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Composition and Properties of Camel Milk

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Jiwan Sidhu*

Abstract

Camel is considered as one of the most important and ecologically harmless domesticated animals in the dry region of Asia and Africa. Camels have considerable economic importance not only as a draught animal, but also for their milk and its by-products. They can produce a significant amount of milk from poor feed as compared to any other dairy species. This characteristic, in addition to the growing recognition of the economic value, and health benefits of camel milk make it a center of attention for people, particularly in arid- and semi-arid areas. Moreover, camel milk is a highly nutritious medium permissive for the growth of many diverse bacterial species. These bacterial populations are mainly grouped into pathogenic, spoilage, and technologically relevant bacteria. This chapter reviews the existing knowledge on the composition, nutritional value, health-promoting properties, and economic value of camel milk and its by-products. Furthermore, the relevant studies describing the microbiota of camel milk are included.

Keywords: camel milk, pathogens, probiotics, economic value, human health

1. Introduction

Camels are domestic animals exceptionally well-adapted to arid lands. They can survive extended dry periods and heat and reproduce under harsh conditions, intolerable to other domestic animals. According to the Food and Agriculture Organization of the United Nations, 28 million camels were enumerated worldwide in 2016 [1]. There are two species of camels, one-humped Arabian camels or dromedaries (*Camelus dromedarius*) found in the Arab peninsula mostly in the Horn of Africa, the Sahel, Maghreb, Middle East, and South Asia. The second species is the two-humped Bactrian camels (*Camelus bactrianus*) domesticated in China and Mongolia [2]. The economic value and other benefits of camels make them the focus of attention of numerous scientific studies pinpointing the anatomic characteristics, a physiological adaptation of camels to adverse climates, and the bioactive molecules present in camel milk [3]. Their humps consist of stored fat that can be metabolized when food and water are inaccessible beside the ability of their organs to release water when needed. As additional ways for adaptation to their environment, camels have a third, clear eyelid protecting their eyes from sand and flat broader feet for walking in the desert. Camels are multi-purpose animals raised for riding, carrying loads, and producing milk, wool, hair, and meat (**Figure 1**). Milk is the most valuable camel product and it is known as 'white gold of the desert' [4, 5]. It is mainly consumed raw

by the Bedouins (people who inhabited the desert) where access to green vegetables and fruits is limited, thus providing, in that case, a significant nutritional relevance. Although camel milk is linked to the culture identity of Bedouins for a long time, small-scale and large-scale farms for intensive production of camel milk have been implemented worldwide only in recent years. The establishment of these farming systems was synchronized with the increased consumer's interest in unprocessed raw non-bovine milk consumption. While cow milk represents 82% of the total quantity of milk produced in the world, non-bovine dairy species provided 133 million tons in 2016 [1]. Camel is considered one of the most important dairy animals contributing to about 0.3% of the milk produced in the world [1] (Figure 2). Raw camel milk has



Figure 1.
Dromedary camel.

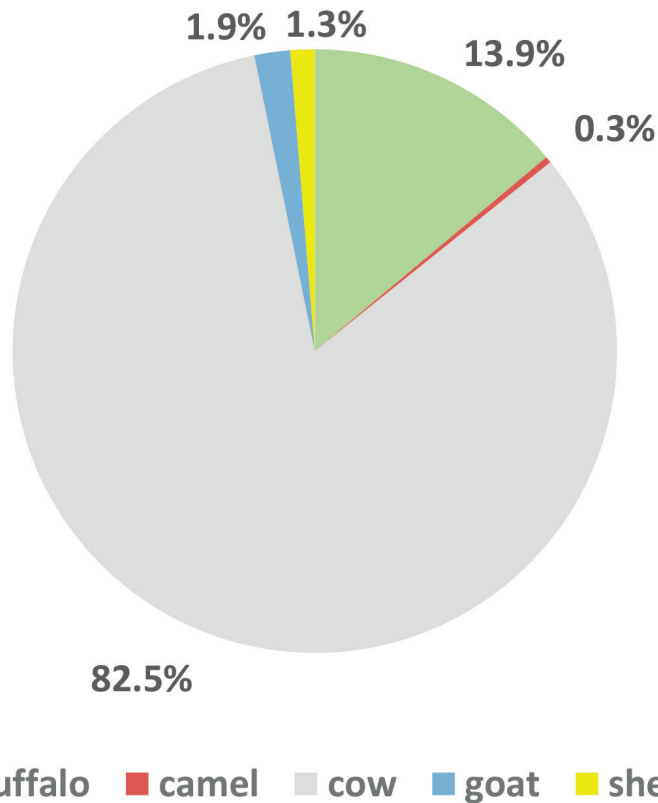


Figure 2.
Pie chart showing the percentage of the total quantity of milk produced by different species in the world.

been reported to possess several technological and medicinal advantages: (i) it can be produced in significant amounts from poor feed than any other dairy species in geographical areas with climatic constraints; (ii) it contributes to the national incomes and the international market integration; and (iii) it satisfies the growing consumer demand for functional foods that, in addition to their nutritional values, have health benefits [6]. Moreover, camel milk is a highly nutritious medium permissive for the growth of many diverse bacterial species. These bacterial populations are mainly grouped into pathogenic, spoilage, and technologically relevant bacteria (health promoter, starter cultures, and preservative agents) [7]. The microbial composition can significantly influence the safety and technological properties of this type of milk. Consequently, the consumption of raw camel milk or of dairy products made with milk that was poorly handled or not properly pasteurized can lead to serious food infections and foodborne diseases. Despite the importance of the information regarding the safety level of raw camel milk, studies investigating its microbiota are limited. Therefore, further studies in this field are required. This chapter reviews the existing knowledge on the composition, nutritional value, health beneficial properties, and economic value of camel milk and its by-products. Furthermore, the relevant studies describing the microbiota of camel milk and the approaches used for their detection are also included.

2. Past and present of camel milk

During the last 50 years, a fundamental shift has occurred in the way of housing and managing the camels. Today, in some countries, the extensive or nomadic production system for camels has become semi-intensive or intensive modern well-organized farms and industries [8]. Camels were known as “ships of the desert” commonly used as a mean of transport for thousands of years, carrying up to 600 lbs. on their backs. Currently, they are mainly considered for their milk and meat production, in particular, their milk. Camel milk contributed to the non-bovine milk production with a total amount of 2.7 million tons in 2016 [1]. Since the quantity and quality of milk production are highly dependent on the housing and management of animals, intensive production systems are currently being set up. All the world over, camel milk has proved to be suitable for producing various derived products with significant nutritional value [9].

3. Chemical composition and nutritive value of camel milk

Concurrently with the growing interest in foods that, in addition to their nutritional values, have physiological benefits, the attention toward camel milk is notably increasing [10]. The specific composition of camel milk makes it a promising alternative to bovine milk. Compared with the milk produced by other ruminants, camel milk is mainly valued for its better digestibility in the human gastrointestinal system due to the smallest milk-fat globules and its hypoallergenic properties [11]. As in human milk, dromedary camel and Bactrian camel milk do not contain β -lactoglobulins. There are no reports concerning allergy indicators possessed by these milks. Therefore, α -lactalbumin is the main whey protein in camel milk whereas this protein constitutes only 25% of the total whey proteins in cow milk [12]. Also, the fat globules in camel milk are the smallest among all ruminants, and they do not naturally aggregate due to the absence of agglutinin [9]. Consequently, camel milk can easily be digested and safely consumed by people with weak immune systems or lactose intolerance and can be considered a valid substitute to

bovine milk for children more than 2 years old [13, 14]. Moreover, camel milk has lower amounts of fat, protein, and carbohydrates compared to bovine milk [15, 16]. Milk is one of the major contributors to saturated fatty acid (SFA) and unsaturated fatty acid (USFA) intake. The SFA content of milk has received much attention due to its association with the increased cholesterol level in the plasma and subsequently the cardiovascular disease risk. However, the monounsaturated fatty acids (MUFA) are known to be a healthy cardioprotective type of fat [17]. Interestingly, the SFA content of Bactrian camel milk (average 50/100 g total FA) and dromedary camel milk (average 60/100 g total FA) is lower and slightly lower than that of cow milk, respectively. The MUFA content in dromedary camel milk (56–80/100 g total FAs) is higher than in cow milk (26/100 g total FAs) [18]. This fact may have beneficial effects on consumers with cardiovascular disease risk. Camel milk has higher amounts of certain vitamins and minerals. Its richness in vitamins, especially vitamin C (24–52 mg/kg) which is 3–5 times and 1.5 times higher than bovine and human milk, respectively, gives this milk a great significance in arid areas where green foods are not easily available [19]. Bactrian camel milk is a source of vitamin A (approximately twice that in cow milk) and is high in vitamin D and riboflavin. Two cups of camel milk supply 160% of the recommended nutrient intake of vitamin D (5 µg/day) and 0.5 mg/day of riboflavin [20]. In addition, this milk could provide the most of nutritional mineral requirements of humans due to its mineral content being almost similar to that of human milk [9]. Compared to goat and cow, it contains 55% more zinc, an essential trace element considered as the limiting dietary growth nutrient in populations suffering from deficiencies in micronutrients [21].

4. Health beneficial properties of camel milk

Camel milk is not only valued for its physicochemical composition, but traditionally, camel milk and its fermented products have also been consumed for many years due to consumer's recognition of its important health-promoting properties. Camel milk has been known for its ability to promote bone formation in infants, and its curative properties against many internal diseases [22]. Nowadays, these medicinal virtues have been scientifically supported, in particular, the association of camel milk with a decreased prevalence of diabetes type I and II by reducing the demand for insulin in patients and improving residual β -cell function in the pancreas, due to its immunomodulatory influence [23]. This hypoglycemic potential is either due to the presence of insulin-like small molecules that are easily absorbed into circulation compared to insulin from other sources or to the existence of insulin in camel milk in indigestible form, i.e., encapsulated in nanoparticles (lipid vesicles) [24]. In addition to its anti-diabetic properties, camel milk and its derived products have a therapeutic role in gastrointestinal ulcers, liver disorders, diarrhea causing viruses, and tuberculosis [25]. Moreover, this milk has received great attention for its ability to cure several diseases including jaundice, lung- and spleen-related illnesses, asthma, anemia, autism, edema, milk allergies, and dermatological autoimmune diseases [15, 16, 26, 27]. Additionally, camel milk is considered a good source of many antimicrobial substances and bioactive compounds, such as, lactoferrins and immunoglobulins, in addition to a greater quantity of lysozyme [28]. The level of lysosomal enzyme (N-acetyl- β -d-glucosaminidase) that provides antimicrobial activity is high in camel milk as compared to other ruminants. This may confer a strong innate immunity providing higher natural resistance toward infections [29]. As camel milk is a highly nutritious medium supporting the growth of various bacterial species, in particular, lactic acid bacteria, it is considered to be

Geographical area	Milk sample type	Detected genus	Bacteriocin	Reference
Kuwait	Raw camel milk	<i>Enterococcus faecium</i>	Enterocins A, B, and P	[58]
Algeria	Raw camel milk	<i>Enterococcus faecium</i>	Enterocins L50A and L50B	[43]
China	Fermented camel milk (Shubat)	<i>Lactobacillus casei</i>	Caseicin TN-2	[22]
Jordan	Raw and fermented camel milk	<i>Lactobacillus plantarum</i> <i>Lactobacillus rhamnosus</i> <i>Lactobacillus brevis</i> <i>Lactobacillus paracasei</i> <i>Lactobacillus fermentum</i>	Bacteriocin-like substances	[59]
Saudi Arabia	Raw camel milk	<i>Lactobacillus acidophilus</i>	Acidophilucin AA105	[60]
Algeria	Raw camel milk	<i>Leuconostoc mesenteroides</i>	Leucocin B	[3]
Algeria	Butter made from camel milk	<i>Lactobacillus plantarum</i>	Bacteriocin-like substance	[61]

Table 1.
 Published studies on isolation of bacteriocin-producing lactic acid bacteria from camel milk and its by-products.

a potential source of probiotics and novel bioactive compounds. The few published studies on camel milk have shown that this milk is considered a niche of lactic acid bacteria producing antimicrobial peptides (bacteriocins) (Table 1).

