MOROCCAN TRADITIONAL FERMENTED DAIRY PRODUCTS: CURRENT PROCESSING PRACTICES AND PHYSICOCHEMICAL AND MICROBIOLOGICAL PROPERTIES - A REVIEW

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ABSTRACT

Milk is an important source of energy and a wide range of vital nutrients, but can also harbor a variety of microorganisms that can be important sources of foodborne diseases. Storage conditions and poor processing of raw milk can lead to spoilage and reduced food safety. Indeed, the role of milk fermentation is to mitigate the impact of these conditions by enhancing shelf life and food safety. Traditional fermented dairy products are widely distributed in Morocco and rely on product specific microbiota responsible for texture, aroma and flavor. Therefore, the knowledge of indigenous microbiota of Moroccan raw milk and fermented dairy products can be of great interest in preservation of Moroccan traditional dairy products. The traditional dairy products included in this review are Lben (a fermented milk), Rayeb (a coagulated fermented milk), Zebda beldiya (a raw fresh butter), Smen (a fermented butter), and Jben (a fresh cheese). Other products were referred as Lfrik (a fermented camel milk) and Klila (a hard cheese). Little information is available on the general characteristics and processing practices of these traditional fermented dairy products. Therefore, this review will provide a brief overview of available data about artisanal dairy products preparation, and physicochemical and microbiological characteristics.

Keywords: Moroccan fermented dairy foods, Lben, Rayeb, Zebda beldiya, Smen, Jben, Lfrik

INTRODUCTION

Milk is an important source of nutrients that can be obtained from a wide variety of animals like cows, sheep, goats and buffalo, as well as humans. Milk delivers high nutrient contents including proteins, vitamins, carbohydrates, minerals, fats and essential amino acids. Milk is often consumed as raw as well as in the form of fermented dairy products for an extended shelf life (Jans et al., 2017). Fermentation process is one of the oldest and most economical technology for producing and preserving foods as well as improving their nutritional values and sensory properties (Garcia-Burgos et al., 2020; Marco et al., 2017; Rasane et al., 2017). It has been practiced since olden times as a low cost effective method to ensure the longevity of products (beverages and foods) (Gadaga et al., 1999).

Traditional fermented foods are defined as foods prepared by indigenous people from animal or plant materials, using their skillful technology and inherited knowledge (Rawat et al., 2018). They can be manufactured by the action of native microorganisms or by the addition of starter cultures containing microorganisms able to convert the substrates into socially and ethically edible products suitable for the local population (Koutinas, 2017).

Fermented dairy products are consumed worldwide, and are vital components of human diets in many parts of the world (Rasane et al., 2017). Their manufacturing process consists on following the fermentation of milk by a particular group of microorganisms, which results in a decrease of pH and a subsequent coagulation of milk proteins (Hallén, 2008). Most commonly found microorganisms in fermented dairy products are Lactic acid bacteria (LAB). The fermentation action of LAB is widely known to have a crucial role in the preservation and the production of nutritious fermented foods (Satish Kumar et al., 2013).

In recent years, fermented dairy products have experienced a substantial increase due to their high nutritional and health related benefits including the prevention of lactose intolerance and accumulation of galactose (Shiby & Mishra, 2013), due to the action of LAB, which lead to the removal of lactose and galactose. They are also supportive in preventing the gastrointestinal infections as well as reducing serum cholesterol levels (Rasane et al., 2017). In addition, fermented dairy products are beneficial for maintaining a healthy configuration of the celiac microbiota (Kok & Hutkins, 2018). The latter has a crucial protective effect against many diseases and can support physiological homeostasis (Rawat et al., 2018).

Fermented dairy products play also a vital role in enhancement of whole quality, aroma and taste of the milk (Sanlier et al., 2019) as well as improvement of the bioavailability of essential nutrients such as vitamins, amino acids and minerals.

Located in northern Africa, Morocco has a long and ancient tradition in dairy products consumption. Its eating habits, based on vegetables, cereals and animal products, contribute to low prevalence of cardiovascular diseases and obesity (Mehio Sibai et al., 2011; Srairi et al., 2013). Since the independence era (early 1960s), the country has experienced a rapid demographic growth coupled with diet changes. As a result, a sharp increase in food demand has occurred, especially in animal products like meat and dairy products (Lampietti et al., 2011). The latter have an important place in the traditional diet of Moroccan people and are part of the main staple foods (Srairi et al., 2013).

Fermented dairy products in Morocco have an important place in the traditional diet, not only because they serve as a milk preservation form, but also meet the need for diversifying milk products, while contributing to enhance the digestibility, functionality as well as the nutritional profile of milk.

Milk in Morocco comes from four different sources including cows, sheep, goats and camels. According to the Food and Agriculture Organization corporate statistical Database (FAOSTAT, 2021), Morocco was home to an estimated 3.31 million cattle, 5.93 million goats, 21.59 million sheep and 60 thousand camels. Total national milk production has more than doubled in 25 years, going from 513 thousand tons in 1975 to 1.25 million tons in 2000. This production continued to grow very rapidly to reach 2.64 million tons in 2019. The average milk yield in the same year was estimated at 1.46, 0.03, 0.208 and 0.27 tons/year for cows, sheep, goats and camels, respectively (FAOSTAT, 2021).

The milk in Morocco is processed both by approved industries and by a multitude of small traditional traders working in small dairy shops locally known as “Malahbas”. They are mainly located in popular suburbs in large cities where around 10 to 15% of Moroccan raw milk are processed (Srairi et al., 2013). In these traditional urban dairies, raw milk can be sold out fresh or converted into traditional fermented dairy products, which are an integral part of the Moroccan heritage.

Because of their refreshing qualities, these traditional fermented dairy products are very popular in the country and are highly appreciated and consumed. The most popular Moroccan fermented milk products manufactured using traditional methods are Lben (a fermented milk), Rayeb (a coagulated milk), Zebda beldiya (a raw fresh butter), Smen (a fermented butter) and Jben (a fresh cheese). Other products were referred as Lfrik (a fermented camel milk) and Klila (a hardened...
cheese obtained by dehydrating the curd from Lben). Their physicochemical properties are similar to those commercially produced yogurt, fresh cheese and butter. They are basically manufactured by allowing the raw milk to ferment naturally at ambient temperature for 1 to 3 days depending on the season. The coagulated milk Rayeb is thus obtained. It can be consumed as is or churned in an earthen jar to separate Lben from Zebda beldiya. The latter is transformed into salted butter Smen and consumed as a food additive. Jben is produced by placing Rayeb in a clot at ambient temperature and draining the whey. With regard to Lyrik, this one is obtained by the spontaneous fermentation of camel milk at ambient temperature. Klilo is produced by heating Lben until curdling. The overview of these indigenous fermented dairy products is represented in Figure 1.

**Figure 1 Schematic illustration of production of principal Moroccan traditional fermented dairy products.**

Consumers in all over the world demand for dairy products of high quality, hygiene, standards and proper presentation (Zalalem & Faye, 2013). A good hygienic quality of milk is necessary for producing fermented dairy products of good quality and adequate shelf life (Pathot, 2019). The quality control of milk and fermented milk products mainly addresses chemical and microbiological composition. The chemical composition, in particular fat content is usually used as a quality test (Zalalem & Faye, 2013). The density of milk is also used to test the addition of water to milk or removal of fats (Ehner et al., 2017). Free fatty acids (FFAs) and peroxide values (PV) serve as indicators of rancidity of butter (Esfarjani et al., 2019).

