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Artisanal and industrial Maroilles cheeses: Are they different? Comparison using sensory, physico-chemical and microbiological approaches

Menouar Nacef, Maud Lelièvre-Desmas, Djamel Drider, Christophe Flahaut, Sylvie Chollet*

ISA, Univ. Lille, INRA, Univ. Artois, Univ. Littoral Côte d'Opale, EA 7394 – ICV – Institut Charles Viollette, F-59000 Lille, France

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ABSTRACT

The Maroilles cheese is a soft French protected designation of origin (PDO) cheese with washed rind. The Maroilles is available in several brands and can either be manufactured by hand or industrially in the North of France. But are the artisanal and industrial Maroilles really different? To investigate this question, seven artisanal and eight industrial Maroilles were subjected to a sensory analysis based on a sorting task, a microbiological evaluation, an analysis of main physico-chemical parameters (concentrations in organic matter and protein, pH, water activity, and ions), a texture analysis by penetration test and an evaluation of colour parameters (L^*, a^* and b^*). The analyses showed large differences among the 15 Maroilles on almost all the measured parameters. Moreover, the overall analysis of the datasets by multiple factor analysis (MFA) highlighted two clusters of artisanal Maroilles and one cluster that includes all the industrial Maroilles.

1. Introduction

Cheese is a dairy product that played a key role in human nutrition for centuries (Muehlhoff, Bennett, & Mcmahon, 2013). The wide range of types of cheeses is primarily due to the environmental features of every region, and consequently to the production technologies that have been constantly adapted to the context and optimised. The main objective has always been and remains in converting perishable milk into a product with a longer shelf life, whilst preserving most of its nutrients and benefits (Elsamani, Habbani, Babiker, & Mohamed Ahmed, 2014; Mohamed Ahmed, Babiker, & Mori, 2010). Cheese remains a relatively expensive product, synonym of gustatory delight, and can have either beneficial or harmful effects on health depending on many factors, such as the gross composition, above all the content of fat matter and the levels of salt, and also on the presence of bioactive compounds, added or produced in situ, and harmful bacteria such as *Listeria* or pathogen *Escherichia coli*.

In France, cheese is a national pride, an identity product and a very appreciated food that takes a key and staple place on French consumers' table. There are more than 1000 different varieties of cheese (Dugat-Bony et al., 2016). In 2015, the French consumed 26.8 kg of cheese per person and per year (Cniel, 2016). Maroilles cheese is a northern variety holding a protected designation of origin (PDO) that is produced in relatively large amounts (more than 4000 tons were produced in 2015; Cniel, 2016). At first, the Maroilles was an artisanal cheese made with raw milk. Nowadays with the emergence of industrial processes and also for food safety reasons, pasteurised milk is used to produce Maroilles cheese in large scale industrial operations. Thus, artisanal cheeses are made from raw milk that undergoes specific traditional processes and ripening conditions; whereas industrial cheeses are made from pasteurised milk and are processed and ripened in large scale.

The PDO Maroilles cheese is a soft cheese with washed rind that is manufactured in the Thiérache area of the Hauts-de-France region located in northern France. The Maroilles is ripened for 4–6 weeks depending on the size, during which the rind is washed 2–3 times a week with salt water (at least 30 g L^{-1}) and eventually red ferment (mixture of microorganisms such as *Geotricum candidum*, *Kluyveryomyces lactis*). It has a straight paver shape and weighs between 180 and 750 g. The cheese body has an ivory-white colour while the rind has a red-orange colour uniformly distributed due to the growth of surface flora (*Brevibacterium linens* and *Brevibacterium aurantiacum*) (Delcenserie et al., 2014; Gori, Ryssel, Arneborg, & Jespersen, 2013; Nacef, Chevalier, Chollet, Drider, & Flahaut, 2017).

* Corresponding author. Tel.: +33 328384636.
E-mail address: Sylvie.chollet@yncrea.fr (S. Chollet).

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During the last few years, several studies have been carried out to characterise cheeses. Examples include Salers cheese (Didienne et al., 2012), Camembert (Ktoury, Mpagana, & Hardy, 1989; Schlesser, Schmidt, & Speckman, 1992; Vassal, Monnet, Le Bars, Roux, & Gripon, 1986), and Emmental (Deegan et al., 2013; Falentin et al., 2010; Saurel, Pajonk, & Andrieu, 2004). Few studies using physicochemical, textural, colouring, microbiological and/or sensory techniques focused on the comparison between artisanal and industrial cheeses (Albenzio et al., 2001; Buffa, Guamis, Saldo, & Trujillo, 2004; Horne et al., 2005; Rea et al., 2016; Tunick & Van Hekken, 2010). Only two studies comparing both types of cheeses assessed the effect of maturation time on microbiological parameters (Rocha, Buriti, & Saad, 2006; Visotto, Oliveira, Prado, & Bergamini, 2011). For Maroilles cheese, given that artisanal cheeses have a longer maturation time compared with industrial cheeses, these two types of cheeses should be different and a comparison of these two types of cheeses should allow characterising this difference. Moreover, the very few studies that have been carried out on the PDO Maroilles cheese focused on the neutral volatile compounds of this cheese (Dumont, Roger, & Adda, 1974) or its colour (Dufossé, Galaup, Carlet, Flamin, & Valla, 2005). However, these studies did not take into consideration the differences between artisanal and industrial Maroilles cheeses. Based on the above, a series of questions has been raised: (i) are artisanal and industrial Maroilles cheeses really different? (ii) are consumers able to perceive this difference, if it exists? and (iii) do artisanal and industrial Maroilles cheeses have distinct odour, colour, taste, texture, and microbiological and physico-chemical features?

One approach to protect and better understand the quality of PDO Maroilles cheese is to conduct an overall characterisation of artisanal and industrial Maroilles cheeses available in the market. The present study aimed to determine the main characteristics that give each type of Maroilles cheeses their unique, specific and distinctive features. Therefore, the objectives of this work were (i) to assess the sensory, the microbiological and physicochemical parameters of artisanal and industrial Maroilles cheeses and (ii) to test whether these two types of Maroilles cheeses can be discriminated.

2. Materials and methods

2.1. Cheese samples and sampling

Fifteen commercially available Maroilles of a same size were used and are listed in Table 1. Seven of them were artisanal products (Table 1, A-prefix) made from raw milk while the eight others were industrial products (Table 1, I- prefix) made from pasteurised milk. For a given cheese, all samples were chosen from the same batch and across brands, the samples were taken just at the end of the ripening period with a maximum difference of six days. For each cheese, samples from the rind (surface) and from the heart (cheese body) were taken. Rind sampling was performed on the first 5 mm depth in each cheese side. Heart sampling was carried out on the remaining part of the cheese at a depth of 5 mm. Rind and heart samples were analysed separately only for colorimetry, water activity and microbiological analyses. For the other types of analyses, a cheese sample (rind and heart) were homogenised and analysed together.

Table 1
Maroilles cheeses sampled for this study.[a]

Brand	Producer	Abbreviation
Bonne sence	SARL laiterie des étangs de Sommeron	I-Leduc 1
Château Courbet	G.A.E.C du Château Courbet	A-Courbet
Ponts des loups	La ferme du pont des loups	A-Loups
Fauquet	Les Fromagers de Thiérache	I-Fauquet 1
Lesire (demi affiné)	ETS Lesire et Roger	I-Lesire 1
Maroilles FR	Maroilles Freres	A-Freres
Moulin	La ferme du Moulin	A-Moulin
Leduc	SARL laiterie des étangs de Sommeron	I-Leduc 2
Cerfmont	La Ferme de Cerfmont	A-Cerfmont
Finaud	Les Fromagers de Thiérache	I-Fauquet 2
Lesire (affiné)	ETS Lesire et Roger	I-Lesire 2
Beffroi	SARL laiterie des étangs de Sommeron	I-Leduc 3
Bahardes	La Ferme des Bahardes	A-Bahardes
Hennart	SAS Hennart Frères	A-Hennart
Fonné	Les Fromagers de Thiérache	I-Fauquet 3

[a] In the abbreviation, the A- and I- prefixes indicate artisanal and industrial production, respectively.

2.2. Analyses

2.2.1. Sensory analysis

The methodology of sorting task (Chollet, Lelièvre, Abdi, & Valentin, 2011; Chollet, Valentin, & Abdi, 2014) was used to obtain a positioning and a description of the 15 different Maroilles cheeses. In the sorting task procedure, the entire set of 15 cheeses was presented to assessors. The presentation order of samples was randomised and was different for each assessor. Assessors started to taste all the cheeses one at a time. Then the assessors were asked to group the cheeses that seemed similar to them. No criterion was provided to perform the sorting task. Visual appearance, aroma, taste and texture could be used. Assessors were free to make as many groups as they wanted and to put as many cheeses as they wanted in each group. No time restriction was imposed on the assessors to perform this exercise. The experiment was conducted in separate booths. Mineral water was provided for assessors to rinse their palate between two tests. For each Maroilles cheese, a cylindrical piece of 25 g of cheese with the rind and the heart was stored at 4 °C and served at 12 °C in a plastic cup coded with a 3-digit number. The experiment was carried out with 20 consumers from Lille (9 males and 11 females aged from 20 to 55 y old, mean age 45 y).

2.2.2. Microbiological analysis

For each cheese, 25 g sampled from the rind or the heart were homogenised in 225 mL 0.9% sterile saline solution (BagMixerR 400, Interscience, Saint-Nom-la-Bretèche, France). Serial dilutions (10^{-1} to 10^{-7}) were performed and 1 mL was spread over a surface of a nutrient medium in a Petri dish. Total mesophilic bacteria were enumerated on standard plate count agar (PCA) after incubation at 30 °C for 72 h according to ISO 4833-1:2013 (ISO, 2013). Lactic acid bacteria (LAB) were enumerated on Man, Rogosa & Sharpe (MRS) medium (VWR international, Fontenay-sous-Bois, France) after incubation at 30 °C for 24–48 h (ISO 15214:1998; ISO, 1998). Enterobacteriaceae were enumerated on violet red bile glucose agar (VRBGA) after incubation at 37 °C for 18–24 h (ISO 21528-2:2017; ISO, 2017) and the moulds and yeasts on Sabouraud chloramphenicol agar (SCA) after incubation at 22 °C for five days (ISO 21527-2:2008; ISO, 2008). All Maroilles cheese samples were analysed in one single session, 3 replicates per sample.

2.2.3. Chemical analysis

Moisture and ash contents were determined according to AOAC (2000). Five grams of each sample were placed in a stainless steel lid-covered dish. Weight loss after drying (oven drying at 104 ± 2 °C) to a final constant weight was recorded as moisture content. For ash, five grams of dried cheese sample were incinerated in an oven, overnight using a heating rate of 50 °C h^{-1} up to a final temperature of 550 °C (AOAC, 2000). Total nitrogen was measured by the Kjeldahl method with a conversion factor of 6.38 for crude protein. Lipid content was evaluated using a Gerber butyrometer especially developed for cheeses (NF V04-287, 2002; NF, 2002). The pH was determined by direct insertion of pH probe into the cheese (pH meter 507 Crison, Crison Instrument S.P.A., Carpi, Italy). Water activity (a_w) was measured using an Aqua-Lab Dew Point Analyser CX-2 (Decagon Devices Inc., Pullman, WA, USA) at room temperature. Three replicates per sample were carried out.

The analysis of mineral elements was performed using an AA-6800 flame atomic absorption spectrometer (Shimadzu Corporation, Tokyo, Japan) equipped with an ASC-6100 auto sampler (Shimadzu Corporation). The wavelengths used were 422.7 nm for Ca, 589.6 nm for Na, 285.2 nm for Mg, 766.5 nm for K, 213.9 nm for Zn, 228.8 nm for Cd, 283.3 nm for Pb and 248.3 nm for Fe. The ash samples were weighed in a high precision balance and 0.1 g of each sample were placed in a 15 mL glass tube followed by the addition of 3 mL HNO_3 (70%, w/v) and 3 mL H_2O_2 (30%, w/v) solutions. Afterwards, the samples were heated in a hotblock device at 95 °C for 1.5 h. The samples were finally rinsed by ultra-pure water up to 15 mL and were homogenised by agitation. The samples were diluted up to a final volume of 10 mL for the Ca, Mg, Na and K assays where Tris (cyclopentadienyl)lanthanum (III) (LaCP3-1%, w/v) was used as dilution agent for Ca (dilution factor-DF 100) and Mg (DF 20), while distilled H_2O was used for Na (DF 1000) and K (DF 20). For Pb and Fe, no dilution was applied. The mineral assays were performed in triplicate for each sample.

2.2.4. Texture analysis: penetration test

Entire cheese samples were used to measure hardness and adhesiveness by penetration test that was carried out using a TA-XT2 texture analyser (Stable Micro Systems Ltd., Godalming, UK) equipped with a 10 mm diameter cylindrical probe. The application forces were tuned at 20% (corresponding to the peripheral area of the cheese, i.e., rind) and 80% (corresponding to the heart of the cheese) of cheese height with a penetration rate of 1 mm s^{-1}. The force value (KG) at the penetration depth was used to compare the cheeses: positive peak (PP) for hardness and negative peak (PN) for adhesiveness (corresponding to the exit of the probe after relaxation phase). Three replicas per cheese were carried out for each depth.

2.2.5. Colour analysis

Colour analysis was carried out using a reflectance colorimeter spectrophotometer CM- 3610d (Konica Minolta, Osaka, Japan). Illuminant D65 was used with an illumination angle of 10°. Three measurements were carried out at different points of the surface. The CIELab colour space parameters studied were: lightness (L^*) changing from dark 0% to light 100% chromaticity, the red–green dimension (a^*) changing from green −60 to red +60 chromaticity and the blue-yellow dimension (b^*) changing from blue −60 to yellow +60 chromaticity. The results obtained were interpreted using the software package Colour Data Software CM-S100w Spectra Magic TM NX version 1.9, Pro USB (Konica Minolta).

2.3. Statistical analysis

Sensory data were analysed using DISTATIS (Abdi, O'Toole, Valentin, & Edelman, 2005; Abdi, Valentin, Chollet, & Chrea, 2007). This analysis provides a cheese map representing the similarities among the cheeses. The words used to describe the cheese groups of the sorting task are projected as supplementary points on the DISTATIS map (i.e., they do not contribute to the DISTATIS dimensions). Statistical analysis was performed using R software.

For all the other analyses (microbiological, chemical, texture and colour analyses), the results were expressed as means and standard deviations (±SD). The data were assessed by analysis of variance (ANOVA) with nested design considering the cheeses (15 Maroilles cheeses) and the type (Artisanal or Industrial) as factors and microbiological, chemical, texture and colour parameters as dependent variables. Post-hoc pairwise testing among all cheeses or between types was performed using Tukey test (with a $P < 0.05$).

For each set of analyses (microbiological, chemical, texture and colour), a principal component analysis (PCA) was applied to the mean values of three replicates to identify correlations among parameters and to group the cheeses accordingly. After computing PCA, a hierarchical cluster analysis (HCA) using the Ward algorithm was performed on the PCA coordinates of the first two axes to obtain clusters of Maroilles cheeses. Finally, a multiple factor analysis (MFA) was carried out to investigate the relationship among the different sets of analyses (sensory, microbiological, chemical, texture and colour).

3. Results and discussion

3.1. Sensory analysis

As shown in Fig. 1, the DISTATIS map explains 25.17% of the variance and illustrates the clusters of Maroilles cheeses and their description. Three clusters that resulted: cluster #1 contains 6 industrial Maroilles cheeses (Fauquet 1, 2 and 3, Leduc 1 and 3, Lesire 1), cluster #2 contains 4 artisanal Maroilles cheeses (Loups, Moulin, Courbet, Freres) and cluster #3 is a mixed cluster containing both types of Maroilles cheeses (2 industrial Maroilles Lesire 2, Leduc 2 and 3 artisanal Maroilles Cerfmont, Bahardes, Hennart).

Cluster #1 is characterised by the terms “beige”, “weak” and “unpleasant” odour, “salt”, “pungent”, “sticky”, “hole” and “damp texture”. Cluster #2 is defined by the terms “yellow”, “smoked”, “floral”, “barn”, “strong” odour “melting”, and “mature” and cluster #3 by the terms “fruity”, “bland”, “chalky”, “dry”, “firm” and “not mature”. Therefore, from a sensory point of view, globally the consumers differentiated and characterised the artisanal and industrial Maroilles. The use of the sorting method with descriptive comments helps to better understand the categorisation choices of assessors as shown, for instance, by the work on olive oil of Santosa, Abdi, and Guinard (2010).

3.2. Microbiological analysis

As reported in the Table 2, mesophilic aerobic flora and LAB were clearly the dominant micro-organisms. Briefly, the total mesophilic bacteria contents ranged between 7.85 and 8.91 log cfu g^{-1} for the rind and ranged between 7.10 and 8.48 log cfu g^{-1} for the heart. The LAB contents were between 6.21 and 7.92 log cfu g^{-1} for the rind and ranged between 6.32 and 8.06 log cfu g^{-1} for the heart. These results on the levels of mesophilic aerobic flora and LAB in the rind and the heart are in line with those reported for the Herve cheese (Delcenserie et al., 2014), the gouda-type cheese (Mankai, Boulares, Ben Moussa, Karoui, & Hassouna, 2012), the Saint-Paulin cheese (Boulares, Mankai, & Hassouna, 2011) and for the Serra da Estrela Portuguese cheese (Dahl, Tavaria, & Malcata, 2000).

As demonstrated by the significant p-value ($P < 0.05$) associated with the cheese as a factor, the 15 Maroilles cheeses were significantly different for three microbiological parameters in the rind and heart: total mesophilic bacteria ($P < 0.0001$), lactic acid bacteria ($P < 0.0001$) and the yeasts and moulds ($P = 0.013$ and $P < 0.001$, respectively). The Enterobacteriaceae did not allow to discriminate

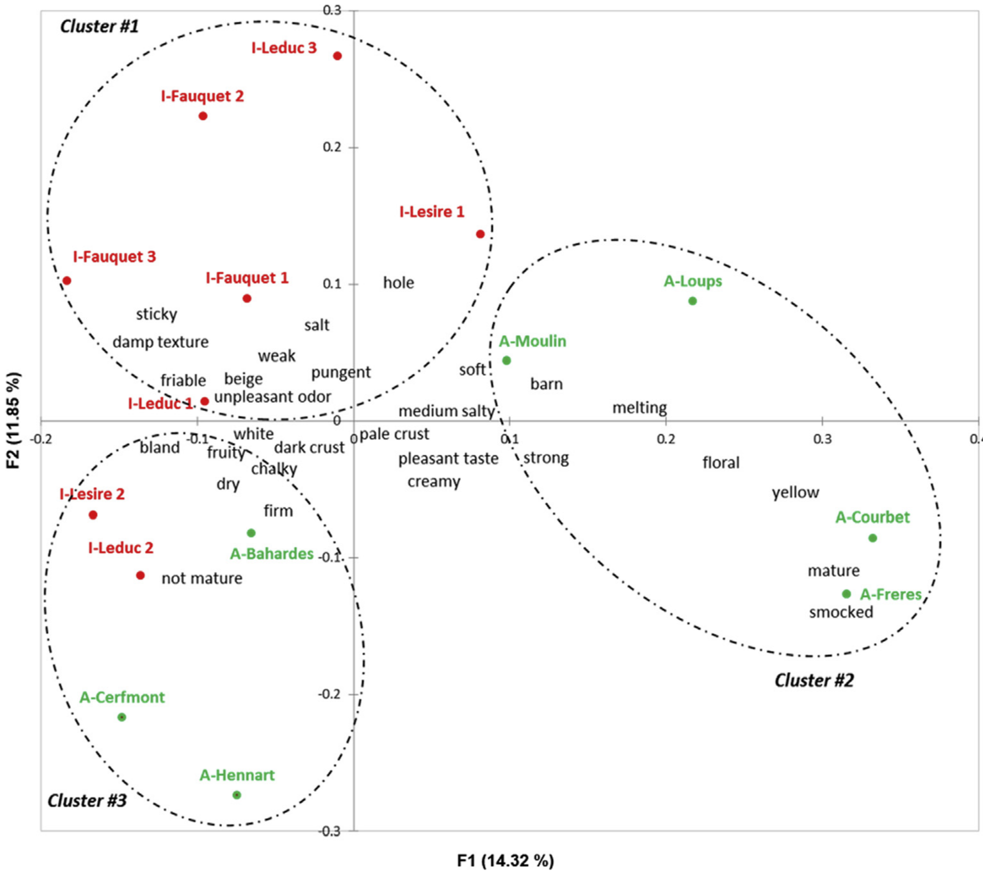

Fig. 1. Positioning of 15 Maroilles cheeses and the associated descriptors used by 20 consumers issued from the sorting task; the ellipses represent the clusters yielded by the hierarchical cluster analysis. The green font represents the artisanal Maroilles (also indicated by the A-prefix) while the red font represents the industrial Maroilles (also indicated by the I-prefix). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

among the 15 Maroilles cheeses ($P = 0.105$ and $P = 0.065$, respectively in the rind and the heart).

The rind of artisanal Maroilles cheeses contained less mesophilic bacteria ($P = 0.015$) and LAB ($P < 0.0001$) and more Enterobacteriaceae than did industrial Maroilles cheeses ($P < 0.001$) whereas the heart of artisanal Maroilles cheeses contained more lactic acid bacteria ($P = 0.003$) and Enterobacteriaceae ($P < 0.0001$) than did industrial Maroilles cheese.

The fluctuation in the enumeration of the bacteria among the different cheeses is partly due to the milk treatment before

Table 2
Microbiological evaluation of 15 Maroilles cheeses.[a]

Cheese	Rind				Heart			
	Total mesophilic bacteria	Lactic acid bacteria	Enterobacteriaceae	Yeasts and moulds	Total mesophilic bacteria	Lactic acid bacteria	Enterobacteriaceae	Yeasts and moulds
A-Bahardes	8.40 ± 0.22^{de}	7.71 ± 0.09^{b}	3.57 ± 0.50^{abc}	5.07 ± 0.36^{b}	8.40 ± 0.02^{ab}	8.06 ± 0.31^{a}	2.88 ± 0.79^{ab}	4.12 ± 0.18^{b}
A-Cerfmont	8.01 ± 0.09^{cde}	7.11 ± 0.21^{c}	3.46 ± 0.38^{abc}	5.38 ± 0.35^{b}	7.93 ± 0.00^{cd}	7.66 ± 0.43^{bcd}	3.37 ± 0.18^{a}	4.47 ± 0.52^{ab}
A-Courbet	8.31 ± 1.15^{cd}	7.00 ± 0.7^{c}	3.86 ± 0.64^{a}	3.55 ± 0.11^{b}	8.38 ± 1.15^{ab}	7.42 ± 0.34^{cd}	1.54 ± 0.21^{ab}	0.00 ± 0.00^{b}
A-Freres	8.54 ± 0.32^{de}	6.52 ± 0.29^{c}	3.75 ± 0.65^{a}	4.83 ± 0.38^{b}	8.22 ± 0.41^{bc}	7.95 ± 0.44^{ab}	3.23 ± 0.31^{ab}	3.64 ± 0.49^{b}
A-Hennart	7.94 ± 0.05^{bc}	7.12 ± 0.21^{c}	0.00 ± 0.00^{c}	6.36 ± 0.37^{a}	7.76 ± 0.34^{d}	7.26 ± 0.18^{cd}	0.00 ± 0.00^{b}	4.36 ± 0.25^{ab}
A-Moulin	8.61 ± 0.05^{cde}	6.97 ± 0.22^{c}	3.64 ± 0.40^{abc}	5.17 ± 0.31^{b}	7.41 ± 0.10^{d}	6.79 ± 0.32^{d}	3.25 ± 0.42^{ab}	3.91 ± 0.02^{b}
A-Loups	8.43 ± 0.01^{cde}	7.00 ± 1^{c}	3.85 ± 0.56^{ab}	5.08 ± 0.7^{b}	7.39 ± 0.35^{d}	7.03 ± 0.43^{d}	3.18 ± 0.12^{ab}	4.48 ± 0.25^{ab}
I-Leduc 3	8.47 ± 0.06^{cde}	6.63 ± 0.7^{c}	3.16 ± 0.35^{abc}	5.32 ± 0.04^{b}	8.25 ± 0.96^{bc}	7.86 ± 0.13^{abc}	0.00 ± 0.00^{b}	4.21 ± 0.11^{b}
I-Leduc 1	8.35 ± 0.05^{cde}	7.84 ± 0.22^{ab}	2.64 ± 0.37^{abc}	3.21 ± 0.02^{b}	7.10 ± 0.19^{d}	6.54 ± 0.11^{d}	0.94 ± 0.18^{b}	0.00 ± 0.00^{b}
I-Fauquet 2	7.85 ± 0.51^{e}	7.12 ± 0.24^{c}	0.00 ± 0.00^{c}	5.24 ± 0.04^{b}	7.56 ± 0.40^{d}	6.95 ± 0.00^{d}	0.52 ± 0.76^{b}	4.76 ± 0.21^{a}
I-Fauquet 3	8.26 ± 0.04^{cde}	7.77 ± 0.05^{b}	0.00 ± 0.00^{c}	4.78 ± 0.04^{b}	8.48 ± 0.33^{a}	7.85 ± 0.37^{abc}	0.00 ± 0.00^{b}	4.16 ± 0.07^{b}
I-Fauquet 1	8.8 ± 0.21^{ab}	7.30 ± 0.03^{c}	2.53 ± 0.82^{abc}	4.27 ± 0.00^{b}	8.32 ± 0.47^{ab}	7.31 ± 0.00^{cd}	1.56 ± 0.8^{ab}	3.29 ± 0.42^{b}
I-Leduc 2	8.91 ± 0.22^{a}	6.21 ± 0.25^{c}	1.00 ± 0.00^{c}	5.24 ± 0.20^{b}	7.23 ± 0.34^{d}	6.32 ± 0.41^{d}	0.00 ± 0.00^{b}	3.20 ± 0.09^{b}
I-Lesire 2	7.85 ± 0.11^{e}	7.32 ± 0.28^{c}	1.00 ± 0.00^{c}	4.28 ± 0.26^{b}	7.13 ± 0.43^{d}	6.95 ± 0.06^{d}	0.00 ± 0.00^{b}	3.16 ± 0.12^{b}
I-Lesire 1	8.23 ± 0.57^{cde}	7.92 ± 0.03^{a}	2.22 ± 0.38^{bc}	4.80 ± 0.07^{b}	7.89 ± 0.05^{cd}	7.44 ± 0.38^{cd}	1.85 ± 0.05^{ab}	0.00 ± 0.00^{b}
P-value (cheese)	<0.0001	<0.0001	0.105	0.013	<0.0001	<0.0001	0.065	<0.0001
Artisanal cheeses	8.38 ± 0.13^{b}	7.20 ± 0.20^{b}	3.64 ± 0.56^{a}	5.63 ± 1.00^{a}	8.08 ± 0.01^{a}	7.65 ± 0.65^{a}	3.06 ± 0.10^{a}	4.19 ± 0.25^{a}
Industrial cheeses	8.49 ± 0.43^{a}	7.53 ± 0.50^{a}	2.48 ± 0.91^{b}	4.95 ± 0.97^{a}	8.02 ± 0.03^{a}	7.43 ± 0.46^{b}	1.17 ± 0.66^{b}	4.06 ± 0.29^{a}
P-value (type)	0.015	<0.0001	<0.0001	0.07	0.128	0.003	<0.0001	0.289

[a] Values, in log cfu g^{-1}, are means ± SD (n = 3); different superscript letters indicate means that significantly differ among cheeses and between types at $P < 0.05$ (Tukey test).

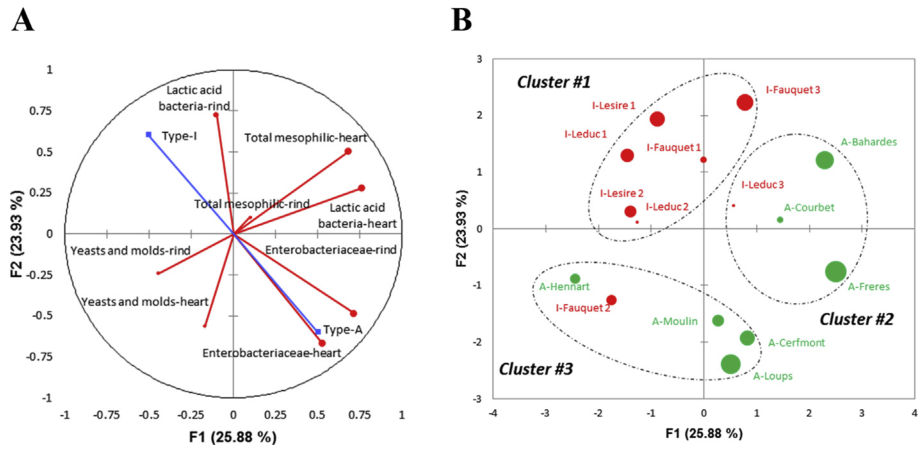

Fig. 2. Principal component analysis (PCA) for dimension 1 and 2: A, microbiological variables; B, Maroilles cheeses. Types of cheeses (A-, artisanal; I-, industrial) are considered as supplementary variables. The size of the dots depends on the $\cos^2$ and indicates the representativity of Maroilles cheeses.

processing, the manufacturing process and the hygiene. Moreover, the superiority of total mesophilic bacteria and Lactic acid bacteria in the rind of the industrial cheeses could be explained by the washing step of the Maroilles cheese process. Indeed, such a washing is traditionally done with water and salt (at least 30 g L^{-1}). According to the specifications of the appellation of origin of Maroilles (Ministry of Agriculture, 2015), the addition of red ferments (mixture of bacteria) is allowed to obtain the rind coloration. However, only industrial manufacturers use this type of addition. In both types of cheeses, the yeasts and moulds are quantitatively present at values ranging from about 3.00 to 6.36 log cfu g^{-1}. As reported by different authors, the presence of yeasts has been associated with the secondary microflora of other variety of cheeses (Centi, Matteucci, Lepidi, Gallo, & Ercole, 2017).

As it is well known, the Enterobacteriaceae count is an excellent indicator of the hygienic quality of a product. Elevated counts from milk and cheese indicate poor hygiene practices during milk collection and/or cheese manufacturing. Enterobacteriaceae are generally not detected from products manufactured from pasteurised milk. However, in this study, low counts of Enterobacteriaceae were obtained in Maroilles manufactured with pasteurised milk. Moreover, high standard deviation for Enterobacteriaceae was observed because only 4 cheeses out of 8 were contaminated, indicating probably a hygiene issue during manufacturing for these cheeses.

The two first dimensions of the PCA explained 49.81% of the variance (Fig. 2). Fig. 2B illustrates the clustering based on the microbiological contents of Maroilles cheeses. Three clusters emerge from the PCA: cluster #1 contains only industrial cheeses (Lesire 1, Lesire 2, Fauquet 1, Fauquet 3, Leduc 1 and Leduc 2) that are rich in lactic acid bacteria (rind) and are poor in Enterobacteriaceae (both in the rind and heart); cluster #2 is composed of three artisanal cheeses (Bahardes, Courbet and Freres) and one industrial cheese (Leduc 3) that contain high value of Enterobacteriaceae, total mesophilic bacteria and lactic acid bacteria (heart only); cluster #3 is composed of four artisanal cheeses (Loups, Cerfmont, Moulin and Hennart) and one industrial (Fauquet 2) that are rich in yeasts and moulds and poor in total mesophilic bacteria and Lactic acid bacteria (heart). In general, all microbiological parameters do not differentiate artisanal Maroilles cheeses from industrial Maroilles cheeses. Indeed, only Enterobacteriaceae content in the rind and in the heart and the total mesophilic bacteria and lactic acid bacteria in the heart are discriminant (Fig. 2). Feurer, Irlinger, Spinnler, Glaser, and Vallaeys (2004) reported that the bacterial diversity on the surface of the

Table 3
Chemical parameters of the 15 Maroilles cheeses.[a]

Cheese	Protein (%)	pH	Ash (%)	Fat (%)	Moisture (%)	a_w rind	a_w heart
A-Bahardes	20.72 ± 0.25^{de}	5.41 ± 0.06^{b}	2.73 ± 0.03^{e}	27.5 ± 0.5^{def}	47.5 ± 0.38^{cd}	0.943 ± 0.004^{a}	0.948 ± 0.004^{ab}
A-Cerfmont	20.03 ± 0.19^{fg}	5.15 ± 0.11^{cd}	2.94 ± 0.08^{cd}	27.67 ± 0.29^{de}	47.55 ± 0.37^{cd}	0.929 ± 0.003^{ab}	0.93 ± 0.002^{de}
A-Courbet	21.61 ± 0.17^{c}	5.06 ± 0.03^{cd}	2.46 ± 0.03^{f}	29.5 ± 0.5^{ab}	42.89 ± 0.08^{g}	0.946 ± 0.006^{bc}	0.957 ± 0.001^{a}
A-Freres	20.63 ± 0.36^{def}	5.93 ± 0.02^{a}	2.45 ± 0.07^{f}	29.67 ± 0.29^{ab}	46.38 ± 0.35^{ef}	0.912 ± 0.001^{bc}	0.918 ± 0.003^{gh}
A-Hennart	$21.14^{cd} \pm 0.18$	5.17 ± 0.02^{cd}	2.81 ± 0.05^{de}	30.17 ± 0.29^{a}	42.77 ± 0.51^{g}	0.92 ± 0.005^{bc}	0.92 ± 0.001^{fgh}
A-Moulin	19.99 ± 0.28^{g}	5.12 ± 0.07^{cd}	2.68 ± 0.07^{e}	27.17 ± 0.29^{ef}	49.75 ± 0.29^{a}	0.929 ± 0.001^{cd}	0.946 ± 0.002^{b}
A-Loups	20.16 ± 0.19^{efg}	5.12 ± 0.09^{cd}	2.79 ± 0.04^{de}	28.17 ± 0.29^{cde}	48.7 ± 0.18^{b}	0.934 ± 0.002^{cd}	0.944 ± 0.003^{b}
I-Leduc 3	21.1 ± 0.15^{cd}	5.14 ± 0.04^{cd}	2.93 ± 0.07^{cd}	27.67 ± 0.29^{de}	46.98 ± 0.19^{de}	0.926 ± 0.002^{ef}	0.932 ± 0.001^{d}
I-Leduc 1	22.33 ± 0.23^{b}	5.01 ± 0.08^{d}	3.29 ± 0.04^{a}	25.5 ± 0.5^{gh}	48.16 ± 0.25^{bc}	0.915 ± 0.003^{cde}	0.949 ± 0.005^{ab}
I-Fauquet 2	21.37 ± 0.11^{c}	5.16 ± 0.09^{cd}	3 ± 0.05^{bc}	24.5 ± 0.5^{h}	49.99 ± 0.37^{a}	0.935 ± 0.002^{cde}	0.928 ± 0.005^{def}
I-Fauquet 3	21.03 ± 0.14^{cd}	5.17 ± 0.02^{cd}	2.95 ± 0.04^{cd}	26.33 ± 0.58^{fg}	48.84 ± 0.07^{b}	0.918 ± 0.005^{def}	0.913 ± 0.004^{h}
I-Fauquet 1	21.53 ± 0.14^{c}	5.26 ± 0.07^{bc}	2.91 ± 0.07^{cd}	24.33 ± 0.58^{h}	49.91 ± 0.23^{a}	0.916 ± 0.005^{ef}	0.922 ± 0.002^{efg}
I-Leduc 2	23.16 ± 0.15^{a}	5 ± 0.04^{d}	3 ± 0.02^{bc}	29 ± 0.5^{abc}	43.5 ± 0.41^{g}	0.926 ± 0.001^{cd}	0.934 ± 0.002^{cd}
I-Lesire 2	19.65 ± 0.11^{g}	5.07 ± 0.03^{cd}	3.13 ± 0.04^{ab}	28.67 ± 0.29^{bcd}	45.98 ± 0.18^{f}	0.928 ± 0.003^{f}	0.941 ± 0.003^{bc}
I-Lesire 1	19.68 ± 0.11^{g}	4.98 ± 0.05^{d}	3.01 ± 0.08^{bc}	28.17 ± 0.29^{cde}	48.06 ± 0.26^{bc}	0.934 ± 0.002^{f}	0.947 ± 0.004^{b}
P-value (cheese)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Artisanal cheeses	20.61 ± 0.61^{b}	5.28 ± 0.3^{a}	2.70 ± 0.18^{b}	28.55 ± 1.18^{a}	46.51 ± 2.6^{b}	0.930 ± 0.012^{a}	0.938 ± 0.014^{a}
Industrial cheeses	21.23 ± 1.15^{a}	5.10 ± 0.1^{b}	3.03 ± 0.12^{a}	26.77 ± 1.82^{b}	47.6 ± 2.08^{a}	0.925 ± 0.008^{b}	0.933 ± 0.012^{b}
P-value (type)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Values are means ± standard deviation (n = 3); different superscript letters indicate means that significantly differ among cheeses and between types at $P < 0.05$ (Tukey test).