5. Economic value of camel milk and its by-products

Although most of the camel milk is consumed raw or fermented by the local community, this milk and its by-products are now being promoted in the market and have considerable economic importance internationally due to the following properties: (i) It has specific nutritional features and health benefits; (ii) camels possess exceptional adaptation to poor quality and quantity of feed, and they can produce a significant amount of milk during the whole year, even during the dry season [30, 31]. Milk yield in camels is approximately 3.5 kg/day in hot summer [32], and it could reach a maximum of 6000 L/lactation in selected breeds in Saudi Arabia [33]; (iii) it has a long lactation period of about 12 months but it may last up to 24 months depending on the farming and breeding systems [21]; (iv) it can significantly contribute to the national revenues as the total production of camel milk was estimated to be 1.3 million tons [34], with the global trade of \$10 billion per year; (v) machine milking of dromedaries is now under design to improve the camel milk production [35].

Shortly, a higher amount of camel milk is expected to be available to the dairy industry. There are indications of the potential for growth of this market in the future and that camel milk manufacturers will dramatically expand [36]. Many manufacturers of camel milk-based products are spread out worldwide; for example, Desert Farms (US), Camel Milk Victoria (Australia), Vital Camel Milk (Kenya), Camel Milk UK (UK), Wang Yuan Camel Milk (China), and Camel Milk



Figure 3.
Camel milk based products in Australia.

Australia (Australia). Large camel farms are being established, and increased funding for camel research is noticed. Moreover, a wide variety of camel milk-derived products are now available in the market, including various new dairy products, such as pasteurized milk, fermented milk, flavored milk, butter, cheese, and milk tea [37, 38]. As a specific example, Bactrian camel milk is used for making cheese, butter, and yogurt in Mongolia [13]. Traditional fermented camel milk is produced and consumed in several countries, such as, Shubat (Turkey, Kazakhstan, and Turkmenistan), Suusac (Eastern Africa, Kenya, and Somalia), and Garis (Sudan and Somalia). Despite the effort made by researchers to produce yogurt from camel milk, the manufacturing of this by-product needs more study due to the fact that camel milk does not easily coagulate [39]. In Dubai, a coffee shop business specializing in different hot and cold drinks and pastries made with fresh camel milk called “Cafe2go” was set up recently. Since 2011, it has expanded successfully to 10 locations in Dubai and Pakistan and is soon to be opened in Oman and Saudi Arabia. Furthermore, camel milk utilization is not limited anymore to the producer region only, but it is now marketed overseas also. It has recently been exported from the United Arab Emirates to the European Union [40]. Furthermore, recent studies have investigated the optimization of fermentation processes [41] and cheese-production from camel milk [42].

Based on the belief of many consumers that camel milk products address various allergies and skin problems, this milk reached the international markets due to the manufacturing of a broad range of healthcare products, including soap, lip balm, hand cream, and lotions. Other cosmetic product lines based on camel milk have also been developed (**Figure 3**).

6. Microbiota of camel milk

In light of the industrial interest generated in camel milk, its by-products and its medicinal features, the investigation of the safety and quality of camel milk became mandatory. In the past, the majority of the scientific studies focused on the anatomic characteristics, a physiological adaptation of camels to adverse climates, and the biomolecules present in camel milk [3]. However, information on the microbiology of camel milk is very limited. While many studies focused on the microbiology of cow, sheep, and goats milk, only a few studies have focused on camel milk despite

the fact that the difference in the composition of camel milk compared to milk from other animals, its biological features, and its production in a desert environment could underlie significant differences in its microbial ecosystem and its biological characteristics [7, 43].

Nevertheless, the available information on camel milk microbiota originates from studies based mostly on a culture-dependent approach, which is culturing the microbes using general or selective media followed by subsequent analysis.

