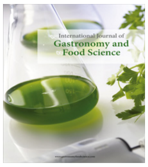

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Scientific Paper

Preparation methods influence gastronomical outcome of hollandaise sauce

Guro Helgesdotter Rognså[a,b], Morten Rathe[a], Morten Thyregod Paulsen[c], Mikael Agerlin Petersen[b], Dagmar Adeline Brüggemann[d], Morten Sivertsvik[e,*], Jens Risbo[b]

[a]*The Culinary Institute of Norway (Gastronomisk Institutt), Richard Johnsensgate 4, 4021 Stavanger, Norway*
[b]*Department of Food Science, University of Copenhagen, Rolighedsvej 30, 1958 Frederiksberg C, Denmark*
[c]*Nofima AS, P.O. Box 5003, 1432 Ås, Norway*
[d]*Faculty of Life Science, Hochschule Rhein-Waal, Marie-Curie Straße 1, 47533 Kleve, Germany*
[e]*Nofima AS, P.O. Box 8034, 4068 Stavanger, Norway*

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Abstract

Egg yolk stabilized butter sauces, such as hollandaise sauce, are classics in the French cuisine and adopted all over the world. They can be made using a number of different procedures. This study was done to determine how common butter sauce preparation methods influence perceptional parameters such as texture, mouthfeel and flavor. The goal was to evaluate the effects of the various preparation methods in order to gain control of the process and obtain the desired sauce properties. Five model sauces, prepared with the same amounts of ingredients, but with different procedures, were produced and analyzed. Sauce preparation methods differed regarding the amount of mechanical treatment, order of addition of ingredients, ingredient temperatures and states reached during production. The five model sauces were analyzed by particle size distribution, water and airiness measurements, microscopy, color measurement, descriptive sensory analysis and analysis of volatiles. Results demonstrated large differences between the explored types of hollandaise sauce, with texture and mouthfeel properties varying significantly with different preparation techniques. This study also included feedback from experienced chefs regarding their habits related to hollandaise sauce preparation.

Keywords: Hollandaise sauce; Butter sauce; Emulsion; Flavor; Molecular gastronomy

Introduction

Relatively few studies have focused on the culinary perspectives of butter sauces (Nygren et al., 2001; Perram et al., 1977; Rapp et al., 2007; Small and Bernstein, 1979; Weenen et al., 2003), although sauces are characterized as a fundamental element in classic French cuisine. Julia Child even stated: "Sauces are the splendor and the glory of French cooking" (Child et al., 1961). According to Larousse (Larousse, 1993), the most important sensory qualities of sauces are "color, luster, aroma, taste, texture and viscosity", thus underlining the importance of the sauce in a dish.

Carême (1783–1833) is said to be the origin of many of the sauces in the French cuisine. In addition to sauce creation, he also classified the French sauces, and sorted them into groups derived from what he called four mother sauces (Larousse, 1993; Peterson, 2008); béchamel, allemande, espagnole and velouté. Escoffier (1846–1935) later adopted and rearranged Carême's classification, and also added one more sauce to the list of mother sauces. In Escoffier's system, the mother sauces were; béchamel, espagnole, velouté, hollandaise (and mayonnaise) and tomato sauce (Peterson, 2008). Sauces based on one of the mother sauces were called secondary, small or derivative sauces, and they are still numerous in the French cuisine.

*Corresponding author. Tel.: +47 51844637.
E-mail address: morten.sivertsvik@nofima.no (M. Sivertsvik).
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According to the system, béarnaise is a secondary sauce of hollandaise sauce. This classification of sauces is referred to as "the French sauce system" (Larousse, 1993).

Egg stabilized butter sauces are structurally similar, and differ mainly regarding the aromatics used to impart sauce flavor. General sauce ingredients are egg yolks, butter and an aqueous phase containing acid and aroma depending on the sauce type. The sauces normally also contain salt, and sometimes freshly ground pepper, either black or white. Hollandaise sauce and its derivatives are used both to accompany fish, meat and vegetables, which make them quite versatile. These sauces contain high percentages of milk fat, and butter incorporated into sauces is known to make sauces "lighter, smoother, glossier, thicker and mellower" (Rapp et al., 2007). The egg yolk is a key ingredient in hollandaise sauce, due to its emulsifying and stabilizing properties. Nonetheless, these butter sauces have a reputation for being difficult, because of their instability, which is why few make them from scratch at home.

From a scientific point of view, a hollandaise sauce is a colloidal suspension of oil in an aqueous phase, called an oil-in-water (O/W) emulsion (McClements, 2005). As the sauces contain varying amounts of air bubbles, they can also be characterized as foams. The oil phase of the emulsion, called the dispersed phase, consists of butter fat and egg yolk lipids (Perram, et al., 1977). The continuous phase, into which the fat is dispersed, often consists of a wine reduction, with various amounts of vinegar. From a chemistry perspective, this phase can therefore be characterized as an aqueous solution of acids, depending on the ingredient choice. The emulsion is created by mechanical treatment, where the oil phase is broken down to small droplets incorporated into the continuous phase. The size of the droplets depends on the emulsification power and tool of choice, which influences the viscosity of the final product (Kilcast and Clegg, 2002). The viscosity is also influenced by the amount of air and fat incorporated into the sauce (Kilcast and Clegg, 2002; McGee, 2004).

Culinary practice and molecular gastronomy often focuses on how the choice of ingredients influences the final product. In contrast to this, the procedure is the field of interest in this study, because there are many different ways to make an egg yolk-stabilized butter sauce. It is improbable that these different ways of making sauce yield identical sauce structures. The hollandaise sauce process may vary on several levels; the mechanical treatment, the order of addition of ingredients, the ingredient states and the temperatures reached during preparation. These preparation variations may influence sauce parameters such as texture, mouthfeel, appearance and aroma.

The aim of this study is to evaluate and quantify the differences in texture and flavor originating from different butter sauce preparation methods. In his book *On Food and Cooking – The Science and Lore of the Kitchen* (McGee, 2004), Harold McGee describes different methods for making egg yolk stabilized butter sauces. Inspired by McGee, we used five distinct sauce-making techniques to create model sauces, using the same composition of ingredients for all. The explored methods represent both old and new techniques, preparations using different tools and the difference between addition of warm and cold butter. The experimental setup gives less emphasis on the effect of continuous variation of single procedure parameters.

Materials and methods

Product development took place as a preliminary step in order to create the model sauces. As McGee refers to the original recipes of Carême (Carême, 1854, 2006) and Escoffier (Escoffier, 1921, 2009) in his book, these recipes were consulted. Carême's recipe originated in his book "L'Art de la cuisine Française au dix-neuvième siècle" first published in 1854 (Carême, 1854, 2006). Escoffier published his recipe in the book "Le guide culinaire" in 1921 (McGee, 2004). There are several special features of these sauces. In Carême's recipe, a wooden spoon is used to incorporate butter into the sauce, which would result in a less airy sauce than made with a balloon whisk. Carême used whole butter and flavored the sauce with salt, pepper, vinegar and nutmeg. The temperature of the butter was not specified. In Escoffier's method, the tool is not specified. However, the French word *monter* is used to indicate how the butter should be incorporated, which means to mount, raise or lift in English. The sauce is "lifted" with butter, but it is unclear whether this reflects the manner of incorporation or if it reflects the taste. Escoffier writes that both whole and melted butter can be used. Escoffier flavored his sauce with vinegar, salt, pepper and lemon juice. None of the recipes specify temperatures for sauce intermediates, nor ingredients.

Traditionally, butter sauces have been made by hand, in a saucepan or over a *bain-marie*. