt prepared from yak and cattle milk (data from various sources)

	Total solids (g/L)	Fat (g/L)	Protein (g/L)	Lactose (g/L)	Ash (g/L)	Energy (MJ/kg)	Lactic acid bacteria (log CFU/mL)	Yeast (log CFU/mL)	Coliforms (MPN/100 mL)
Yak[a]	143	53.7	54.4	23.4	8.6	4.21	9.18[c]	8.33	20
Cow[b]	123	27	25	63	8	3.01	6–8[a]	3–6[c]	<90[d]

[a]Zhang et al. (2008).
[b]Cited from Institute of Nutrition and Food Safety, Scientific Academy of China (1991).
[c]Data quoted in Zhang et al. (2008)
[d]According to Guo (2003).
CFU = colony-forming units, MPN = most probable number.

results were also found in yak cheese and butter (Table 6). However, because the Tibetans' diet primarily consists of dairy products and meat (Beall and Goldstein, 1993), these people still are exposed to a higher thrombogenic risk than people consuming less fat and including vegetable oils in their diet. As the incidence of CVD is no greater than in other populations, this risk factor seems to be reduced by other properties of yak milk and milk products.

n-3 Fatty Acids

In general, the proportions of total polyunsaturated fatty acids (PUFA), total unsaturated fatty acid (UFA), and the *n*-3/*n*-6 FA ratio are higher in yak milk fat and its products than in milk fat from cattle, sheep, and goats (Tables 5 and 6). Recent studies have shown that yak milk and its products are particularly rich in some biologically active FA. This list includes the *n*-3 FA, especially 20:5 *n*-3 [EPA (eicosapentaenoic acid)] and 22:6 *n*-3 [DHA (docosahexaenoic acid)], but also 18:3 *n*-3 (Table 6). According to Du (2009), EPA and DHA account for 0.41% versus 0.19% and 0.25 versus 0.03 g/kg total FA in yak and cattle milk fat, respectively. Two authors report that 20:5 *n*-3 and 22:6 *n*-3 may even be absent in cattle milk (Yu et al., 2006; Du, 2009). Compared with Canadian cheddar cheese, cheese produced from yak's milk in Nepal has an *n*-3/*n*-6 FA ratio that is more than four times higher (0.87 vs. 0.20; Table 6). The ratio is also much higher than that found in goat cheese, but similar to sheep cheese. The content of *n*-3 PUFA in yak cheese lipids is much higher than in that of cheddar cheese (3.2 times), sheep cheese, and goat cheese (Table 6).

Reasons for these differences, apart from genotype effects, may include high-altitude grazing as a factor, because cattle grazing in the Alps at about 2000 m altitude is reported to have increased proportions of *n*-3 FA and *n*-3/*n*-6 FA ratio in their milk (Bianchi et al., 2003; Kraft et al., 2003; Hauswirth et al., 2004; Leiber et al., 2005). However, as this was mainly a result of elevated 18:3 *n*-3 and not of 20:5 *n*-3 and 22:6 *n*-3 (Leiber et al., 2005), a genetic influence specific for the yaks would seem a more probable explanation.

Table 5 Comparison of proportions of various groups of fatty acids in milk fat of different ruminants (g/kg of total fat)

Livestock species	SFA	MUFA	PUFA	CLA	Reference
Yak on pasture	675	281	44.3	21.7	Du (2009)
Cattle	744	232	24.2	10.8	Jahreis et al. (1999)
Ewe	731	230	38.5	10.8	Jahreis et al. (1999)
Goat on pasture	705	269	25.8	6.5	Jahreis et al. (1999)
Goat indoor	741	218	40.5	6.4	Jahreis et al. (1999)

SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, CLA = conjugated linoleic acids.

High blood cholesterol level, particularly the low-density lipoprotein (LDL) cholesterol, is a well-established risk factor for CHD; HDL cholesterol concentrations are inversely associated with this risk (Lunn and Theobald, 2006). High TAG concentrations are also reported being closely related with an increased risk of CHD (Austin, 1989; Assmann et al., 1998). Several meta-analyses have demonstrated that monounsaturated fatty acids (MUFA) and PUFA may reduce both total serum cholesterol and LDL cholesterol, and increase serum HDL cholesterol (Mensink and Katan 1992; Clarke et al. 1997; Howell et al. 1997), thus reducing the risk of CHD (Lunn and Theobald, 2006). Still *n*-3 FA and, especially, 20:5 *n*-3 and 22:6 *n*-3, are the most effective in that respect. Regular consumption of sufficient amounts of 20:5 *n*-3 and 22:6 *n*-3 may reduce the incidence of sudden death, myocardial infarction, stroke, atherosclerosis, CHD, inflammatory diseases, and perhaps even behavioral disorders (Connor, 2000; Harris et al., 2008; Simopoulos, 2008; Riediger et al., 2009; Gogus and Smith, 2010). The *n*-3 FA are essential for human health, and a deficiency-related disease may occur when they are consumed in quantities that are insufficient in relation to the *n*-6 FA. For adults, the *n*-3/*n*-6 FA ratio should be at least 0.25 in fatty foods (Simopoulos, 2002).

The particularly high ratio of *n*-3/*n*-6 of > 0.8 reported in milk from yaks and cows kept in the Alps may help to explain the so-called 'Alpine paradox,' meaning the presence of a robust cardiovascular health of alpine human populations despite a high fat intake (Hauswirth et al., 2004). Accordingly, the high ratio of *n*-3/*n*-6 FA and concentration of *n*-3 FA or other PUFA habitually consumed with yak milk and its products by the nomadic Tibetan people appear to play a vital role in maintaining their health. As outlined above, Tibetans have a thrombogenic serum lipid profile (Fujimoto et al., 1989), but other variables do not support this risk factor (Pieroni and Price, 2006). It remains to be explored whether the low CHD risk profile of Tibetans, as compared with the Hans described earlier (Yang et al., 2008) is the result of the consumption of the *n*-3 FA with yak milk

Table 6 Proportions of fatty acids and groups of fatty acids in cheese and butter from different ruminant species (g/kg of total fatty acids)

	Yak		Cattle (*Bos taurus*)		Sheep		Goat
Fatty acid	Cheese[a]	Butter[b]	Cheese[a]	Butter[c]	Cheese[d]	Butter[e]	Cheese[f]
n-3 PUFA	21	14	6.6	9.6	16	14	6.5
EPA	0.68	0.63	0.41	0.27	–	–	–
DHA	0.23	0.24	0.06	0.0	–	–	–
α-linolenic acid	17	8.3	4.9	8.6	16	6	6.5
Vaccenic acid	62	60	14	15	22	26	12
CLA	23	25	5.7	7.0	13.0	7.0	4.6
Linoleic acid	21	10	28	35	18	45	22
Arachidonic acid	1.2	1.3	1.5	3.6	–	2	–
SFA	595	627	651	682	684	662	728
MUFA	324	270	301	254	270	249	223
PUFA	45	41	37	65	46	69	40
n-3:*n*-6 PUFA	0.87	0.51	0.20	0.17	0.89	0.25	0.30

"–" indicates not detected.
[a]Or-Rashid et al. (2008).
[b]Yu et al. (2006).
[c]Baer et al. (2001).
[d]Addis et al. (2005).
[e]Zlatanos et al. (2002).
[f]Lucas et al. (2008).
EPA = eicosapentaenoic acid, DHA = docosahexaenoic acid, CLA = conjugated linoleic acids, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids.

and its products, or a genetic adaptation or both where yak milk might facilitate the expression of this favorable profile.

Conjugated Linoleic Acids

Extensive studies have demonstrated that conjugated linoleic acids (CLA), especially the *cis*-9, *trans*-11-18:2 isomer (rumenic acid), can have anticarcinogenic and antidiabetic (Type II) functions, and can improve bone mineralization, reduce body fat accretion, retard the development of atherosclerosis, and modulate the immune system (Belury, 2002; Barceló-Coblijn and Murphy, 2009; Benjamin and Spener, 2009). Oral administration of CLA to hypoxic rat was shown to significantly increase serum nitric oxide synthase (Wei and Wei, 2004). This enzyme catalyzes L-arginine to produce nitrous oxide, which is an endogenous relaxation factor of blood vessels and can alleviate the damage to cells, improve microcirculation, and inhibit lipid peroxidation, thereby preventing atherosclerotic lesions (Christodoulides et al., 1995; Tan et al., 2000). Like the *n*-3 FA, CLA may reduce the risk of development of CVD as it reduces plasma TAG, total plasma cholesterol, LDL cholesterol, and LDL/HDL-cholesterol ratio in animals (Lee et al., 1994; Nicolosi et al., 1997; Kritchevsky et al., 2000, 2002, 2004; Wilson et al., 2000) and in humans (Noone et al., 2002; Tricon et al., 2004).

Dairy products and foods derived from ruminants are the major dietary source of CLA, especially rumenic acid, for humans (Bauman and Lock, 2006). Rumenic acid is mainly formed in the mammary gland of ruminants from *trans*-11-18:1 (vaccenic acid), a ruminal biohydrogenation intermediate (Griinari et al., 2000). However, also the conversion of vaccenic acid to rumenic acid in the human body could substantially increase the metabolic supply of CLA. Therefore, ruminant-source food that is rich in vaccenic acid is favorable as well. Accordingly, biomedical studies with animal models have shown that vaccenic acid has anticarcinogenic and antiatherogenic properties because it is converted to rumenic acid (Bauman and Lock, 2006).

Proportions of total CLA, rumenic acid, and vaccenic acid in the fat of milk, butter, and cheese from yaks are at least twice as high as those observed in cattle (Tables 5 and 6; Neupaney et al., 2003a; Du, 2009). When comparing yak and Canadian cheddar cheeses, it was shown that this ratio was 4.2:1 and 2.8:1 for total CLA and total 18:1 *trans*-FA (Or-Rashid et al., 2008). Rumenic acid makes up proportionately 0.9 of total CLA in yak butter (Neupaney et al., 2003a; Or-Rashid et al., 2008). Thus, the daily ingestion of yak milk-derived foods may also contribute to the high-altitude tolerance of the Tibetan nomads as they are rich sources of CLA and vaccenic acid.

Different from the *n*-3 FA, the CLA content in milk appears to be promoted by feeding fresh and conserved grass as opposed to maize silage and concentrates (Leiber et al., 2005). Again, there may be a genotype effect, but also an effect caused by specific plant species expressing activity inhibiting certain steps of the ruminal biohydrogenation cascade. This was suspected as the cause of the very unusually high levels of rumenic acid found in two sheep species grazing mountainous pastures in Bulgaria (Leiber et al., 2010).

Antioxidant Vitamins

Vitamins A, E, and C are known to be major antioxidants, and assist in the elimination of free radicals. Vitamin A also

Table 7 Comparison of average concentrations of vitamins with antioxidant properties in milk products of yak and dairy cattle[a]

		Vitamin A	Vitamin E	Vitamin C	Reference
Milk	Yak	408 μg	1009 μg	150 mg	Chang (2007)
	Cattle	302 μg	903 μg	7 mg	Zhang et al. (2008)
Butter	Yak	4.0 mg	28.3 mg	–	Neupaney et al. (2003b)
	Cattle	6.9 mg	23.4 mg	–	Wang et al. (1999)
Yogurt	Yak	51.6 mg	–	17.4 mg	Zhang et al. (2008)
	Cattle	24.2 mg	4.4 mg	10 mg	

"–" indicates no data available in the literature.
[a]Data are presented as per 1 kg of either milk or milk products from yaks and cattle.

plays an important role in the maintenance of good eyesight. Extensive research indicates that an increased intake of antioxidant vitamins, especially of vitamin E, is beneficial in alleviating altitude-induced oxidative damage (Simon-Schnass, 1992; Askew, 1995; 2002; Schmidt et al., 2002; Dosek et al., 2007) and diseases induced by reactive oxygen species (Negri et al., 1991; Steinmetz and Potter, 1991; Keli et al., 1996). Oral supplementation of vitamin E (40 mg/day) in rats was found to reduce the increase in lipid peroxidation induced by exposure to a hypoxic environment equivalent to 7500 m of altitude (Ilavazhagan et al., 2001).

The vitamins with antioxidant properties are present in yak dairy products in higher concentrations than in the corresponding dairy products from cattle (Table 7) (Neupaney et al., 2003a; Chang, 2007). The DRIs of vitamins A, E, and C for adults (Chinese Nutrition Society, 2000) are 2500 IU, 14 mg, and 60 mg, respectively. From the data shown in Tables 2 and 7, it can be estimated that Tibetan adults can obtain sufficient vitamin A and at least 50% of DRIs for vitamins E and C only by the daily consumption of yak dairy products. Therefore, despite the almost complete absence of vitamin intake from vegetables during most of the year (Goldstein and Beall, 1987), yak dairy products provide a valuable alternative source of antioxidant vitamins, which explains why these people show no obvious signs of vitamin deficiency.

Enzymes

A comparative study showed that the activity of some hydrolases and oxidoreductases, such as acid phosphatase, alkaline phosphatase, lipase, catalase, and superoxide dismutase, are much higher in yak milk than in milk from Holstein cows (Tang, 2007). These enzymes could facilitate essential physiological functions by eliminating excessive reactive oxygen species (free radicals), which then do not exceed the levels tolerated in the bodies of high-altitude-dwelling Tibetans.

Probiotics and Undesired Germs

Consumption of yogurt is known to provide several health benefits, mainly due to its cultures acting as probiotics. The potential health effects of probiotic bacteria include blocking gastroenteric pathogens, neutralizing food mutagens produced in the colon, enhancing the immune response, lowering serum cholesterol, preventing colon cancer and hepatic encephalopathy, curing intestinal dysfunction and constipation, treating peptic ulcers, and normalizing stool transit (Lee et al., 2009; Dicks and Botes, 2010; Higashikawa et al., 2010).

The average count of lactic acid bacteria in yak yoghurt is higher than that in yoghurt made from cattle milk (Table 4). Therefore, it can be concluded that Tibetan nomadic people actually ingest large numbers of viable lactic acid bacteria with their high daily portion of yoghurt, especially in summer. Lactic acid bacteria, especially *Lactobacillus* spp. and *Bifidobacterium* spp., are important intestinal tract residents and are used as probiotic strains to improve health (Lee et al., 2009). *Lactobacillus fermentum* (31%) and *Lactobacillus casei* (28%) are the predominant lactic acid bacteria species in traditionally fermented yak yoghurt (Airidengcaicike et al., 2010).

As another group of potential probiotics, some yeast strains can inhibit the growth of spoilage and pathogenic microorganisms, and the combination of low pH produced by the bacterial starter with the alcohol and CO_2 produced by the yeasts is also inhibitory to many undesirable microorganisms (Ferreira and Viljoen, 2003; Narvhus and Gadaga, 2003). Like lactic acid bacteria, yeast numbers in yak yoghurt are higher than those in cattle yoghurt (Zhang et al., 2008; Chen et al., 2009; Table 4).

Coliforms, microorganisms derived from fecal contamination or enteric pathogens, seem to be much lower in yak yoghurt compared with cattle yoghurt (Table 4) and the maximum number recommended by the National Standard of People's Republic of China for yoghurt (GB 2746-1999; Guo, 2003). This low number of coliforms in yak yoghurt suggests that this food is quite safe. Thus, the production of yak yoghurt presents a very favorable and easy method of preservation.

Lactose Intolerance

Because of the high consumption of yak milk products, even by the adults, the question arises whether lactose intolerance, associated with diarrhea, is a problem in the Tibetan nomads. Lactose from intensive milk consumption has also been proposed as a possible risk factor for ischemic heart disease (Segall, 1994). This might be concluded from indirect metabolic evidence, considering that calcium can increase fecal excretion of lipids, and hence elicit a hypolipidemic effect, while this process is counteracted by lactose, which facilitates calcium absorption (Pieroni and Price, 2006). However, as unprocessed milk constitutes only a relatively small proportion of total consumption, it is not likely that this issue is of concern to Tibetans. Yoghurt contains much less lactose, because it is fermented by lactic acid bacteria (Pieroni and Price, 2006), and these bacteria can further help to ferment the remaining lactose in the digestive tract. Butter and cheese contain little or no lactose anyway, and these foods show no correlation with CVD (Segall, 1994).

Non-nutritional Functions

Yak milk and its products also have certain functions in the life of the Tibetan nomads, other than nourishment. Yak butter is believed to exhibit some unique physicochemical properties different from milk fat of other mammals. Therefore, it is also used as a natural medicine to heal wounds and provide relief from body pains. In addition, the nomadic people use yak butter to protect their skin from insect bites and the adhesion of pathogenic bacteria. To investigate the possible medical benefits of yak butter, a study was conducted to examine the tyrosinase inhibition activity of this product (Neupaney et al., 2003b). The results indicated that yak butter with its lactic acid, NaCl, citric acid, and ascorbic acid showed pronounced tyrosinase inhibition activity. Tibetan nomadic people live in a strong UV radiation environment and local people state that they often use the yak butter to protect their face and skin from sunburn or cold. The benefits can probably be attributed to the biochemical pathway by which the amino acid L-tyrosine in the yak butter is converted to melanin by tyrosinase; melanin is a vital component of skin and hair that facilitates pigment formation and protects the skin from damage by UV rays (Neupaney et al., 2003b). However, so far, relatively little is understood of the pharmaceutical role that yak butter plays in the daily life of the local people.

CONCLUSIONS

The relative richness of nutritional and biologically active ingredients in yak milk and its products, under the inhospitable high-altitude environment, is an excellent example of how an indigenous diet may have enabled these nomads to adapt and live healthily for thousands of years in the extreme environment of the Qinghai-Tibetan Plateau. Although some research has been conducted to investigate the multifunctionality of yak milk and its products, systematic studies are still needed to demonstrate the potential role of the functional ingredients in the foods derived from yak milk on human health in a more mechanistic way. The Tibetan nomads as managers of the plateau ecosystem not only rely heavily on other biological components such as microbial sources, vegetation, and animals, but have coexisted and been interdependent on these foods for a very long time. However, global warming and overgrazing in recent decades is leading to a destabilization of the Tibetan ecosystem, which is a potential risk to the simplicity of the Tibetan herders' food chain because of a reduction in both quantity and quality of yak milk. That such changes may have an adverse impact on Tibetan nomads' health, and possibly even the long-term survival of their present system of pastoral agriculture, should also be the cause for serious concern.

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