industrial soft red-smear cheese at the end of the ripening process is defined. Conversely, the bacterial flora in traditional process is expected to be much more diverse and variable.

3.3. Chemical analysis

Table 3 summarises the results of chemical parameters of all the analysed cheeses. The data are reported as mean ± SD and are not described in detail but are interpreted with regard to each parameter and type of cheese and accordingly to *P*-values. First of all, the Pb contents (data not shown) are below the detection level (<0.002 μg kg^{-1}). Secondly, regardless of the chemical parameters, the 15 Maroilles cheeses are significantly different ($P < 0.0001$) except for the Cd amount ($P = 0.451$).

The discrimination of Maroilles types according to some chemical parameters was relatively easy. Indeed, the artisanal and industrial cheeses could be differentiated, as demonstrated by the $P < 0.0001$, for protein %, pH, ash %, fat, moisture % and a_w. In contrast, practically no mineral elements, except Fe and Mg, allowed discrimination between the artisanal and the industrial Maroilles cheeses. Our results are in agreement with previous studies reporting that artisanal smear-ripened cheeses have higher pH value than industrial cheeses because industrial cheeses have a shorter ripening time than the artisanal cheeses and the pH increases during ripening (Brennan et al., 2002). Concerning a_w, our mean values range from 0.91 to 0.95. The water activity allows differentiation of the two types of cheese; nevertheless, the two a_w values for each type remain very close.

As shown in Fig. 3, the two first dimensions of the PCA of all chemical parameters explained 47.16% of the variance. Three clusters of Maroilles cheeses appeared (Fig. 3B): cluster #1 comprised three industrial cheeses (Fauquet 1, Fauquet 2 and Fauquet 3) and three artisanal cheeses (Moulin, Bahardes and Cerfmont) that contain high amounts of moisture, K and Na but are lower in fat; cluster #2 contains only one artisanal cheese (Freres) that has a high pH and cluster #3 encompassing three artisanal cheeses (Loups, Hennart and Courbet) and five industrial cheeses (Leduc 1, Leduc 2, Leduc 3, Lesire 1 and Lesire 2) that contain high amounts of ash, Ca and Zn and have a low pH (Fig. 3). Interestingly, cheeses made by the same cheesemaker are in the same clusters, indicating special features due to the own skill of each cheesemaker.

3.4. Texture analysis: penetration test

As previously reported, cheese composition plays an important role in rheological and textural properties (Verdini & Rubiolo, 2002). Therefore, all cheeses were subjected to a penetration test as detailed in the material and method section. Table 4 summarises the results obtained on hardness (positive value) and adhesiveness (negative value) measured with application forces of 20% and 80%. Individually, regardless of the applied force, hardness and adhesiveness significantly discriminate ($P < 0.0001$) the 15 cheeses, highlighting a great texture variability among the cheeses. Moreover, adhesiveness absolute values at 20% and 80% were significantly higher for industrial cheeses than those for the artisanal cheeses. Concerning the hardness, different results are obtained in the rind (20% position) and in the heart (80% position): the heart of industrial Maroilles is harder than that of artisanal Maroilles ($P < 0.0001$) whereas the rind is firmer in artisanal cheese than that of the industrial cheeses ($P = 0.004$).

Given that ripening time of the artisanal Maroilles is longer than that of industrial Maroilles, our results are in agreement with previous works where the rind firmness of brie-type cheese increases with the ripening time, whereas the heart of industrial cheeses is harder than that of artisanal cheeses (Champagne, Soulignac, Marcotte, & Innocent, 2003).

The PCA corresponding to values obtained from the penetration test are depicted in Fig. 4. The two first dimensions of the PCA explained 93.36% of the variance. The PCA map (Fig. 4B) highlights three clusters of Maroilles cheeses: cluster #1 gathers the three industrial cheeses from Leduc (Leduc 1, Leduc 2 and Leduc 3) and is characterised by a hard heart and a low adhesiveness, cluster #2 contains four artisanal cheeses (Bahardes, Loup, Freres and Moulin) and the three Fauquet's industrial cheeses (Fauquet 1, Fauquet 2 and Fauquet 3) that appear as not hard but sticky and cluster #3 comprised two industrial cheeses (Lesire 1 and Lesire 2) and three artisanal cheeses (Courbet, Hennart and Cerfmont) with a hard rind (Fig. 4). Interestingly, once again, the textural parameters grouped under different clusters, cheeses from the same cheesemaker

