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Influence of environmental conditions and building structure on food quality: A survey of hand-crafted dairies in Northern Italy

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A B S T R A C T

The present study investigated several small dairies, located in mountain areas of Northern Italy, with the aim to identify critical factors that are frequently neglected despite their potentially decisive role in improving hygiene standards of dairy processing and work safety. The results highlighted the structural and procedural aspects involved in sanitary requirements of traditional dairy production.

Our analysis has made it clear that processing environment is often inadequately protected from external contamination, and design and realisation of buildings is not suitable for food processing requirements. For example, the main critical points for food safety in relation to building structure are indoor layout of a dairy, and coating materials for floors and walls that, although smooth and washable, do not withstand chemical attack, environmental conditions, and mechanical stress. From a procedural point of view, cleaning operations are not carried out thoroughly, and working practices are hygienically deficient.

1. Introduction

A clean environment free of any source of contamination (pests, rodents, pathogenic and spoilage microorganisms) is essential for quality and safety of foods (Mariani, 1991). Hygienic quality of working environments depends on building structure and use of correct work procedures (Cialdea, Coppola, Succi, & Ranieri, 2001; De Montis & Cansella, 2000a, 2000b; Dioguardi, 2008; Failla, Tomaselli, & Pappalardo, 2000; Fichera, Di Fazio, & Bonomo, 2000).

In addition, for traditional foods, such as mountain cheeses, environmental quality is important not only to ensure suitable sanitary conditions, but also to preserve the characteristics of flavour and taste which are typical of craft foods (Bailoni et al., 2005; Baroni & Timini, 2006; Dioguardi, Colombo, & Franzett, 2007; Dioguardi, Franzetti, & Sangiorgi, 2008). Moreover, small dairies, that are numerous in Italian Alps, where homemade cheese is prepared according to traditional practices, represent an important richness for the territory.

The production system usually consists of several buildings, such as the farmer's home, cattle-shed, and dairy. Traditional buildings are made of locally available wood and stone, while the newer, more modern ones are generally made of concrete, and finished off using washable and smooth materials.

Whether old or new dairies, there are structural or procedural weaknesses that make difficult to achieve sanitary and environmental conditions suitable for production process (Belli, Dioguardi, Pessina, & Sangiorgi, 2005; Dioguardi, 2004). Major weaknesses are due to non functional layouts, finishing materials, and building design that contribute to 'dirtiness' accumulation (Dioguardi, Franzetti, & Sangiorgi, 2005; Dioguardi & Sangiorgi, 2008; Guercini, Bordin, Spolaor, & Cattelan, 2005). The architectural quality of buildings, along with application of HACCP principles are important requirements in the production of quality foods, and if food-environment interactions are not monitored correctly food safety can be invalidated (Orefice, 1984). For example, incorrect cleaning operations and poor hygiene habits by workers can facilitate microbial transfer from environment to food, where microorganisms find suitable substrates and environmental growth conditions (ICMSF, 2002; Jouve, 2000). Microbial proliferation is very frequent if work surfaces are not continuous and difficult to be cleaned. Also the use of a tiled surface – as is usually employed in new and modern dairies – can be unhygienic if not properly constructed and regularly cleaned.

Finally, in accordance with HACCP rules, the quality of raw materials, and cleaning operations of processing environment are other important aspects to guarantee safety and quality of final products (Colombo, Dioguardi, & Franzetti, 2007).

This paper focused on interactions between building (design, layout, and coating materials) and environmental quality (microbial charge in the air, worktops, and equipment), with the aim to identify critical points for hygiene and work safety.

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2. Materials and methods

2.1. Dairies

Ten craft and family-run dairies, located in Lombardy (Camonica Valley) and Veneto (Plateau of Asiago and Mount Grappa) were studied (Fig. 1). Seven dairies are located in high mountain areas, and can be reached only by jeep (30–45 min), while three are located in valley floor settings within villages, and linked to main roads. High mountain dairies are small sized, while those in valley floor sites are medium sized.

The small typology consists of family-run activities. Two people are involved in production: one in breeding, the other in cheese-making. Or, sometimes, only one worker can manage all activities, and – if necessary – other components of his/her family can help him/her. Dairies in valley floor locations also employ more than two workers. In the case of natural milk skimming, equipment and plants consist of several steel basins; a small steel churn to make butter; one or two gas- or wood-heated copper or steel vats; rarely steam double-layer vats; some steel or wooden tables to purge whey; food grade plastic or metal curd moulds; plastic tanks for brine salting; and wooden boards for cheese drying and ripening.

The quantities of milk processed each day ranged between 100 and 500 L, corresponding to an output of 6–30 kg of cheese. Traditional mountain cheeses, such as Silter, Cadolet, Formaggella of Camonica Valley, Asiago, Bastardo, are produced only from raw milk. Other dairy products are butter and ricotta (the latter being similar to cottage cheese).

Fig. 1. Geographic location of investigated dairies.

Table 1 shows the structural characteristics of investigated dairies.

2.2. Building and layout

In each dairy, functional and construction aspects were analysed to find out everything that was incongruent to ensure good hygiene and safety (Seaman, 2010), and welfare for the staff (Assettati, 1990; Barra & De Montis, 1995a, 1995b; Cansella & De Montis, 2001; Dioguardi, 2009; Failla, Tomaselli, & Pappalardo, 2001; Fichera, Di Fazio, & Bonomo, 2001). We checked for basic building requirements that were consistent with EC Regulation No. 852, 2004.04.29 (Attachment II), Consolidated Law No. 81, 2008.04.09 and its subsequent amendments, and other guidelines related to food buildings design (Bulletin No. 324, FIL-IDF, 1997; CCFRA Guideline No. 39, 2002; CCFRA Guideline No. 40, 2002; CCFRA Guideline No. 41, 2003; CRITT IAA IDF, 1992; Hayes, 1985; Moore, 1995), also in consideration of structural exceptions allowed to traditional productions. Therefore, information was gathered about building structure, such as its layout; building typology; peculiarities of its architectural parts (Dal Sasso & Ottolino, 2000; Rizzo, 1993a, 1993b, 1993c; Romero del Castello, Nicolau, Pont, & Saldo, 2005); finishing materials (Caraci, 1995a, 1995b); state of repair and cleanliness of premises; and about dairy processing (flowchart, environmental conditions resulting from processing and required by different productive steps); technology and productive capacity:

Specifically, the following aspects were considered in examining building structure:

(1) Protection of its interior from outside contamination, or aerial contamination spread inside areas with different hygienic standards by measuring air microbial charge.
(2) Cleanliness and preservation of premises with respect to their specific processing, such as skimming, cheese-making and ripening.

As to aspect 1, i.e. protection of areas devoted to processing from contamination, and reduction of transmission of aerial contamination, the following aspects were examined:

- Level of care and state of repair of external areas of the dairy.
- Presence of flooring between cattle-shed/dairy and the area around dairy buildings.
- Layout, i.e. location and distance of cattle-shed from dairy; entrance to buildings; arrangement of processing premises; plants and equipment in relation to cheese-making flowchart.

Table 1
Characteristics of investigated dairies.

Characteristics	Dairy									
	A	B	C	D	E	F	G	H	I	L
Cheese	Silter	Silter	Silter	Silter	Silter	Silter	Asiago	Asiago	Asiago	Bastardo
Dairy Localization	High Mountain	High Mountain	High Mountain	Valley	Valley	Valley	High Mountain	High Mountain	High Mountain	High Mountain
Material of vat	Copper	Copper	Steel	Copper	Steel	Copper	Copper	Steel	Copper	Copper
Heating	Wood	Methane	Steam	Methane	Steam	Wood	Wood	Steam	Wood	Wood
Area (m^2)	104	43	45	56	114	70	120	100	40	80
Building age	Recent	Recent	Obsolete	Recent	Recent	Obsolete	Obsolete	Recent	Recent	Obsolete
Drinking water availability	Yes	Yes	Yes	Yes	Yes	Yes	Rainwater	Yes	Rainwater	Rainwater
Washable finishing	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear layout	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes
Ripening room inside the dairy	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes
Anti-insect nets installed	No	Yes (broken)	Yes (broken)	No	–	Yes (large)	Yes	Yes	Yes	No
Floor slipperiness	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No
Distance from cattle-shed	<10 m	<50 m	–	<3 m	–	–	<100 m	–	<50 m	<3 m
Retail	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No

– Presence and integrity of systems thanks to stopping infestation from outside, e.g. anti-insect nets, protective grids for openings, vents, drainage, and so on.
– Presence of structural parts favouring dust accumulation and dispersion.
– Regarding aspect 2, adequate hygienic conditions and maintenance were carefully checked.
– Internal finishes, which should be easily cleanable, by measuring microbial contamination on their surfaces, and considering both how frequently and the way they had been cleaned.
– Resilience and state of repair of such finishes by evaluating their level of damage/deterioration.
– Any hollows, cracks, gaps, or any surfaces difficult to be reached.
– Dimension of processing premises.
– Possible presence of condensation or undesirable moulds.

2.3. Microbiological monitoring of air

Microbial air contamination evaluation was performed by Surface Air System (S.A.S.), an active air sampler (P.B.I., Italy) which collects a known volume of air per minute (L/min).

Contact plates with a suitable agar medium are clipped in place. These plates are then covered with a 'lid' with a precision pattern of holes. A known volume of air is sucked through the holes with an air flow of 180 L/min, and any airborne particles hit the plates and impact on the agar surface. At the end of suction step, the air sampler cover is removed, and the agar plate recovered and incubated at an appropriate temperature (Section 2.5). The number of colonies developed on agar is converted to colony forming units (cfu) per cubic metre of air. Air samples are collected in skimming milk and cheese-making rooms. The samples are collected by positioning the S.A.S. sampler at different heights (0.5; 1.0, and 2.0 m), and in different points of premises as showed in Fig. 2 (Pasquarella, Pitzurra, & Savino, 2000). All results are the average of three replicates carried out at the same point.

2.4. Microbiological monitoring of surfaces

Microbial surface contamination was determined by two different techniques.

2.4.1. The swab method

A sterile cotton swab is moistened by inserting it into a tube containing 1.5 mL of ringer solution. The swab is then passed over the examined surface (100 cm^2) using 10 horizontal and 10 vertical strokes. During sampling, the swab is rotated to ensure that the entire surface is used. After sampling, the swab is put into Ringer solution of known volume, and agitated (shaken) to transfer the microorganisms present on the swab into the solution.

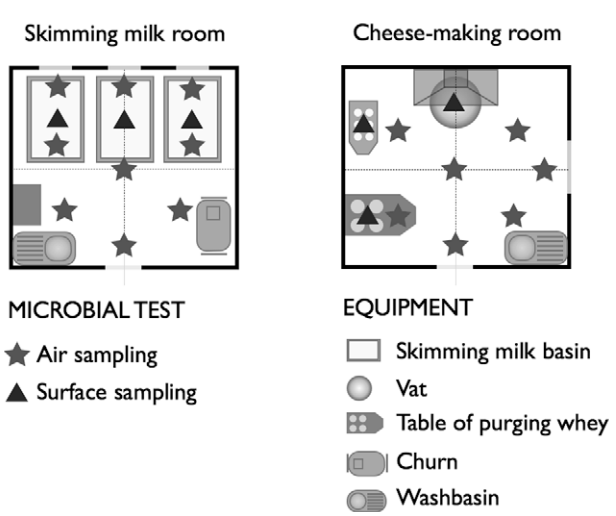

Fig. 2. Location of points sampled for air and surface microbial tests.