The microbiological content of milk and fermented dairy products is a major feature in determining their quality. On the one hand, milk and traditionally fermented dairy products are generally a major source of microorganisms that are important in the dairy industry due to the desirable flavors and physical characteristics they produce during their manufacture (Zalalem & Faye, 2013). On the other hand, dairy products may become contaminated with spoilage and pathogen germs or microbial toxins and thereby serve as vehicles for several diseases to consumers (Cancino-Padilla et al., 2017). They are also able to cause physical defects and off flavors in dairy products (Marchand et al., 2017).

Several factors may have a significant influence on the microbial composition of milk and traditionally made dairy products including health status of the animal, origin and quality of milk, environmental conditions such as temperature, manufacturing and sanitary conditions as well as geographical location (Ouali, 2009; Owusu-Kwarteng et al., 2020).

While the knowledge on the hygienic aspects of the most popular Moroccan fermented dairy products and raw milk has been widely discussed (El Marnissi et al., 2013; Filali, 2018; Haini et al., 2018; Menane et al., 2007a), few studies have addressed the characterization and identification of their microbiota. In fact, a thorough identification of the microbiota of these products can be useful in order to establish and preserve the microbial species diversity of Moroccan dairy products, as well as the selection of appropriate starter cultures for dairy fermentation (Ouadghirii et al., 2005). Thus, this review is intended to provide the current status of knowledge from available data of the main microbiota identified in Moroccan raw milk and traditional fermented dairy products. The review also summarizes research results on the physicochemical properties of these products, as well as their indigenous manufacturing process.

**Moroccan traditional fermented dairy products**

**Raw milk**

The Codex Alimentarius defines milk as normal mammary secretion from milking animals obtained from one or more milkings, without any addition or subtraction, intended for consumption as milk liquid or further processing (CODEX STAN 206-1999, 1999). Milk is considered as a nutritious food for humans and also constitutes a favorable environment for microbial growth, including spoilage and food-borne pathogens (Chye et al., 2004). Over the past decade, the traditional Moroccan diet -which was previously characterized by high consumption of cereals and vegetables and a low consumption of meat and dairy products- is rapidly transforming into a westernized diet (El Kinany et al., 2020). One of the most nutritional changes was the increasing consumption of dairy products (103 g/person/day) (FAO, 2019). In Morocco, several animal species like cow, goat, sheep and camel provide milk for human consumption. The national milk production in 2019 was estimated in 2550000, 45935, 35512 and 8860 tones for cows, goats, sheep and camels, respectively (FAOSTAT, 2021). Cow’s milk is considered as the most common type of milk in terms of availability and quantity produced.

Cow’s milk is considered as a staple in many diets, healthy drink and its consumption is associated with a quality diet. It provides an easily accessible matrix containing a wide variety of essential nutrients such as vitamins, minerals and easily digestible proteins, which are essential for all body functions (Steijns, 2008). It is sold at 6 MAD (Moroccan Dirham) (Lben).

Along with meats, grains, fruits and vegetables foods, dairy products are nutrient dense foods, providing many nutrients that are relatively low in energy and are considered as essential for health throughout the life cycle (Drewnowski, 2005). Furthermore, their consumption is also associated with beneficial effects on human health (Mitsu et al., 2007).

Also, milk and dairy products have served as functional food ingredients vectors including fatty acids, phytosterols and various probiotics. In addition, these products are a rich source for the development of large variety of innovative health promoting ingredients, which find their way onto market like “dietary supplements” (Michaelidou & Steijns, 2006). Furthermore, milk proteins are preferentially introduced into special formula intended to reconstruction of muscle mass and tissues for infantile, aged, athletes, and hospital patients (Steijns, 2008).

**Moroccan traditional fermented dairy products**

Morocco has a wide range of traditional fermented dairy products included in consumers habits and highly appreciated (Benkerroum & Tamime, 2004). Their nature depends on type of milk used, pretreatments, fermentation conditions and subsequent treatments. The dairy production enjoys a very special status in agricultural sector and development plans. In addition to income generation opportunities, it contributes to supply of food for Moroccan population, in full demographic development, and whose consumers habits are evolving towards more quality products in dietary protein (Srairi et al., 2005).

**Lben**

The traditional Moroccan Lben is a fermented milk obtained by spontaneous fermentation mainly of cow’s milk, or in smaller quantities of goat’s, camel’s or sheep’s milk. Therefore, these minoritary milks are used alone or in combination with cow’s milk (Benkerroum & Tamime, 2004; Tantauoi-Elaraki & El Marrakchi, 1997). It is sold at 5 MAD.L⁻¹. In order to prepare Lben, raw milk is heated in a earthenware jar or in a goat leather bag called “Checou” and kept at room temperature for 24-72h - depending on the temperature during the summer and winter, respectively- until souring and coagulation occurs (Samet-Bali et al., 2012). After coagulation, the resulting product is called Rayeb, which is separated after vigorously shaking during 30 to 40 min into Lben and Zebda beldiya (raw butter) (Benkerroum & Tamime, 2004; Tantauoi-Elaraki & El Marrakchi, 1987). Finally, Lben is added with 10% of water to facilitate butter recovery (water is added cold or hot depending on ambient temperature to bring the temperature of the whole to a level suitable for collecting the grains of butter).

Traditional Moroccan Lben usually lasts for 2 or 3 days, since afterwards it becomes more acidic over time and very sour, acquiring a bitter taste and a strong yeast flavor (Mangia et al., 2014). This can be attributed to the growth of undesirable microorganisms present in raw milk (such as coliforms, enterococci and Bacillus species), equipment and personal (Benkerroum & Tamime, 2004; Erkmen & Bozoglu, 2016; Mangia et al., 2014).

**Rayeb**

**Rayeb** is a traditional Moroccan coagulated milk, obtained by spontaneous fermentation, which has some resemblance to yoghurt. It is semi-solid product and has a pleasant taste and odor. It is also smooth, thick and of uniform appearance and sold at 25 MAD.L⁻¹. Rayeb, a very popular traditional fermented product, is consumed in Morocco by weaning age children and elderly. It constitutes a primary fermented whole milk product, from which other products can be processed (Lben and Zebda beldiya). Several milk types are used (cow’s, goat’s, ewe’s or camel’s milks) in Rayeb process. The fermentation takes place normally at ambient temperature (approx. 15-30°C) for 24-72 h (Bendimerad et al., 2012).
Zebda beldiya

Zebda beldiya, product with great commercial value (60 MAD.kg⁻¹), can be obtained by churning fresh milk, fermented milk, or cream (Mourad & Bettache, 2020). Indeed, the use of fermented milk has several advantages:

- The product is homogenous and stable.
- The production is easy.
- It allows the accumulation of milk for several days.
- Its process is faster than that based on fresh milk.

Moreover, with fermented milk, a higher percentage of milk fats may be extracted. It gives a more stable product, probably due to the presence of low pH which can eliminate some pathogens (Mourad & Bettache, 2020; O’Connor & Tripathi, 1992).

Sometimes, a limited amount of water (about 10%) is added to improve the cohesion of fat globules and to increase yields of Zebda beldiya recovered manually (Benkerroum & Tamime, 2004). In addition, some manufactures filtered Lben on a canvas in order to collect the maximum amount of butter (Tantaoui-Elaraki & El Marrakchi, 1987).

The use of mechanical churning machine contributes to flotation of fat globules on Lben surface. Subsequently, it will be removed using a perforated spoon. Due to its higher moisture content, this butter has a strong diacetyl flavor and a smoother surface just before packaging step or incorporated in raw butter during manufacturing steps (Benkerroum & Tamime, 2004).