Ca (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Na (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Cd (mg kg^{-1})
3582.26 ± 163.44^{bcd}	18.91 ± 1.36^{efg}	0.71 ± 0.01^{abcd}	0.56 ± 0.03^{defg}	12150.08 ± 419.25^{a}	1063.25 ± 23.64^{ab}	127.8 ± 1^{cde}	0.04 ± 0.05^{a}
4855.94 ± 125.25^{a}	18.62 ± 1.18^{efg}	0.81 ± 0.03^{abc}	0.49 ± 0.01^{fgh}	13027.83 ± 389.67^{a}	1149.05 ± 13.45^{a}	157.47 ± 5.18^{a}	0.01 ± 0.01^{a}
4311.26 ± 583.49^{ab}	21.95 ± 1.66^{bcde}	0.71 ± 0.03^{abcd}	0.7 ± 0.05^{bcd}	5748.71 ± 205.59^{f}	905.7 ± 19.80^{cd}	85.21 ± 0.54^{g}	0.02 ± 0.01^{a}
1785.48 ± 84.84^{f}	19.04 ± 0.95^{efg}	0.85 ± 0.06^{ab}	0.38 ± 0.03^{h}	8001.42 ± 470.83^{de}	950.21 ± 40.12^{bcd}	85.18 ± 4.68^{g}	0.01 ± 0.01^{a}
3769.25 ± 49.84^{bcd}	26 ± 0.47^{ab}	0.73 ± 0.01^{abcd}	0.78 ± 0.05^{b}	7273.5 ± 516.15^{def}	765.69 ± 28.51^{e}	119.05 ± 3.98^{def}	0.03 ± 0.05^{a}
2775.56 ± 97.16^{e}	16.05 ± 1.91^{g}	0.86 ± 0.06^{a}	0.54 ± 0.06^{efg}	10316.63 ± 430.83^{bc}	996.78 ± 38.58^{bc}	117.95 ± 1.93^{ef}	0.02 ± 0.01^{a}
3749.85 ± 315.35^{bcd}	20.86 ± 1.45^{cdef}	0.84 ± 0.13^{ab}	1.07 ± 0.01^{a}	7243.21 ± 433.76^{ef}	920.01 ± 14.72^{cd}	74.89 ± 4.45^{g}	0.05 ± 0.03^{a}
3733.72 ± 246.81^{bcd}	24.72 ± 1.03^{abc}	0.59 ± 0.05^{def}	0.63 ± 0.02^{bcdef}	8097.89 ± 101.93^{de}	919.27 ± 40.36^{cd}	133.86 ± 4.57^{bc}	0.04 ± 0.01^{a}
3760.44 ± 218.13^{bcd}	26.87 ± 1.28^{a}	0.81 ± 0.04^{abc}	0.53 ± 0.01^{efg}	8795.72 ± 248.14^{cd}	1015.33 ± 35.29^{bc}	161.72 ± 1.57^{a}	0.02 ± 0.02^{a}
3174.53 ± 225.5^{de}	17.1 ± 1.14^{fg}	0.47 ± 0.06^{f}	0.59 ± 0.12^{cdef}	10342.53 ± 374.93^{bc}	1051.3 ± 21.01^{ab}	144.02 ± 3.32^{b}	0.07 ± 0.09^{a}
4022.87 ± 109.78^{bc}	19.11 ± 1.45^{efg}	0.51 ± 0.03^{ef}	0.51 ± 0.07^{efgh}	10549 ± 648.86^{b}	1038.19 ± 69.39^{ab}	116.5 ± 1.79^{ef}	0 ± 0^{a}
3384.58 ± 224.68^{cde}	16.75 ± 0.51^{fg}	0.68 ± 0.06^{bcde}	1.11 ± 0.02^{a}	10180.2 ± 685.26^{bc}	990.44 ± 39.95^{bc}	127.4 ± 2.38^{cde}	0.11 ± 0.04^{a}
3798.37 ± 349.59^{bcd}	24.45 ± 1.81^{abcd}	0.88 ± 0.07^{a}	0.64 ± 0.06^{bcde}	8810.57 ± 423.28^{cd}	854.94 ± 45.14^{de}	129.13 ± 4.78^{cd}	0.05 ± 0.03^{a}
3833.72 ± 257.99^{bcd}	18.91 ± 1.11^{efg}	0.65 ± 0.03^{cde}	0.73 ± 0.02^{bc}	9676.12 ± 1067.64^{bc}	971.52 ± 59.73^{bc}	126.74 ± 5.5^{cdef}	0.06 ± 0.03^{a}
3884.12 ± 172.47^{bcd}	19.96 ± 3.22^{defg}	0.74 ± 0.08^{abcd}	0.43 ± 0.05^{gh}	7838.23 ± 576.59^{de}	856.99 ± 28.52^{de}	132.5 ± 1.71^{c}	0.06 ± 0.1^{a}
<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.451
3547.08 ± 981.44^{a}	20.20 ± 3.2^{a}	0.79 ± 0.08^{a}	0.65 ± 0.22^{a}	9108.77 ± 2634.01^{a}	964.38 ± 118.44^{a}	109.65 ± 28.03^{b}	0.02 ± 0.03^{a}
3699.04 ± 330.95^{a}	20.98 ± 3.9^{a}	0.67 ± 0.14^{b}	0.65 ± 0.21^{a}	9286.28 ± 1111.62^{a}	962.25 ± 82.83^{a}	133.99 ± 13.33^{a}	0.05 ± 0.05^{a}
0.051	0.094	<0.0001	0.947	0.258	0.851	<0.0001	0.050

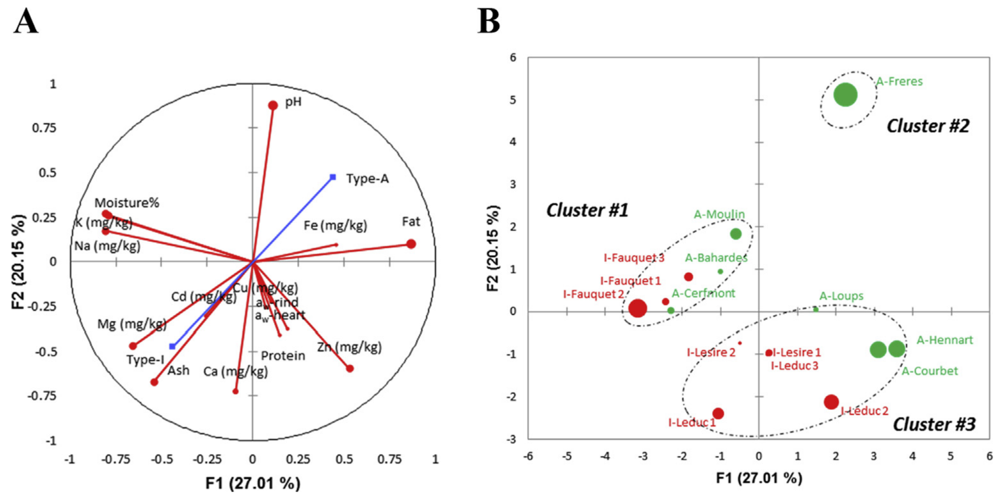

Fig. 3. Principal component analysis (PCA) for dimension 1 and 2: A, chemical composition analysis; B, Maroilles cheeses. Type of cheeses (A-, artisanal; I-, industrial) are considered as supplementary variables. The size of the dots depends on the $\cos^2$ and indicates the representativity of Maroilles cheeses.

(Lesire, Leduc and Fauquet), indicating a specific skill of the cheesemaker.

3.5. Colour analysis

The colour of cheeses is one of the factor for the selection of a product and the consumer acceptability (Magenis et al., 2014; Mathias-Rettig & Ah-Hen, 2014). The colour of cheeses is due to the dispersal of light caused by casein micelles, fat globules and colloidal calcium phosphate. The carotene and riboflavin contribute also to this effect (Mortensen, Bertelsen, Mortensen, & Stapelfeldt, 2004; Sandoval-Copado, Orozco-Villafuerte, Pedrero-Fuehrer, & Colín-Cruz, 2016). The lightness (L*), the red-green (a*) and the blue-yellow (b*) dimensions were measured for the rind and the heart for all Maroilles cheeses and the results are summarised in Table 5.

Concerning the colour measured by L*, a* and b* parameters in the rind and the heart, the 15 Maroilles cheeses were significantly different as indicated by the *P*-values < 0.0001. This great variability could also be observed in another PDO cheese, the Munster produced in eastern France (Dufossé et al., 2005). L* parameter indicates the lightness and the capacity of an object to either reflect or transmit the light. The higher L* value, the brighter the product.

The rind of industrial cheeses had a higher value of a* ($P < 0.001$) and b* ($P < 0.0001$) and lower value of L* ($P < 0.0001$) than the rind of artisanal cheeses. In summary, this means that the rind of industrial cheeses is more orange and darker than the rind of artisanal cheeses, due probably to washings with the red ferments of Maroilles (mixture of bacteria). Rind coloration is a complex process involving many interactions: between bacteria (Bockelmann, Willems, Neve, & Heller, 2005; Brennan et al., 2002; Leclercq-Perlat & Spinnler, 2010), between bacteria and yeasts (Leclercq-Perlat, Corrieu, & Spinnler, 2004), as well as between physical, chemical and microbiological parameters (Galaup, Flamin, Carlet, & Dufossé, 2005; Galaup et al., 2007, 2015). The heart of artisanal cheeses is redder a*($P < 0.0001$) and more yellow b*($P < 0.0001$) than the heart of industrial cheeses. Given that artisanal Maroilles undergo a longer maturation time compared with industrial Maroilles, these results are in agreement with previous studies where the authors described a slight increase in redness (a*) and yellowness (b*) with the maturation time while

Table 4
Texture analysis of 15 Maroilles cheeses.[a]

Cheese	20% (rind)		80% (heart)	
	Hardness (kg s^{-1})	Adhesiveness (kg s^{-1})	Hardness (kg s^{-1})	Adhesiveness (kg s^{-1})
A-Bahardes	0.26 ± 0.01^{f}	-0.11 ± 0.02^{abc}	0.90 ± 0.01^{gh}	-0.56 ± 0.02^{abc}
A-Cerfmont	0.76 ± 0.03^{c}	-0.24 ± 0.01^{f}	2.39 ± 0.13^{bc}	-0.74 ± 0.02^{cde}
A-Courbet	1.26 ± 0.01^{a}	-0.26 ± 0.03^{f}	1.94 ± 0.11^{d}	-1.17 ± 0.02^{fgh}
A-Freres	0.49 ± 0.01^{e}	-0.08 ± 0^{ab}	0.66 ± 0.08^{h}	-0.37 ± 0.02^{a}
A-Hennart	0.83 ± 0.06^{bc}	-0.26 ± 0.03^{f}	1.64 ± 0.1^{de}	-0.98 ± 0.09^{efg}
A-Moulin	0.30 ± 0.03^{f}	-0.08 ± 0.01^{a}	0.78 ± 0.07^{gh}	-0.43 ± 0.03^{ab}
A-Loups	0.46 ± 0.02^{e}	-0.16 ± 0.03^{cde}	1.76 ± 0.03^{de}	-0.93 ± 0.01^{def}
I-Leduc 3	0.6 ± 0.03^{d}	-0.21 ± 0.01^{def}	2.46 ± 0.19^{b}	-1.44 ± 0.18^{i}
I-Leduc 1	0.62 ± 0.04^{d}	-0.22 ± 0.02^{ef}	2.52 ± 0.2^{b}	-1.34 ± 0.13^{hi}
I-Fauquet 2	0.42 ± 0.04^{e}	-0.25 ± 0.03^{f}	1.4 ± 0.11^{ef}	-0.67 ± 0.04^{bcd}
I-Fauquet 3	0.24 ± 0.03^{f}	-0.1 ± 0.03^{abc}	1.05 ± 0.05^{fgh}	-0.48 ± 0.05^{abc}
I-Fauquet 1	0.44 ± 0.02^{e}	-0.15 ± 0.04^{bcd}	1.13 ± 0.05^{fg}	-0.45 ± 0.04^{ab}
I-Leduc 2	0.91 ± 0.02^{b}	-0.38 ± 0.03^{g}	3.12 ± 0.35^{a}	-1.76 ± 0.11^{j}
I-Lesire 2	0.76 ± 0.03^{c}	-0.28 ± 0.02^{f}	1.82 ± 0.27^{de}	-1.22 ± 0.16^{ghi}
I-Lesire 1	0.75 ± 0.05^{c}	-0.24 ± 0.02^{f}	1.97 ± 0.06^{cd}	-0.88 ± 0.1^{de}
P-value (cheese)	<0.0001	<0.0001	<0.0001	<0.0001
Artisanal cheeses	0.62 ± 0.39^{a}	-0.17 ± 0.08^{a}	1.44 ± 0.63^{a}	-0.74 ± 0.28^{a}
Industrial cheeses	0.59 ± 0.21^{b}	-0.23 ± 0.08^{a}	1.93 ± 0.72^{a}	-1.03 ± 0.47^{b}
P-value (type)	0.004	<0.0001	<0.0001	<0.0001

[a] Values are means ± standard deviation (n = 3); different superscript letters indicate means that significantly differ among cheeses and between types at $P < 0.05$ (Tukey test). 20% position correspond to the periphery of the cheese (rind) and the 80% position to the heart of the cheese.

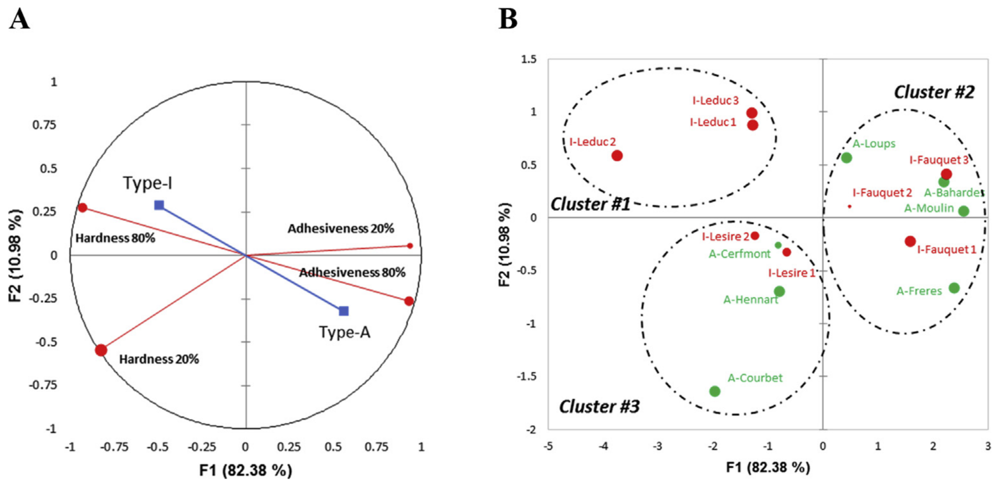

Fig. 4. Principal component analysis (PCA) for dimension 1 and 2: A, texture analysis; B, Maroilles cheeses. For hardness and adhesiveness, 20% position correspond to the periphery of the cheese (rind) and the 80% position to the heart of the cheese. Type of cheeses (A-, artisanal; I-, industrial) are considered as supplementary variables. The size of the dots depends on the cos^2 and indicates the representativity of Maroilles cheeses.

Table 5
Colour analysis of 15 Maroilles cheeses.[a]

Cheese	Rind			Heart		
	L*	a*	b*	L*	a*	b*
A-Bahardes	71.96 ± 0.23^{c}	4.27 ± 0.09^{h}	19.28 ± 0.17^{c}	77.39 ± 0.03^{c}	−0.83 ± 0.01^{g}	8.02 ± 0.1^{h}
A-Cerfmont	72.61 ± 0.02^{b}	3.68 ± 0.03^{i}	18.09 ± 0.04^{d}	77.74 ± 0.05^{c}	0.24 ± 0.05^{c}	10.1 ± 0.08^{f}
A-Courbet	67.51 ± 0.24^{g}	3.6 ± 0.03^{i}	14.22 ± 0.05^{g}	79.96 ± 0.19^{b}	1.39 ± 0.06^{a}	15.82 ± 0.03^{a}
A-Freres	66.44 ± 0.04^{i}	6.71 ± 0.02^{e}	18.03 ± 0.05^{d}	75.87 ± 0.04^{d}	0.03 ± 0.02^{d}	12.29 ± 0.04^{bc}
A-Hennart	76.47 ± 0.3^{a}	0.66 ± 0.02^{k}	12.21 ± 0.04^{h}	73.93 ± 0.01^{f}	0.89 ± 0.03^{b}	15.97 ± 0.04^{a}
A-Moulin	68.79 ± 0.05^{ef}	4.55 ± 0.08^{g}	20.23 ± 0.04^{b}	76.11 ± 0.14^{d}	0.1 ± 0.01^{d}	12.07 ± 0.03^{c}
A-Loups	68.84 ± 0.02^{ef}	5.29 ± 0.06^{f}	17.15 ± 0.11^{e}	79.73 ± 0.13^{b}	0.24 ± 0.02^{c}	11.06 ± 0.04^{e}
I-Leduc 3	67.88 ± 0.15^{g}	9.74 ± 0.19^{b}	18.11 ± 0.1^{d}	74.87 ± 0.08^{e}	−1.11 ± 0.03^{h}	9.37 ± 0.05^{g}
I-Leduc 1	69.67 ± 0.04^{d}	8.69 ± 0.05^{d}	20.06 ± 0.04^{b}	76.04 ± 0.04^{d}	0.25 ± 0.03^{c}	10.97 ± 0.13^{e}
I-Fauquet 2	72.77 ± 0.03^{b}	1.83 ± 0.02^{j}	20.66 ± 0.05^{a}	76.37 ± 0.4^{d}	0.08 ± 0.05^{d}	9.97 ± 0.19^{f}
I-Fauquet 3	68.54 ± 0.19^{f}	9 ± 0.07^{c}	20.71 ± 0.13^{a}	77.77 ± 0.18^{c}	−0.64 ± 0.02^{f}	11.57 ± 0.03^{d}
I-Fauquet 1	66.68 ± 0.11^{hi}	8.49 ± 0.02^{d}	17.89 ± 0.07^{d}	80.77 ± 0.14^{a}	−0.49 ± 0^{e}	12.54 ± 0.03^{b}
I-Leduc 2	66.88 ± 0.02^{h}	9.68 ± 0.03^{b}	16.4 ± 0.03^{f}	77.44 ± 0.25^{c}	−0.78 ± 0.03^{g}	11.67 ± 0.04^{d}
I-Lesire 2	69.06 ± 0.15^{e}	9.13 ± 0.07^{c}	19.36 ± 0.24^{c}	80.65 ± 0.33^{a}	−0.56 ± 0.03^{ef}	12.41 ± 0.18^{b}
I-Lesire 1	68.88 ± 0.11^{ef}	12.44 ± 0.09^{a}	19.45 ± 0.03^{c}	75.15 ± 0.06^{e}	−0.49 ± 0.01^{e}	9.99 ± 0.01^{f}
P-value (cheese)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Artisanal cheeses	70.37 ± 3.32^{a}	4.11 ± 1.77^{b}	17.03 ± 2.7^{b}	77.25 ± 2.05^{b}	0.29 ± 0.66^{a}	12.19 ± 2.75^{a}
Industrial cheeses	68.80 ± 2.72^{b}	8.63 ± 2.88^{a}	19.08 ± 1.44^{a}	77.38 ± 2.19^{a}	−0.47 ± 0.42^{b}	11.06 ± 1.14^{b}
P-value (type)	<0.0001	<0.0001	<0.0001	0.016	<0.0001	<0.0001

[a] Values are means ± standard deviation (n = 3): different superscript letters indicate means that significantly differ among cheeses and between types at $P < 0.05$ (Tukey test).

the lightness decreased (Fresno & Álvarez, 2012; Pinho, Mendes, Alves, & Ferreira, 2004).