2.4.2. The sponge method

The sponge (4 × 8 cm) is placed into a sterile bag with 100 mL Ringer solution. After wearing disposable gloves, the hydrated sponge is squeezed to remove the excess diluent. Then, both sides are gently stroked across 100 cm^2 of examined surface. The sponge is finally returned to a sterile bag containing Ringer solution.

All samples, swabs, and sponges are immediately refrigerated, and analysed within 24 h. The microbial suspension is tested by the direct plating method according to a serial dilution technique (ISO, 2004a).

2.5. Microbiological analysis

The following microbial investigations were performed on the air and surface samples (i.e., swabs and sponge):

– Total bacterial count following Plate Count Agar (PCA, VWR Germany) (ISO, 2003) incubation at 30 °C for 48–72 h.
– Eumycetes (yeasts and moulds) following Yeast Glucose Chloramphenicol incubation at 25 °C for 3–5 days (ISO, 2004b).
– Total and faecal coliforms following Violet Red Bile Agar (VRB, VWR Germany) (Hitchins, Hartman, & Tood, 1992) incubation at 37 °C and 44 °C, respectively, for 24 h.

3. Results and discussion

3.1. Building characteristics of mountain dairies

External areas surrounding dairies do not necessarily imply dangerous contaminating sources as polluting industrial settlements are rare, and dairies are usually located within small urban contexts or within isolated areas, such as alpine grazing.

In high mountain sites, dairies are surrounded by pastureland. The outside flooring is a reduced slab of concrete surrounding the dairy. Generally, there are no pathways linking the cattle-shed to the dairy. This is a possible critical point for hygiene because farmers, after crossing the open land, could dirty the dairy if they enter into it without changing their shoes. Paved paths are needed to reduce dairy's contamination. Even a layer of gravel is enough.

In valley floor settings, the external area surrounding the dairy and cattle-shed is generally covered by concrete or asphalt.

Examined dairies span an area of less than 100 m^2, and are generally divided into three rooms that are dedicated to skimming milk, moulding and purging curd, and salting and ripening cheese. Ripening premises may be located in underground cellars or another building. Most dairies have a shop area, and in its absence products are directly sold in processing rooms, even during cheese-making process (B, D, and F). Distribution of processing premises within the dairy not always allows unidirectional progress of processing flow, as it can be in some dairies (Fig. 3). Indeed, in many cases there is a superposition in milk-to-cheese transformation flow. In some dairies, the layout is quite random. This means that various processing steps, that really require different hygiene standards, are combined in the same area. Other critical situations for hygiene are due to a mixed use of processing premises for production, storing, and selling (Hall & Rosén, 1963), and the presence of external people during productive activities.

To reduce contamination, which is transmitted through air, the location of cattle-shed with respect to the dairy, as well as its internal layout is considered very important.

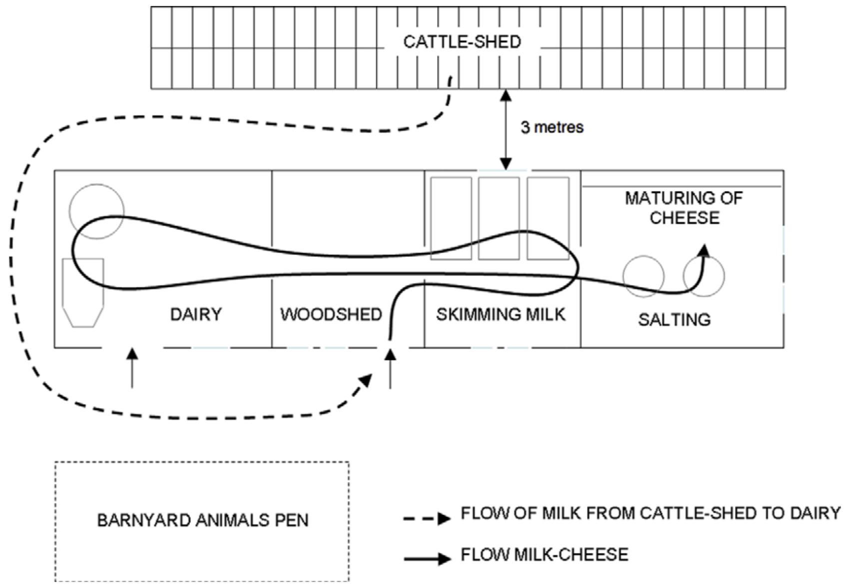

Fig. 3. Example of unsuitable layout which can cause cross-contamination of food.