Smen

Zebda beldiya can be transformed into another homemade traditional product called Smen (Benkerroum & Tamime, 2004). Indeed, Smen is a fermented and salted Moroccan butter (contain approx. 8-10% of salt), mainly consumed as a food additive or as an ingredient in processed foods (Sarhir et al., 2021). It is also designed to conserve and protect butter for a long time (Benkerroum & Tamime, 2004). Also, its pleasant and unique aroma can enhance and improve the taste of many Moroccan plates (Sarhir et al., 2021; Tantaoui-Elaraki & El Marrakchi, 1987).

This Moroccan traditional fermented butter has been sold at more than 120 MAD.kg⁻¹. The preparation of Smen mainly brings out the following characteristics: a) absence of any heat treatment; b) salting constitutes element of preservation. Smen manufacture is carried out in several steps:

- First, the curdled milk is prepared through spontaneous fermentation of cows’, ewes’ or goats’ raw milk.
- The raw butter is separated from the fermented milk by the churning step (Sarhir et al., 2021).
- The butter obtained is washed with warm water, decanted and then replaced by fresh salted water. This step is repeated so many times until the rinsing water is becoming clear. This indicates that the product is free from any residual Lben that may cause spoilage/putrefaction during the maturation step (Benkerroum & Tamime, 2004).
- Smen is salted (at approx. 8-10% of salt) and packaged in an earthenware pot, completely compacted to avoid trapped air.
- The pot is completely filled to minimize free space and promote anaerobiosis.
- Smen is stored in dark and cool place for about 3 to 6 months for maturation. In some Moroccan regions, this container is barred underground to ensure anaerobiosis, darkness and to minimize temperature variations (Benkerroum & Tamime, 2004).

Moreover, storage conditions are also standardized (anaerobic conditions and ambient temperature) (Marrakchi et al., 1986). This artisanal technology, practiced throughout Morocco, is subject to some modifications (according to provinces and regions). Indeed, raw butter can be made from a mixture of cow’s and goat’s milk. This method of preparation is carried out in the southern and northern regions of Morocco, where goat farming predominates (Marrakchi et al., 1986). Besides, before salting, raw butter can be exceptionally submitted to heat during 1 hour to promote residual water evaporation. This type of Smen is only made in Marrakech (Marrakchi et al., 1986). Finally, Smen can be flavored with coarsely ground leaves of aromatic plants, like thyme or rosemary, to prevent molds growth and to enhance the flavor of end product. They are either placed on Smen surface just before packaging step or incorporated in raw butter during manufacturing steps (Benkerroum & Tamime, 2004).

Jben

Jben is an artisanal fresh cheese, manufactured with traditional techniques, without intentional addition of starter cultures. It is the most famous fresh cheese in Morocco and has been widely manufactured and consumed for a very long time (Ouadhghiri, 2009). The consumption of Jben has increased lately, due to the installation of a large number of traditional dairies in urban areas. This traditional product is prepared from raw milk using often artisanal procedures. Indeed, the artisanal methods are essentially based on the knowledge acquired from a long experience (Salmerón et al., 2002). Besides this traditional sector, some semi-industrial dairy units are also interested in manufacture of Jben, using both raw or pasteurized milk, and more or less improved preparation processes (Benkerroum & Tamime, 2004). Consequently, as result of these different methods used for preparation of Jben, different varieties of this white fresh cheese (as an artisanal cheese of special characteristics) are marketed under popular name of Jben (Benkerroum & Tamime, 2004). Indeed, the technological parameters have a great influence on final characteristic of cheese and can play an important role in its microbial composition, which is considered by manufactures and consumers as a special characteristic of artisanal cheese (Randazzo et al., 2009).

In general, Jben is made from either cow’s or goat’s milk. The manufacturing process requires three major steps: coagulation of milk, drainage of whey and molding (Benkerroum et al., 2007a).

- The coagulation consists in incubating raw milk at room temperature for a variable period to promote the multiplication of lactic acid bacteria (that will play an important role in acidification of milk). This coagulation can be spontaneous or induced by rennet or any other coagulating enzyme. The coagulant activity (constancy) is determined by milk temperature, acidity and strength of rennet (Randazzo et al., 2002).
- After renneting, milk is left to stand at room temperature for 6 to 10 hours. Then, the curd (coagulum) is recovered by filtration using canvas. The curd obtained, characterized with high moisture content, is salted at 1 g. 100g⁻¹ (Hamama et al., 2002) to improve draining of residual whey and to extend product shelf life.
- The drained Jben is processed in molds that give cheese its shape and can be submitted optionally to mechanical pressure actions.

Other traditional Moroccan products

Lfrik

In Morocco, precisely in southern area, the traditionally fermented raw camel milk is called Lfrik. The preparation of this product is carried out in goat skin bags (named “Tassoufra”) by spontaneous fermentation at ambient temperature during about 12h (Alaoui Ismaïli et al., 2017,2018). Generally, Lfrik is prepared from unpasteurized camel milk, however, some preparations are based on pasteurized milk. As result, different sensory characteristics of Lfrik are obtained (Alaoui Ismaïli et al., 2017).

In addition to Lfrik, other locally fermented camel milk products (such as Sligh and Mtame) are processed using similar equipment and techniques and with different incubation periods. Indeed, Sligh andMtame are fermented during 3h and 24h respectively, which confered to product different sensory properties (Alaoui Ismaïli et al., 2017).

Klika

Klika is a traditional fresh cheese manufactured from raw cow’s milk with spontaneous fermentation (Guetoanche & Guessass, 2015). Klika is prepared by heating Lben to obtain curd. The curd cheese is drained and dried (Leksiir et al., 2019; Memnane et al., 2007a,b) Cheese (Klika) can be consumed fresh or after drying step. This product is mainly prepared in Taza, Tetouan, Tangier and Oujda (Morocco).

Physicochemical characteristics of raw milk and traditional fermented dairy products of Morocco

Raw milk

Milk is a white, matte and slightly viscos liquid whose composition and physicochemical characteristics vary significantly depending on the animal species, and even between races (Soryal et al., 2004). These variations are primarily due to the state of animal such as age, health status, heredity, diet, lactation period, milking speed and conditioning at milking time (Ercolini et al., 2009).

Milk constitutes an emulsion of fat in a liquid, which has similarities with blood plasma. This liquid is itself a suspension of protein material in a serum. The latter is a neutral solution containing mainly lactose and mineral salts (Musambycemaria, 2011). Also, regarding its physicochemical composition, milk is considered as a solution, an emulsion and a suspension. Indeed, lactose and mineral salts (in ionic state or undissociated salts) are in solution. The nitrogenous...
materials (like casein) are in suspension, and fat being in emulsion (Benacir, 1983).

Milk contains a large amount of water, carbohydrates, lipids, proteins, and mineral salts. It contains other minor constituents such as enzymes (lipase, phosphatase, lactoperoxidase, protease), pigment (β carotene), vitamins (A, D, B) and dissolved gases (carbon dioxide, nitrogen, oxygen) (Amiot et al., 2002).

Recent studies conducted in different Moroccan regions showed that the chemical properties of Moroccan raw milk are usually variable depending on the type of milk and the region. With regard to cow’s milk, samples collected from Gh Barb Chraida region of El Hasen farms region located in the north-west of Morocco showed a significant variations in terms of chemical composition of fats, proteins and total solids content (Chrif et al., 2019). The average fat content varied from 3.45 to 3.81% with an average value of 3.57%. The protein content varied from 2.92 to 3.17% with an average of 3.05% and the total solids ranged from 8.92 to 9.48 % with an average value of 9.2%.