The two first dimensions of the PCA performed using the colour parameters explained 73.8% of the variance (Fig. 5). Fig. 5B illustrates the four clusters of Maroilles cheeses resulting of this PCA: cluster #1 gathers seven industrial cheeses (Fauquet 1, Fauquet 3, Lesire 1, Lesire 2, Leduc 1, Leduc 2 and Leduc 3) and three artisanal cheeses (Moulin, Freres and Loups) that have an orange rind and a pale core; cluster #2 contains only one artisanal Maroilles (Courbet) that has a yellow core; in the same way, cluster #3 comprised only one artisanal Maroilles (Hennart) that displays a light rind and a red/yellow core and, finally, cluster #4 contains two artisanal Maroilles (Bahardes and Cerfmont) and one industrial cheese (Fauquet 2) that have a light rind (Fig. 5). This colour variability has also been observed for different PDO red-smear soft cheeses (Epoisses, Munster, Maroilles, Livarot, Limburger or Tilsit) as reported by Dufossé et al. (2005).

3.6. *Sensory, microbiological, chemical, textural and colour analysis relationships*

At the end of the study, we performed a MFA using the sensory, microbiological, chemical and textural parameters evaluated. Fig. 6 presents the two first dimensions of the MFA explaining 41.9% of the variance. As shown in Fig. 6A, the projections of chemical, sensory and colour parameters on dimension 1 are opposed to the projection of the texture, the microbiological projection being at an intermediate position. Dimension 2 opposes the microbiological, texture and chemical projections to the colour projection while the sensory projection went into an intermediate position. The chemical parameters, and to a lesser extent the colour parameters, are the closest to the sensory parameters ($RV_{chemical\text{-}sensory} = 0.471$ and $RV_{colour\text{-}sensory} = 0.337$). So, we can assume that chemical and colour parameters are the closest to the consumer perception. In other words, to evaluate Maroilles consumers based their judgment on

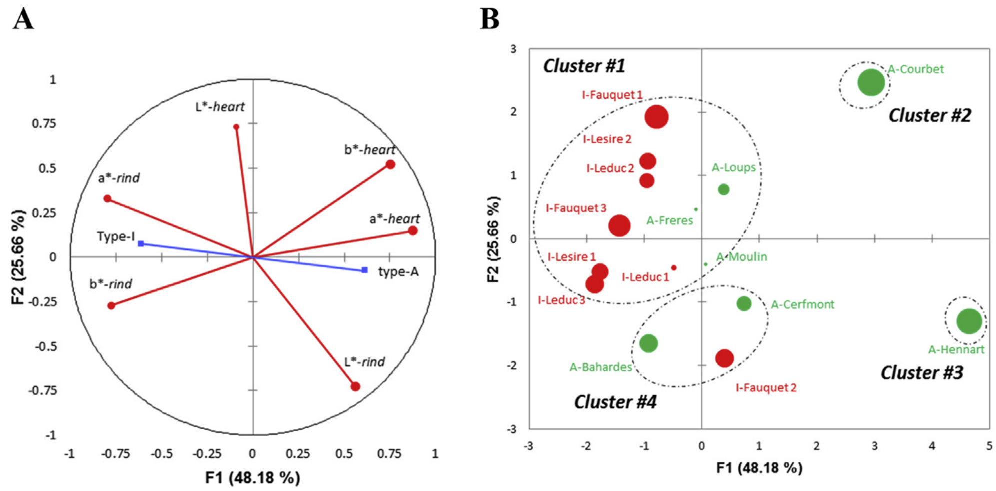

Fig. 5. Principal component analysis (PCA) for dimension 1 and 2: A, colour analysis; B, Maroilles cheeses. Type of cheeses (A-, artisanal; I-, industrial) are considered as supplementary variables. The size of the dots depends on the $\cos^2$ and indicates the representativity of Maroilles cheeses. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

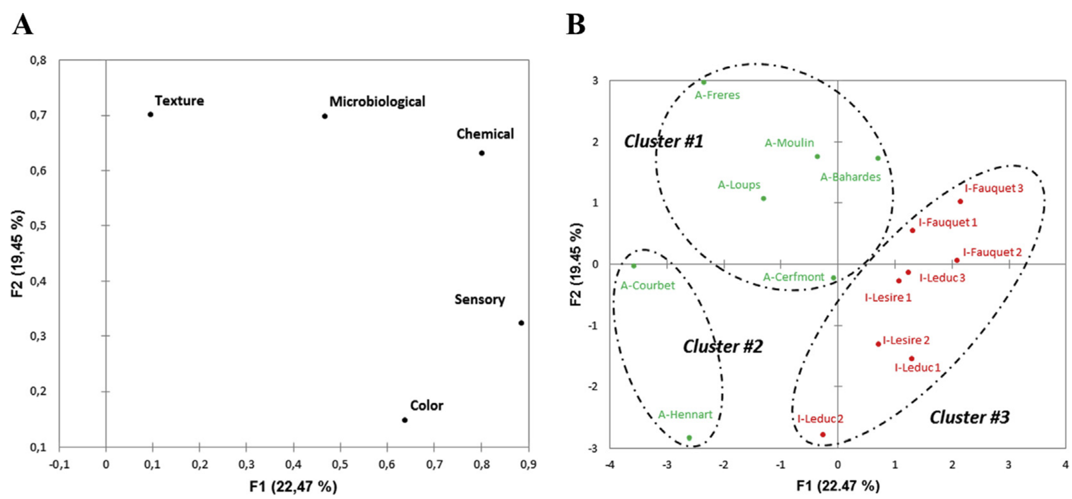

Fig. 6. Multiple factors analysis (MFA) of the sensory, microbiological, chemical, textural and colour analyses (A) and Maroilles cheeses (B) for dimensions 1 and 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

colour and taste characteristics of cheeses. This claim is supported by the descriptions obtained with the sensory analysis.

Finally, as shown on Fig. 6B, three clusters emerge from the MFA: cluster #1 gathers five artisanal cheeses (Freres, Moulin, Loups, Bahardes and Cerfmont); cluster #2 gathers two artisanal cheeses (Courbet and Hennart) and cluster #3 gathers all the industrial cheeses. Taken together, these five sets of analyses combined in a MFA allow the artisanal cheeses to be significantly discriminated from the industrial cheeses. Few publications have previously reported such relevant differences between both these types of cheese with commercial samples of Minas Frescal cheese (Rocha et al., 2006; Visotto et al., 2011). This discrepancy is due to differences of the raw material (raw or pasteurised milk) or of some specific manufacturing parameters (Brighenti, Govindasamy-Lucey, Lim, Nelson, & Lucey, 2008).

4. Conclusions

The artisanal and industrial Maroilles differ by (i) their microbiological contents both in the rind and in the heart (total mesophilic flora, rate of LAB and Enterobacteriaceae), (ii) their chemical contents, (iii) all their penetration test parameters and (iv) all their colour parameters except the L* parameters in the heart. Moreover, the MFA of all datasets leads to three distinct clusters: 2 clusters of artisanal Maroilles and 1 cluster of industrial Maroilles, and therefore significantly discriminates between the two types of cheese. Our study shows that the main difference between the artisanal and industrial Maroilles comes from the pasteurisation step, the possibly different ripening stages of the analysed cheeses and the possible use of surface ripening culture by industrial cheesemakers. Moreover, the presence of Enterobacteriaceae in artisanal Maroilles compared with industrial Maroilles suggests hygiene issues during the manufacturing process. A more in-depth study measuring pathogenic bacteria (*E. coli*, *Salmonella* spp., *L. monocytogenes*) would provide a better understanding of their origin.

Interestingly, the statistical analyses of data sets demonstrate that (i) almost all microbiological parameters (except Enterobacteriaceae rate in the rind), (ii) almost all chemicals (except Cd rate), (iii) all penetration test parameters and (iv) all colour parameters allow significant discrimination between cheeses. Maroilles cheeses produced by various manufacturers from raw or pasteurised milk display heterogeneous features. The differences concern all the analysed parameters: sensory, microbiological, chemical, texture and colour, suggesting a lack of quality standardisation of this type of cheese, which is probably associated with processing differences as well as with ripening conditions and duration. Most importantly, these differences allow consumers to have a great choice of Maroilles on the market and to make their own choice.

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