If the cattle-shed is located into the same building as the dairy, distinct hygienic conditions for the two spaces have to be kept. Air microbial charge measurements showed that a difference in microbial concentration of 10^3–10^4 cfu per cubic metre of air between cattle-shed and dairy can be kept by simply closing entry doors. If the cattle-shed is located in another building close to the dairy, it is important that openings of both buildings are not located on the same side, as is shown in Fig. 3. Microbial contamination can be transmitted through air.

With regard to coating materials, dairies A, B, D, E, F G, H, and I comply with hygienic requirements as their floors and walls are covered with smooth and washable materials. However, this is not sufficient to guarantee good sanitary conditions in those dairies. Coating materials for flooring and walls often do not have suitable resistance to mechanical stress and chemical attack, so they deteriorate quickly. This loss of integrity of coatings makes it difficult to clean and sanitise environments. Moreover, the presence of organic matter, deposited into cracks and not easily removable, helps development of microorganisms.

Doors and windows are made of wood or metal. The wooden ones need frequent cleaning and to be well repaired as they are porous and moisture sensitive. The bacterial charge measured on their surfaces demonstrated that, when regularly brushed, figures concerning wood are low, i.e. only few cfu/cm^2, that is similar to tiles. An important critical point for hygiene is represented by accumulation of dirt between window frames and walls if window frames are not sealed to walls.

Dairies C and L exhibit the worst hygienic situations in their processing and skimming milk rooms, respectively, due to an incorrect structure realisation and choice of materials. For example, dairy C shows deep fissures in its walls due to settling of building; walls are not washable, and concrete flooring is deteriorated because of lactic acid resulting from continuous pouring of acid whey. Furthermore, wall coating has become detached, especially in the poorly ventilated area behind the vat. The same signs of detachment are beginning to become evident also in dairy E's walls, even if they have recently been painted with washable paint.

With regard to safety, we observed that, when wet, almost all floorings (dairies A, D, E, G, H, and I) are slippery: flooring materials do not have appropriate friction coefficients, and slope to drainage points is inadequate. Moreover, water stagnation, together with a patina of fat accumulates in the gaps between tiles, increases slipperiness, and a lack of anti-acid sealing between tiles facilitates microbial proliferation and deterioration of underlying grout.

Not all dairies have anti-insect nets, even though their installation is fundamental when cattle-shed lies next to the dairy or animals are grazing nearby. The lack of anti-insect nets allows entry of numerous insects (flies) in cheese-making rooms, especially when cattle graze close to the dairy.

With regard to water drainage system, siphoned drains are covered with plastic and/or metallic grids. In ripening room of dairy C, we found a linear drainage channel covered by a wooden grid, which is totally unsuitable as wood becomes deformed in the presence of water and humidity. It even happens that grids have been removed in several cheese-making rooms to improve water drainage. This lack of grids may cause entry of rodents by discharges. Thus, it is essential to know the real amount of water that will be produced during cheese-making process in order to correctly assess the necessary capacity of water drainage system.

3.2. Hygienic quality of processing environment

The results of microbial air contamination (Table 2) were compared with European Community Board indications (*European Collaborative Action*) suggesting the following standard of air contamination for indoor environment:

- *Very low*: Less than 50 cfu/m^3.
- *Low*: 50–100 cfu/m^3.
- *Medium*: 100–500 cfu/m^3.
- *High*: More than 500 cfu/m^3.