Another study conducted by Hinini et al. (2018) showed a variability average in the nutritional quality of cow’s milk collected from different regions of Morocco. The milk fat content average obtained from the west-North of the country ranged from the highest value of 37.6 g. L\(^{-1}\) to the lowest value of 33.4 g. L\(^{-1}\) recorded in the North-west areas. The other graded values were about 34.56 and 34.51 g. L\(^{-1}\) in the North and West areas, respectively. Moreover, the average values recorded for milk protein content were between 27.8 and 30.6 g. L\(^{-1}\), whereas for the total solids, they ranged from 115.9 to 122.9 g. L\(^{-1}\).

Regarding Moroccan camel milk, analysis on its physicochemical characteristics revealed an average pH of 6.47, a density of 1.026, a donic acidity of 0.19%, 0.15% of chlorine, 0.87% of ashes, 2.55% of proteins and 2.72% of fats (Afaouisi Ismaili et al., 2016). The same authors revealed a significant effect on the period of the year on fats, proteins and lactose milk contents. In fact, summer camel milk was revealed to have the lowest total solids contents. Another study conducted by Kouniba et al. (2005) on Moroccan camel milk revealed an average pH value of 6.64, a lactic acid content of 0.64%, an acidity of 0.17% and density of 1.032. The camel milk was also composed of 10.8% of total solids, 2.7% of fats, 3.3% of proteins, 4.1% of lactose, 0.83% of ash and 0.24% of chlorides.

In addition to cow and camel milk, the chemical composition of Moroccan goat’s milk was also revealed by Moroccan authors. According to Nontia & Saida (2017), goat’s milk was characterized by a pH value of 6.64, a lactic acid content of 1.77 g.L\(^{-1}\), 13.3% of dry matters, 0.73% of ash, 4.16% of fat and 3.6 % of total nitrogenous matters. Another study conducted by Zantar et al. (2010) revealed that goat’s milk samples collected from two regions of Morocco (the north and oases regions) showed a relatively similar results with a slight superiority concerning dry matters in the milk from oases regions with values of (14.69 vs 13.38%), ashes (0.75 vs 0.67%) and fat content (4.53 vs 3.58%) and from the north region for proteins (3.54 vs 3.98%).

The chemical composition of raw milk varies depending on breed differences, lactation stage, climatic conditions, environment, animal health, diet, feeding practices and animal genetic (Adler et al., 2013; Arnaud et al., 2009; Chrif et al., 2019; Hinini et al., 2018; Moran et al., 2018; Parmar et al., 2020). This variation affected directly yield and quality of processed dairy products (Parmar et al., 2020; O’Callaghan et al., 2017). Indeed, in addition to physicochemical properties, the processed dairy products quality can be linked principally to fat, fatty acid and protein (casein) contents of raw milk (Murphy et al., 2016; Parmar et al., 2020).

Moroccan traditional fermented dairy products

**Lben**

In addition to type of milk used, the physicochemical composition of Lben varies considerably between different farms, regions and localities (Ouadghiri et al., 2009). This variation also depends on chemical composition of raw milk and manufacturing procedures (Benkerroum & Tamime, 2004; El-Baradei et al., 2008).

Lben was characterized by a high acidity (0.81%) and a low pH (4.25), which consequently give this product its specific acid taste (Tantaoui-Elaraki & El Marrakchi, 1987). According to Benkerroum & Tamime (2004), fermentation of lactose increases the titratable acidity in Lben to more than 0.6% of lactic acid. Therefore, pH and lactose all fall below 4.7 and 3.7 g.100 g\(^{-1}\) respectively. In another study carried out by Marrissi et al. (2013), pH of Lben samples analyzed was 4.5 and titratable acidity measured was 80°D. Lben also contained 2.7, 0.9, 2.5, 6.5 and 0.17 % of lactose, fat content, proteins, total solids and chlorides, respectively (Tantaoui-Elaraki & El Marrakchi, 1987).

The fermentation of citrate in milk by microorganisms (especially Lactococcus lactis strains, Enterococcus, Leuconostoc and Lactobacillus species) (Beresford, 2011) results in volatile compounds accumulation, including ethanol, acetoin, acetaldehyde and diacetyl (Figure 2). These components play an important role in development of aroma in Lben (Tantaoui-Elaraki & El Marrakchi, 1987). Ethanol was reported to be present at 179.3 mg.L\(^{-1}\). It was quantitatively the most important volatile compound that might contribute to a typical flavor and aroma of the product. However, its concentration in Lben was too low to give it a typical alcoholic taste (Benkerroum & Tamime, 2004). The amounts of diacetyl and acetoin in Moroccan Lben were also very small (Tantaoui-Elaraki & El Marrakchi, 1987).

![Figure 2 Aroma compounds found in traditional Moroccan Lben (adapted from Benkerroum & Tamime, 2004).](image-url)

**Rayeb**

Rayeb is considered as a product with important nutritional values, since it constitutes a high source of major nutrients (carbohydrates, proteins, fat and vitamins). When consumed fresh, it constitutes low health risks due to its low pH (ranging from 4.2 to 4.5), at which most spoilage and pathogenic microorganisms are inhibited (Gonfa et al., 2001).

The chemical composition of Moroccan Rayeb, was determined by Hamama & Bayi (1991). The values of chemical composition were 10.7%, 2.22%, 3.1%, 4.2%, 0.1%, 0.54% for solids, fat, protein, lactose, chloride and ash, respectively. As stated above, Rayeb was also characterized by a low pH (approx. 4.2), a lactic acid content of 0.67% and a titratable acidity of 70.4°D (Hamama & Bayi, 1991; Marrakchi et al. 1993).

**Zebda beldiya**

The physicochemical composition of Zebda beldiya is depending on several factors such as the animal, its breed, age, health, status and stage of lactation. Environmental conditions as well as herd management also affect the product composition (Alganesh & Yetenayet, 2017).

According to Marrakchi et al. (1986), traditional Zebda beldiya was characterized by pH of 4.5 and lactic acid content of 0.77%. These values resulted from fermentation activity of indigenous microbiota adapted to product. The moisture content value of 23% was referred by Hamama (1997).

Moroccan raw butter contained approx. 73.7%, 1.8%, 1.2% and 76.7% of fats, proteins, lactose and total solids respectively (Marrakchi et al., 1986). In addition, Zebda beldiya had an average acid index of 2.42 mg KOH. g\(^{-1}\) of butter as well as peroxide value of 0.5 mO₂. kg\(^{-1}\) of fat (Figure 3 A,B).
more draining time (up to 10 days), whereas samples from other regions -with a temperate climate- require shorter draining period (2-3 days) (Hamama & Bayi, 1991).

Other products

Lfyrik

Lfyrik was characterized by pH ranging between 4.7 and 5.9. Similar values were reported for other traditional African fermented camel’s milk such as “Susser” in Somalia and “Garis” in Sudan (AlaouI Ismaili et al., 2017; Jans et al., 2012; Suliman & El Zubeir, 2014).

The presence of inhibitor agents and protective proteins in raw camel milk like lactoferrin, lysozyme, immunoglobulin and lactoperoxidase (Kavas, 2015) decreases the rate of lactic acid content in Lfyrik. According to AlaouI Ismaili et al. (2017), lactic acid values ranged from 0.32 to 0.5% which was very much lower than lactic acid content obtained from the traditional fermented cow milk Lben (Bouk ouli et al., 1984).

Other components such as fat, proteins, ash, total solids, density and chlorides showed average values of 3.41, 2.46, 1.027, 0.84, 9.55 and 0.21%, respectively (AlaouI Ismaili et al., 2017). However, due to fermentation process of Lfyrik, lactose content was very much lower than that of raw camel milk with an average value of 3.8%.

Kilia

Due to its high protein content and very low moisture content, Kilia can be considered as hard cheese (Mennane et al., 2007a). Kilia samples analysed by Mennane et al. (2007a) showed an average pH of 4.28, the free acidity value of 75% , whereas the fat and proteins contents of 12.68% and 10.38 %, respectively.

Microbiological overview of Moroccan raw milk and traditional fermented dairy products

Raw milk

Raw milk is a food with a very limited shelf life. The knowledge of its microbial composition is of particular interest to milk processors and farmers. In udder cells, milk is sterile (Taponen et al., 2019), but udder skin, mammary gland, bedding, milking equipment, breeder’s practices and air quality are sources of contamination (Addis et al., 2016; Quigley et al., 2013). Due to its high nutrients, fragility and pH close to neutrality, milk is easily altered by a heterogeneous microbial population (bacteria, yeasts and molds), including spoilage and food-borne pathogens (Fusco et al., 2020).

Prior to pasteurization, LAB is a dominant population in raw milk. The most common include Lactobacillius, Leuconostoc, Lactococcus, Enterococcus and Streptococcus (Issa & Tahergorabi, 2019). Many other Gram positive bacteria can be found in milk like Bacillus, Staphylococcus, Microbacterium, Micrococcus, and Propionibacterium (von Neubeck et al., 2015). Also, Gram negative bacteria were associated with milk such as Pseudomonas,Ralstonia, Acinetobacter, Psychrobacter, Faecalibacterium, and others (Benkerroum & Tamime, 2004). During the ripening period, lipolysis of butter is considered as enzymatic (Benkerroum & Tamime, 2004; Tantaoui et al., 2013). Then, both reactions have a major effect on Smen’s aroma, taste and rheological characteristics (Benkerroum & Tamime, 2004).

In recent study, Sarhri et al. (2021) studied aroma-active compounds and odor activity in Moroccan Smen using gas chromatography-mass spectrometry-olfactometry (GC-MS-olfactometry). Indeed, thirty-four volatile compounds were identified in Smen, including alcohols, acids, esters and ketones. Twenty-two and nineteen aroma active compounds were revealed, with flavor dilution factors ranging from 4 to 409, and odor activity values (OAVs) between 1 and 3359. Ethyl lactate, ethyl butanoate, ethyl hexanoate, hexanoic acid and butanoic acid were the main potent odorants in Moroccan Smen producing creamy-whey, fruity rose, overripe fruit, rancid butyric/soapy and ripened cheese odors, respectively (Sarhri et al., 2021).

Moreover, the chemical study of Moroccan Smen showed a pH value of 4.2, 81.34% of fat content and 1.5% of chlorides (Tantaoui-Elraki & El Marrakchi, 1987). Salting and storage conditions (room temperature for at least 6 months) lead to significant chemical modifications characterized essentially by lipolysis process. During Moroccan Smen maturation undergoes two important transformations. The first one is related to hydrolysis of fat, and the second is linked to decrease of aqueous phase. These reactions are attributed particularly to microbial enzymes. Smen was also characterized by acid index of 52 mg KOH g⁻¹ of butter and peroxide index of 3.7 mO₂·Kg⁻¹ of fat (Figure 3A,B).

Jben

As a result of different methods used for preparation of traditional Moroccan Jben, the physicochemical characteristics are no well-defined. The inconsistency in manufacture of Jben leads to large variation in chemical composition (Benkerroum & Tamime, 2004). The physicochemical characteristics, aroma and organoleptic properties of Jben depend mainly on those of raw milk, which depends on animals breed and their type of diet (Pozanski et al., 2004).

The composition of Moroccan Jben showed high levels of fat (16.4%) and proteins (15.8%). It was also characterized by low pH values of 4.1 and higher acidity (1.04% of lactic acid) (Hamama & Bayi, 1991). Also, pH and titratable acidity, which are least variable parameters in Jben, were reported to be less than 4.2 and higher than 0.99% respectively (Benkerroum & Tamime, 2004). In addition, pH value of 4.3 and titratable acidity of 95°D were referred in Jben samples (Marnissi et al., 2013). The most variable parameter in Moroccan Jben was reported to be dry matter and total fat content (Benkerroum & Tamime, 2004). This variability can be due to different manufacturing procedures used in Jben preparation and composition of raw milk. Indeed, some Jben samples, especially from north of Morocco, need...
Leuconostoc species are generally native to plants. However, Leuc. mesenteroides and Leuc. pseudomesenteroides besides other Leuconostoc species, such as Leuc. mesenteroides subsp. cremoris, Leuc. lactis, Leuc. kimchi and Leuc. citreum were identified in Moroccan raw milk. (Bennani et al., 2017; Khedid et al., 2009; Ouadghiri et al., 2009) In milk with high proteolytic activity, Leuconostoc species can produce many metabolites such as lactate, acetate and acetate (Issa & Tahergorabi, 2019).

Different Enterococci species were also isolated from Moroccan raw milk such as E. faecium, E. galvæa, E. durans, E. casseliflavus and E. hirae (Ananou et al., 2020; Khedid et al., 2009; Ouadghiri et al., 2009). Enterococci are widely known to be producers of bacteriocins (a ribosomally synthetized antimicrobial peptides called also enterocins) (Ananou et al., 2007, 2010; Foulquié Moreno et al., 2006).

Pediococci and Streptococci were also detected in Moroccan raw milk. These genera include P. acidilactici, P. damnosus, P. pentosaceus, Strep. camelii, Strep. salivarius subsp. thermophilus, Strept. equinus and Strep. tajani (Bennani et al., 2017; Kadri et al., 2015; Khedid et al., 2009). Moreover, another LAB genus, which is Weissella (W. cibaria, W. confuse, W. paramesenteroides and W. viridescens) was isolated from Moroccan raw milk (Ouadghiri et al., 2009). Weissella spp. are frequently characterized by a large set of technological and functional properties (enhance nutritional, sensory and safety characteristics). In addition, W. cibaria and W. confuse have been widely described as high producers of exopolysaccharides (Fessard & Remize, 2017). Table 1 summarizes the identified lactic acid bacteria of Moroccan raw milk.

Molds and yeasts were also present in raw milk at moderate level (Ouadghiri et al., 2009). Their prevalence in milk is dependent on animals feeding, health and weather. Due to their broad range of physiological and biological properties, these microorganisms are important in dairy products. Yeasts including Saccharomyces, Candida, Klyveromyces, Cryptococcus and Trichosporon, and molds including Aspergillus, Penicillium, Geotrichum, Mucor and Fusarium were isolated from several raw milk samples (Issa & Tahergorabi, 2019). In this context, it is of great relevance that a very large number of molds can produce mycotoxins (Creppy, 2002). On another side, microbial analyses carried out on Moroccan raw milk have revealed the occurrence of some pathogenic microorganisms including Staphylococcus aureus, Yersinia enterocolitica and Listeria monocytogenes (El Marnissi et al., 2013; Hamama et al., 1992; Marnissi et al., 2013).