Milk in general and camel milk, in particular, is a highly nutritious product providing an ideal environment for the growth of a diverse and complex microbial population. The nature and abundance of the microbial load are highly influenced by many parameters, such as, the surrounding environment (conditions of milk collection) and camel health status, in particular, because the mastitis disease has a great influence on the milk bacterial composition [44]. These bacterial populations are mainly grouped into two major categories: (i) beneficial and technologically relevant bacteria and (ii) pathogenic and spoilage bacteria. So far, only a few studies relying on the culture-dependent approach have been conducted on the identification of the bacterial populations of camel milk [5, 45, 46]. These studies are summarized in **Table 2**. It is well known that the specific bacterial composition of milk has a direct impact on the development of texture and flavor of the finished dairy product [47]. Several lactic acid bacteria present in raw milk have been proven to be technologically relevant in dairy products. Among these bacteria, *Lactococcus* spp., in particular, *Lactococcus lactis*, are primarily known for their role as starter cultures for the cheese industry and are also recognized for the production of flavor compounds [48]. *Lactobacillus* spp. are another example of bacteria found in raw milk, which has been used for many industrial dairy applications. They can contribute to the quality and nutritional value of dairy products through their proteolytic activity and ability to produce aroma compounds [49]. These genera are one of the dominant bacterial populations isolated from camel milk. Beside the technological properties of these microorganisms, it is also known that raw camel milk microorganisms have a health-promoting effect through aiding digestion or reducing the frequency of allergies, including asthma and atopic diseases [50–52]. In addition, camel milk is dominated by biologically active bacteria that produce many antimicrobials, including bacteriocins, antifungal agents, organic acids, and hydrogen peroxide in camel milk, which probably confer to this milk its extended shelf life, evidently resulting in safer consumption even during storage for several days in the absence of refrigeration [53]. The antimicrobial agents produced by these microbial species might be regarded as biopreservative agents that could be used to extend the shelf life and safety of camel milk products and could be of interest to the dairy industry.

On the other hand, microorganisms can also have a negative impact on the quality of camel milk and its shelf life, resulting in milk spoilage. The consumption of raw camel milk contaminated with pathogens can lead to, in some cases, severe illness [46]. Also, the presence of potentially pathogenic bacteria in raw camel milk can have implications for the animal and human health and are, therefore, relevant issues to be considered. Like other dairy animals, camels can also be affected by mastitis, which is defined as the inflammation of one or more of the teats (mammary glands) and is considered as one of the most important diseases in the dairy industry worldwide [54]. It can cause economic loss by reducing the milk production, lower probability of conception, higher treatment cost, and transmission of the disease to other species of animals [55]. It causes suffering for camels and poses a public health risk too. Recent studies on camels have described the effect of mastitis on milk hygiene and yield as well as on the immune system at the level of the mammary gland [40, 56]. Bacterial infections are considered to be the primary

Geographical area	Type of camel	Milk sample type/source	Aim of the study	Media used	Detected genus	Reference
Morocco (four zones) (n = 12)	Dromedary camel	Raw camel milk Composite samples Farm	<ul style="list-style-type: none"> Assessment of the hygienic quality of camel milk Detection of LAB and pathogens 	MRS; Baird-Parker; Litsky medium	<i>Enterococcus</i> (58.8%) <i>Pediococcus</i> (28.2%) <i>Streptococcus</i> (4%) <i>Lactococcus</i> (8%) <i>Leuconostoc</i> (1%)	[62]
Morocco Different regions in the south of Morocco (n = 30)	Dromedary camel	Raw camel milk Individual samples Farm	<ul style="list-style-type: none"> Detection of LAB 	MRS; M17; MSE	<i>Lactobacillus</i> (37.5%) <i>Lactococcus</i> (25.8%) <i>Leuconostoc</i> (11.7%) <i>Enterococcus</i> (10.8%) <i>Streptococcus</i> (9.2%) <i>Pediococcus</i> (5%)	[45]
Iran Golestan (n = 10)	Dromedary camel	Raw camel milk Individual samples Farm	<ul style="list-style-type: none"> Detection of LAB Study of antimicrobial activity and probiotic traits 	MRS; M17; KAA	<i>Enterococci</i> (51%) <i>Lactobacillus</i> (11%) <i>Leuconostoc</i> (5%) <i>Weissella</i> (2%) <i>Pediococcus</i> (2%)	[5]
Kazakhstan (Four regions) Almaty, South Kazakhstan, Kyzylorda, and Atyrau (n = 26)	Dromedary camel	Raw camel milk Fermented camel milk Individual samples Farm	<ul style="list-style-type: none"> Detection of LAB and yeast 	MRS; M17	<i>Enterococcus</i> (51.3%) <i>Lactobacillus</i> (29.8%) <i>Lactococcus</i> (10.9%) <i>Leuconostoc</i> (8%)	[63]