The situation in valley floor dairies appears good, especially in dairies E and F where there are no contamination sources nearby. The exception is dairy D, where a higher value of microbial counts has been found due to nearness of its cattle-shed (less than 3 m away), The most critical situation is observed in the processing room, where the level of contamination according to European Collaborative Action is evaluated as "high" for TBC and moulds. In the same room, total coliforms, though low in number, are found just outside the entrance of the dairy because of defecation in cattle-shed. Moulds are dominant in processing rooms, while yeasts are in skimming-milk ones. In general, a higher contamination is observed in high mountain dairies than in valley floor ones. Indeed,

Table 2
Microbial counts in air. Results expressed in cfu/m^3.

Dairy	TBC		Yeasts		Moulds		Total coliforms	
	Skimming milk basins	Cheese-making	Skimming milk basins	Cheese-making	Skimming milk basins	Cheese-making	Skimming milk basins	Cheese-making
A	1	2	Absent	Absent	1	1	Absent	Absent
B	25	14	Absent	Absent	40	20	Absent	Absent
C	32	44	Absent	Absent	29	27	Absent	Absent
D	166	962	222	Absent	11	938	Absent	6[a]
E	<1	<10	Absent	<10	Absent	<10	Absent	Absent
F	<10	<10	<10	<10	Absent	Absent	Absent	Absent
G	314	276	14	3	108	95	17	<10
H	345	345	17	17	811	811	113	113[a]
I	Absent	250	Absent	Absent	Absent	1.700	Absent	Absent
L	c.c.[b]	c.c.[b]	c.c.[b]	c.c.[b]	c.c.[b]	c.c.[b]	42	1

[a] Faecal coliforms.
[b] Confluent growth.

in mountain diaries, it is common practice that people come and go during cheese-making process, and firewood, bins and other materials are stored close to the dairy. Dairies A, B and C show a very good situation. All investigated indices have values less than 50 cfu/m^3, so the level of contamination is very low. Quite critical conditions are found in diaries G, H, I, and L, where many structural factors increase microbial contamination. Particularly in dairy L, nearness of a cattle-shed determines a marked increase in all analysed indices, and underlines the importance of the structural deficiencies that have been found.

Surface microbial contamination was evaluated on skimming milk basins and vat (top), before and after cleaning operations in order to evaluate effectiveness of these operations. Results are showed in Fig. 4. Hygienic conditions appeared good, with indices of clean and faecal contamination being always absent.

In general, dairies in high mountain sites show higher TBC values than those in valley locations. However, it is indeed in A, a dairy located in a high mountain area, that the lowest value (4.0 cfu mL^{-1}) is found, while in dairy F, located in a valley position, the highest values (7.3 cfu mL^{-1}) are recorded. A similar situation concerns yeasts, which are always present with values of 10 cfu mL^{-1} (diaries E and I), and 5.5 cfu mL^{-1} (C). Cleaning operations involve a reduction in the level of contamination between 30% and 40% except in dairy F, where reduction in TBC value is very low and even yeasts show a slight rise. In general, there is more homogeneity in the controls on tops, and a smaller reduction in