Bendahou et al. (2008) reported the Staphylococci incidence in Moroccan raw milk and milk products. Results showed presence of coagulase positive staphylococci (St. aureus (40%), St. intermedius (2%) and St. hyicus (4%)) with a predominance (54%) of coagulase negative staphylococci (St. arlettae, St. cohnii, St. epidermidis, St. gallinarum, St. hominis, St. lentus, St. simulans and St. xylosus) in milk samples. Different sources of contamination such as milking machines, manipulators not respecting hygienic conditions or from cows with mastitis are responsible of Staphylococcus presence (Marnissi et al., 2013). Also, L. monocytogenes with a prevalence of 8.33% (El Marnissi et al., 2013) and Y. enterocolitica were detected in Moroccan raw milk (Hamama et al., 1992; Issa & Tahergorabi, 2019). Factors such as environment, poor silage fermentation, manipulator’s hygiene, milk equipment and water used can lead to contamination of milk by these pathogenics (Raghante, 2018).

Several studies have reported the isolation of bacteriocin-producing LAB strains with anti-pathogens activities. Such are the cases of enterocin OS1 with anti-listerial activity produced by E. hirae, isolated from Moroccan raw cow’s milk, enterocin RM6 produced by E. faeucalis, enterocin F420 produced by E. hirae isolated from Moroccan raw goat milk as well as diverse bacteriocins isolated from camel milk, produced by E. durans (E204 and E214), E. faeucium (R11 and R122) and E. faeucalis (R75 and R76), E. faeucalis and Strept. salivarius subsp. thermophilus (Achemchem et al., 2012; Ananou et al., 2002; Benkerrou et al., 2007b; Choho et al., 2008; Huang et al., 2013; Khay et al., 2011).

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**Table 1** Identified microbiota in Moroccan raw milk

<table>
<thead>
<tr>
<th>Moroccan dairy products</th>
<th>Identified microbiota</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow milk</td>
<td>Predominant: Lc. lactis, Leuc. pseudomesenteroides, Leuc. mesenteroides, Lb. plantarum.</td>
<td>Ananou et al., 2020; Bendahou et al., 2008; Bennani et al., 2017; Ferrous et al., 2017; Hamama et al., 1992; Marnissi et al., 2013; Ouadghiri, 2009</td>
</tr>
<tr>
<td>Raw milk</td>
<td>Others: Lc. lactis subsp cremoris, Lc. garvæa, Lb. paracasei, Lb. brevis, Lb. delbruecki subsp. bulgaricus, Lc. dextranicum subsp. cremoris, Lc. lactis subsp. cremoris, Lc. lactis biuvor diacetylactis, Leuc. mesenteroides subsp. mesenteroides, Leuc. lactis, Leuc. mesenteroides subsp. cremoris, Leuc. mesenteroides subsp. dextranicum, E. casseliflavus, E. faeucalis, Lc. lactis subsp. thermophilus, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lb. plantarum.</td>
<td>Khedid et al., 2009</td>
</tr>
<tr>
<td>Camel milk</td>
<td>Predominant: Lc. lactis subsp. lactis, Lb. helveticus, Lb. casei, Lb. plantarum, Strep. salivarius subsp. thermophilus.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Others: Lc. lactis subsp. lactis, Lb. delbruecki subsp. delbruecki, Lc. lactis subsp. lactis, Lb. delbruecki subsp. delbruecki, Lb. brevis, Lb. paracasei subsp. tolerans, Lc. lactis subsp. lactis, Lb. delbruecki subsp. bulgaricus, Lb. amylophilus, Lb. casei subsp. rhamnosus, Lc. garvæa, Lc. lactis subsp. cremoris, Lc. lactis biuvor diacetylactis, Leuc. mesenteroides subsp. mesenteroides, Leuc. lactis, Leuc. mesenteroides subsp. cremoris, Leuc. mesenteroides subsp. dextranicum, E. casseliflavus, E. faeucalis, Lc. lactis subsp. thermophilus, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lc. lactis subsp. lactis, Lb. plantarum.</td>
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**Moroccan traditional fermented dairy products**

The microbiota of fermented dairy products is clearly variable (Figure 4). The fermentation of milk depends principally on microbial activities to produce various metabolites. These metabolites have antagonistic and preservative effects to prevent the pathogenic and spoilage food microorganisms. The microbiota of raw milk significantly influences safety, quality and general characteristics of fermented dairy product (Agyei et al., 2020; Ananou et al., 2007).

Lben

Lben is manufactured by a spontaneous fermentation of raw milk. The main microbiota of Moroccan Lben is represented by microorganisms responsible for acidification, aroma and flavor development (Tantaoui-Elaraki & El Marrakhchi, 1987). Lactococcus and Leuconostoc were main LAB involved in fermentation of Moroccan Lben (Tantaoui-Elaraki & El Marrakhchi, 1987) (Table 2). Lactococcus was also reported as abundant microorganism in Lben, which increases from 2.9x10^8 CFU.mL^-1 to reach 7.6x10^8 CFU.mL^-2 at end of Lben elaboration (Berrada et al., 1983). In addition, Lc. lactis subsp. lactis and Lc. lactis subsp. lactis biovar diacetylactis are the main Lactococcus species predominating -with more than 10^9 CFU.ml^-1- in Moroccan Lben (Mangia et al., 2014). However, Lc. lactis subsp. cremoris was also detected at low levels. With regard to Leuconostoc, the main species found in Lben were Leuc. lactis and Leuc. mesenteroides subsp. dextranicum (Mangia et al., 2014). These species certainly play a major role in acidification and flavor elaboration of Lben (Berrada et al., 1983). These species can be distributed between homofermentative acidifying species (such as Lc. lactis subsp. lactis and Lc. lactis subsp. lactis biovar diacetylactis) and heterofermentative species (Leuc. lactis) or homofermentative flavoring species (Lc. lactis subsp. lactis biovar diacetylactis) (Berrada et al., 1983).

Lactobacilli were isolated from several traditional fermented dairy products. This genus is extremely diverse and widely used in dairy industry as starter culture to milk (in order to facilitate the fermentation process) and/or flavoring culture (Issa & Tahergorabi, 2019). Lactobacillus, such as Lb. brevis, was isolated from Moroccan Lben at low levels (1.6x10^8 CFU.g^-1) (Mangia et al., 2014; Tantaoui-Elaraki & El Marrakhchi, 1987).
Despite their relatively low counts, compared to other microorganisms (LAB), the role of molds and yeasts cannot be neglected. On the one hand, some strains are considered spoilage and pathogens microorganisms (El Marnissi et al., 2013). Furthermore, Enterococci are widely known to be producers of bacteriocins (Ananou et al., 2021). In addition to bacteria, molds and yeasts were reported in finished product (Berrada et al., 1983; Tantaoui-Elaraki & El Marrakchi, 1987). This can be due to favorable acidity developed and shaking (aeration) applied during Lben preparation (Berrada et al., 1983). Moreover, the poor hygienic conditions during handling and milk storage could also be an important source of molds and yeasts in Moroccan Lben (Tantaoui-Elaraki & El Marrakchi, 1987). The most dominant yeasts presented in Lben -with more than 10^7 CFU.g^-1- were Saccharomyces cerevisiae and Kluyveromyces lactis (Benkerroum & Tamime, 2004; Mangia et al., 2014).

Despite their relatively low counts, compared to other microorganisms (LAB), the role of molds and yeasts cannot be neglected. On the one hand, they can activate LAB growth and, on the other hand, they can contribute to the specific organoleptic properties of certain molds and yeasts -like Debaryomyces Hansenii and Yarrowia lipolytica- especially their proteolytic activity, make them essential to elaborate the flavor and aroma of fermented dairy products (Büchel & Seiler, 2011; Van Den Tempel & Jakobsen, 2000).