Geographical area	Type of camel	Milk sample type/source	Aim of the study	Media used	Detected genus	Reference
Kenya Central division of Isiolo district of Kenya (n = 15)	Dromedary camel	Fermented camel milk Individual samples Farm	<ul style="list-style-type: none"> Detection of LAB 	MRS	<i>Leuconostoc</i> (24%) <i>Lactobacillus</i> (16%) <i>Lactococcus</i>	[64]
Abu Dhabi (n = 50)	Dromedary camel	Raw camel milk Individual samples Farm	<ul style="list-style-type: none"> Study of probiotic traits 	MRS	<i>Lactococcus</i> <i>Lactobacillus</i>	[65]
Sudan Nine regions Central, western, northern, and eastern geographical areas of Sudan	Dromedary camel	Fermented camel milk 'Garis'	<ul style="list-style-type: none"> Identification of the microbial populations present in Garis Detection of LAB and yeast 	PCA; MRS; M17; PDA	<i>Streptococcus</i> (68%) <i>Lactobacillus</i> <i>Enterococcus</i> <i>Lactobacillus</i>	[66]
Sudan Transhumance and nomadic herds (n = 28)	Dromedary camel	Fermented camel milk 'Garis'	<ul style="list-style-type: none"> Assessment of the microbial contents 	PCA; MRS; M17	<i>Streptococcus</i> (50%) <i>Lactobacillus</i> (50%)	[67]
Sudan Dongola, Kasala, El Gadarif, El Obied, and Omdurman (n = 12)	Dromedary camel	Fermented camel milk 'Garis'	<ul style="list-style-type: none"> Detection of LAB 	MRS; M17	<i>Lactobacillus</i> (66.6%) <i>Lactococcus</i> (33.3%)	[68]
Middle Saudi Arabia Qassim region (n = 33)	Dromedary camel	Raw camel milk	<ul style="list-style-type: none"> Assessment of the microbial quality Detection of pathogens 	PCA; PDA; Baird-Parker agar	<i>S. aureus</i> (70%) <i>Salmonella</i> (24%)	[69]

Geographical area	Type of camel	Milk sample type/source	Aim of the study	Media used	Detected genus	Reference
Somalia Fafen zone, Ethiopian Somali regional state (Gursum, Babile) (n = 126)	Dromedary Camel	Raw camel milk	<ul style="list-style-type: none"> • Assessment of the microbial quality • Detection of pathogens 	Edwards Medium; MSA; MAC; EMB agar; XLD; Brilliant Green Agar; Salmonella and; Shigella Agar; TSI	<i>Staphylococcus</i> (89.8 %) <i>Streptococcus</i> (53.7 %) <i>E. coli</i> (31.5 %) <i>Salmonella</i> (17.6 %) <i>Klebsiella.</i> (5.6 %) <i>Enterobacter</i> (5.6%)	[46]
Egypt Sinai, Aswan, and Sharqia governorates (n = 185)	Dromedary camel	Raw camel milk	<ul style="list-style-type: none"> • Monitoring the possibility of transmission of milk borne pathogens • Detection of pathogens 		<i>Salmonella</i> <i>E. coli</i> <i>Listeria</i>	[70]

Table 2.

Published studies on the bacterial populations detected in raw camel milk and its fermented products using culturing methods and subsequent analysis.

cause of mastitis in domestic animals. The major causes of camel mastitis have been investigated using a classical bacterial culturing approach [32, 54, 57]. Thus, the proper control of this disease will not only improve the quality and quantity of camel milk produced but would also reduce the public health risk to the camel milk consuming population.

7. Conclusions

Camel milk is known for its nutritional quality, being rich in vitamins C and A and low in SFA, its smaller fat globules, and being easy to digest and rich in many minerals and bioactive compounds. The medicinal virtues of camel milk and its association with a decreased prevalence of diabetes type I and II have attracted many studies, but more research is needed to dissect the mechanism of action of the insulin-like small molecules, which may be responsible for the anti-diabetic properties present in camel milk. Further studies are also required to examine the role of camel milk in treating several diseases such as gastrointestinal ulcers, liver disorders, and dermatological autoimmune diseases. In addition to that, camel milk has been proven as a highly important source of natural bioactive compounds and antimicrobial substances that could be targeted to develop functional and health promoting products for the well-being of human population in the coming years.

Conflict of interest

Authors have no conflicts of interest to declare.

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