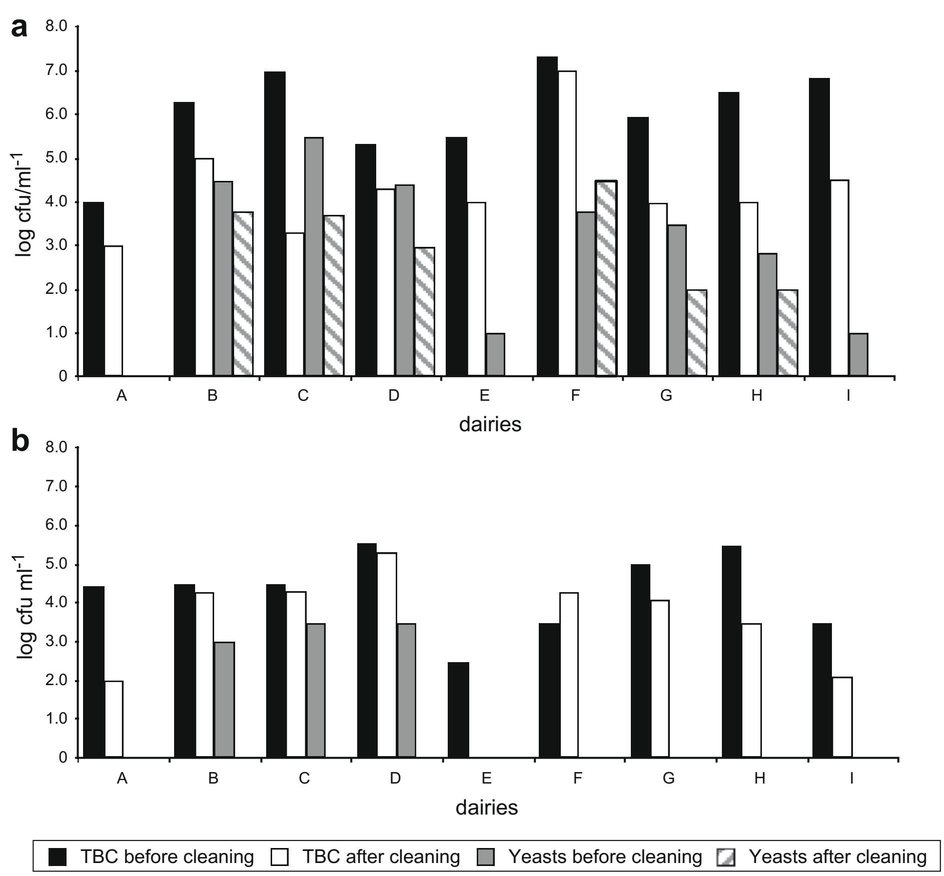

Fig. 4. Microbial counts found on the surface: (a) skimming milk tank; (b) top.

microbial total count is observed in the vat. Also in this case, the most critical situation is observed in dairy F, where cleaning operations determine further contamination. Only yeasts found in dairies B, C, and D are totally eliminated by washing.

There are no microbiological standards concerning hygiene conditions of working surfaces, but only literature guidelines (European Collaborative Action, 1993). According to these values, a total bacterial count of 50 cfu/cm^2 corresponds to good sanitary conditions. However, our results showed that this value is always exceeded, and despite a reduction in microbial counts, it can be seen that cleaning operations are not always effective.

4. Conclusions

Small dairies in high mountain areas employ simple production systems that process small quantities of milk. Indeed, the range of products is very restricted, and equipment is not complex. Despite a limited building design, the choice of layout and inside coating materials must not be neglected as they are very important for both hygiene and safety in processing systems.

Indeed, layout must ensure that processing always takes place under good hygiene conditions (Good Manufacturing Practice) (Hutton, 2001). Therefore, processing rooms have to be distributed according to flow sheet in order to increase functionality; avoid cross-contamination; and separate places where different hygienic standards are needed.

To reduce contamination coming from the outside, it is useful to have a filter zone at the entrance of dairy. In such areas, whenever possible, a water distribution point can be provided to wash boots and external surfaces of incoming milk tanks. Thus, surrounding areas of processing building should be provided with flooring.

Furthermore, our findings reveal suboptimal hygienic conditions for building surfaces, indicating that cleaning operations are not efficient. In this regard, we underline that, especially for high mountain dairies where there is no availability of running water, it would be useful to use boiling whey, as this is certainly more efficient in removing microorganisms, and dries more easily than water alone. Moreover, to avoid drainage directly into the environment, a water drainage recovery system should be provided for dairies without sewers. Additionally, a bioluminescence technique could be very useful to verify effectiveness of cleaning operations. Today, a large number of easy and cheap instruments can be found on the market, and bought by small dairies/farms.

In conclusion, to correctly plan new buildings and renovate old ones, it is indispensable to have a full knowledge of the processing to be employed, and end-product destination. Only in this way it will be possible to draw a HACCP plan according to European laws (Reg. CE 2073/2005). in force that is simple and easily adaptable to a new food chain approach.

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