However, Lben contains undesirable microorganisms in variable levels, depending on several factors such as raw milk quality and hygiene processing. Indeed, the use of initially contaminated raw milk and water -which is generally added during the churning step in order to favor aggregation of butter grains- are sources of contamination. Several studies reported the unsatisfactory hygienic quality and poor sanitary conditions adopted during manufacture and storage of Moroccan Lben. Filali (2018) showed that mesophilic counts and coliforms counts -which must not exceed 3x10^6 and 5 CFU.g^-1- (BO: 5214, 2004) achieved 1.7x10^9 CFU.mL^-1 and 1.6x10^7 CFU.mL^-1 respectively. Another study reported counts of 7.8x10^6, 1.8x10^6 and 8.4x10^5 CFU.mL^-1 for mesophilic, coliforms and enterococci, respectively (Marnissi et al., 2013). In addition, Hadrya et al. (2012) reported 9x10^5 CFU.mL^-1 of mesophilic counts, 2x10^7 CFU.mL^-1 of total coliforms, and 4.5x10^6 CFU.mL^-1 of fecal coliforms.

The occurrence of pathogens in Moroccan Lben has been also investigated. The prevalence of pathogens has been referred as 75% and 55.55% for E. coli and Clostridium perfringens, respectively (Filali, 2018). L2 monocytogenes prevalence was between 5.7% and 19.88% (El Marnissi et al., 2013; Filali, 2018). Also, prevalence of 23.8% for Yersinia spp., and between 18.2% and 75% for St. aureus were referred in Lben samples (Boumyajane et al., 2021; El Marnissi et al., 2013; Filali, 2018; Hadrya et al., 2012; Hamama et al., 1992).

Other staphylococci species were also present in Moroccan Lben. St. cohnii, St. epidermidis, St. hominis, St. lentus, St. sciuri, St. simulans and St. xylosus (as coagulase negative staphylococci), and St. hyicus as well as St. intermedius (as

**Figure 4** Moroccan traditional fermented dairy products and principal microbial groups associated
coagulase positive staphylococci) were isolated from Lben samples (Bendahou et al., 2008). Thus, the occurrence of pathogens in Moroccan Lben can be considered as food safety alert. The health authority must provide consumer protection with establishment of hygiene standard, a broad microbiological assessment, sensibilization of producers and consumers about the importance of milk safety.

Table 2 Identified microbiota in Moroccan Lben.

<table>
<thead>
<tr>
<th>Moroccan dairy product</th>
<th>Identified microbiota</th>
<th>References</th>
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<tbody>
<tr>
<td>Lben</td>
<td>Predominant: L. lactis (L. lactis subsp. lactis biovar diacetylactis, L. lactis subsp. lactis), Leuc. pseudomonosenteroides, Lb. plantarum, L. lactis, S. casei, B. subtilis, B. alvei, B. coagulans. Others: Lc. mesenteroides, Lc. paracasei, L. casei, E. coli, E. faecalis, Lb. brevis, L. lactis subsp. cremoris, Leuc. mesenteroides subsp. dextranicum, Leuc. lactis, St. coliniti, St. epidermidis, St. fecalis, St. intermedius, St. hominis, St. lentus, St. sciuri, St. simulans, St. xylosus.</td>
<td>Bendahou et al., 2008; Hamama et al., 1992; Mangia et al., 2014; Marnissi et al., 2013; Onaghdhiri, 2009</td>
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Rayeb

Moroccan Rayeb is the main product used for preparation of several Moroccan traditional fermented dairy products such as Lben, Zebda beldiya and Smen. Several microbial species were isolated from Rayeb (Elotmani et al., 2002; Hamama & Bayi, 1991). Lactococcus, Lactobacillus, Leuconostoc and several yeasts (especially Saccharomyces and Candida) contribute to the spontaneous fermentation process of Moroccan Rayeb (Bendiderad et al., 2012; Hamama & Bayi, 1991). Indeed, Lactococcus predominated LAB with 1.4x10^10 CFU.mL^{-1} versus 2.6x10^9 CFU.mL^{-1} for Lactobacillus and 2.8x10^9 CFU.mL^{-1} for Leuconostoc. Also, yeasts and molds reached 5.3x10^9 CFU.mL^{-1} in Moroccan Rayeb (Hamama & Bayi, 1991). Due to their strong proteolytic and lipolytic activity, yeasts growth can be essential for development of typical texture and aroma profiles of several fermented dairy products (Alvarez-Martín et al., 2008). It was reported that yeasts produce several valuable nutrients including amino-acids and vitamins, as well as various aromatic compounds like ethanol and diacetyl in these products (Samet-Bali et al., 2010). In addition, a symbiosis between yeasts and LAB was widely suggested in fermented dairy products. In fact, LAB provide acidic conditions which are favorable to yeasts growth, and yeasts provide other growth factors to LAB (Samet-Bali, 2012). Several studies evaluated hygienic quality of Moroccan Rayeb. Coliforms counts reached 1.7x10^7 CFU.mL^{-1} (Hamama & Bayi, 1991), which proved a poor hygienic quality of this product. Moreover, Rayeb may also be the carrier of many pathogens responsible for serious food-borne diseases such as L. monocytogenes (at 10% of prevalence) (Marrakchi et al., 1993). In fact, the frequently use of unpasteurized raw milk, unhygienic and unfavorable environmental conditions mean that Rayeb has variable characteristics and also higher spoilage risks.

However, previous studies suggested the presence of potential bacteriocinogenic LAB in Moroccan Rayeb. Elotmani et al. (2002) characterized several bacteriocins, with anti-listerial activity, produced by LAB strains (lactococci R10/1 and R9/2 produced by L. lactis, enterocin R18 produced by E. faecium and enterocin R09 produced by E. faecalis). Table 3 summarizes the main microbiota identified in Moroccan Rayeb.

Table 3 Identified microbiota in Rayeb.

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<th>Moroccan dairy product</th>
<th>Identified microbiota</th>
<th>References</th>
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Smen

The chemical study of Moroccan Smen revealed the importance of microbial enzymes to product maturation. However, microbiota of Moroccan Smen is very low (El Marrakchi et al., 1988a), due to combined effect of free fatty acids (FFAs) and salt (8-10%), as well as nutrients (proteins, lactose and mineral salts) decrease in aqueous phase (Tantaoui-Elaraki & El Marrakchi, 1987). Moroccan Smen contains principally salt-tolerant microorganisms, mainly represented by Gram positive bacteria. This microbial population is predominated by Bacillus (at 96%), followed by staphylococci (Benkerroum & Tamime, 2004; Tantaoui-Elaraki & El Marrakchi, 1987). The predominance of Bacillus species (such as B. alvei, B. cereus, B. brevis and B. firmus) (Table 4) is due to lipolytic activity, FFAs resistance and salt tolerance. In fact, several species of Bacillus are salt-tolerant bacteria, many of which grow at NaCl concentration of 25% and pH 2 (El Marrakchi et al., 1988a; 1988b; Tantaoui-Elaraki & El Marrakchi, 1987). Also, St. cohnii and Aeromonas hydrophile (these species can grow at salt concentration of 7%) with lipolytic activity are found in Moroccan Smen. In addition, some Lactobacilli (especially Lb. plantarum, Lb. casei, Lb. acidophilus and Lb. helveticus) remained at low levels in Smen (Tantaoui-Elaraki & El Marrakchi, 1987).

Table 4 Identified microbiota in Moroccan Smen.

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<th>Moroccan dairy product</th>
<th>Identified microbiota</th>
<th>References</th>
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Zebda beldiya

In traditional Moroccan raw butter, mesophilic counts were around 10^7 CFU.g^{-1} due to absence of salt and unpasteurized milk use (Hamama, 1989; Rady & Badr, 2003). In addition, shaking and separation processes can enhance microbial counts of raw butter (Idoui et al., 2010).

The lipolytic and proteolytic populations are mainly represented by Gram negative bacteria including Acinetobacter, Pseudomonas, Flavobacterium, Vibrionaceae and Enterobacteriaceae (El Marrakchi et al., 1988b). LAB are only present in this product (Mourad & Bettache, 2018). Indeed, LAB are predominated by Streptococci with 5.0x10^9 CFU.g^{-1}, followed by Lactobacilli with 2.4x10^9 CFU.g^{-1} and Leuconostoc with 1.8x10^9 CFU.g^{-1} (Hamama, 1989).

The coliform contamination was also referred in butter samples with values of 6.5x10^4 CFU.g^{-1}, 2.1x10^4 CFU.g^{-1} and 8.6x10^4 CFU.g^{-1} for total coliforms, fecal coliforms and enterococci respectively (Hamama, 1989). Their existence might be attributed to contaminated equipment, producers unhygienic, handling and/or processing methods and milk origin (Alganesh & Yetenayet, 2017; Gökçe et al., 2010).
Le. rhamnous and Le. buchneri, were reported in Moroccan Jben (Ouadghi et al., 2005) (Table 5). The population of yeasts and molds exceeded 10⁶ CFU.g⁻¹ in Moroccan Jben (Benkerroum & Tamime, 2004). Yeasts can be considered as cheese spoilage agents. Indeed, at higher levels, they can cause several organoleptic alterations such as viscosity or slimy appearance, discoloration, and strong alcoholic odor. However, at moderate levels, yeasts can contribute to flavor elaboration of cheese (Geronikou et al., 2020; Ouadghi, 2009; Wyder & Puhun, 1999).

Yeasts species identified in traditional Moroccan Jben, elaborated with goat’s milk, were Kluveromyces lactis, Saccharomyces cerevisiae, Yarrowia lipolytica, Candida parapsilosis, Kazachstaniz unispora, Kluyveromyces marxianus and Pichia fermentans (Table 5) with percentages of 19.1, 11.7, 10.3, 10.5, 8.7, 7.4 and 5.9% respectively (Ouadghi et al., 2014).

Besides, the production of Moroccan Jben using unpasteurized milks, equipment handlers and non-standardized conditions are responsible for food spoilage and food safety reduction. Several authors have evaluated the hygienic quality of Moroccan Jben (Benkerroum & Tamime, 2004; Marnissi et al. 2013; Mennane et al., 2007a). In fact, fecal contaminants achieved levels of 10⁶ CFU.g⁻¹ (Benkerroum & Tamime, 2004). In addition, many staphylococci species, including coagulase negative staphylococci (such as St. aurecidarle, St. cohnii, St. epidermidis, St. hominis, St. lentus, St. simulans and St. xylosus) as well as coagulase positive staphylococci (like St. aureus, St. intermedius and St. hyicus), were isolated from Moroccan Jben (Bendahou et al., 2008). Even though the limited acidification of Jben (a fresh cheese), pathogens of serious public health concern, such as Y. enterolitica, Salmonella spp. and L. monocytogenes, were detected at 4.1%, 18% and 11.1% of samples respectively (El Marnissi et al., 2013; Hamama, 1997). Thus, Moroccan Jben production must comply with official hygiene -and other regulatory standards- and follows informative marketing routes to be industrialized.

<table>
<thead>
<tr>
<th>Moroccan dairy product</th>
<th>Identified microbiota</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Jben</strong></td>
<td>Predominant: Le. lactis, Leuc. mesenteroides, Lb. casei, Lc. plantarum, Leuc. pseudomesenteroides. Others: Le. paraeae, Le. brevis, Le. rhamnous, Le. buchneri, Le. garviae, Le. raffinolactis, Ec. saccharominus, St. auricularis, St. cohnii, St. epidermidis, St. hyicus, St. intermedius, St. hominis, St. lentus, St. simulans, St. xylosus, Lc. cerevisiae, Y. lipolytica, C. parapsilosis, K. unispora, K. marxianus, K. lactis, P. fermentans. Associated pathogens: Y. enterolitica, Salmonella, L. monocytogenes, St. aureus.</td>
<td>Bendahou et al., 2008; Hamama, 1997; Ouadghi et al., 2005, 2014</td>
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<tr>
<td><strong>Lfrik</strong></td>
<td>Predominant: Le. lactis subsp. lactis biovar diacetylactis, Le. lactis subsp. hordniae, Le. raffinolactis and Le. plantarum. Others: Leuc. mesenteroides, Leuc. destramin, Leuc. lactis and Streptococcus saliviaus subsp. thermophilus. Also, yeasts and molds were detected (5.6x10⁶ CFU.mL⁻¹ and 8.3x10⁶ CFU/mL) respectively (Alaoui Ismaili et al., 2017). The positively effect of yeasts -at high levels- on LAB activities was also reported (Gadaga et al., 2001; Pereira-Dias et al., 2000; Suzzi et al., 2003). In regards to hygienic quality of Moroccan Lfrik, high levels of fecal contamination were detected (5.6x10⁶ CFU.mL⁻¹ and 3.57x10⁶ CFU.mL⁻¹) for total coliforms and fecal coliforms respectively), which reflect a poor hygiene quality. However, pathogens such as Salmonella and St. aureus were undetectable (Alaoui Ismaili et al., 2017). This can be attributed to camel milk use, fermentation duration (about 12h), and Lfrik pH (on average 5.2).</td>
<td>Alaoui Ismaili et al., 2017</td>
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</table>

**CONCLUSIONS**

In this review, we found that traditional Moroccan dairy products are diverse. The Moroccan dairy processing is characterized by indigenous processing methods, which are sometimes accompanied by the application of other transformation steps and the addition of different spices. However, the manufacturing of these traditional products is unfortunately still not standardized. Due to their particular characteristics (flavor and nutritional value), the preservation of these products can be of great importance, especially due to increasing of consumer awareness and interest in fermented dairy products and their nutritional and health benefits.

The great microbial diversity of traditional Moroccan dairy products, making them interesting foods, must be preserved due to the importance of their positive aspects, even if measures have to be implemented to guarantee the hygienic safety of these products. The microbiota of Moroccan raw and fermented dairy products is predominated by LAB and their exact role and prevalence can be product-specific. Moreover, the metabolic interactions between LAB and others microorganisms (particularly with yeasts) are responsible for the typical taste appreciated by consumers. However, the study on biodiversity of Moroccan traditional fermented dairy products and microbial interactions is still limited by the small number of studies given the characterization and identification of their microbiota.

For this purpose, further studies are required, on the one hand, in the isolation of the most abundant strains and the investigation of their physiological and biochemical characteristics to approximate to their role in the fermentation process. On the other hand, these products may become interesting source of beneficial microorganisms. Indeed, the new traditional strains, with attractive technological and functional proprieties, can be developed and used as starter, protective cultures or even probiotics. These traditional cultures can be also used to ensure the hygienic safety with maintaining the original organoleptic proprieties of Moroccan traditional fermented dairy products as well as for new products elaboration with new tastes.

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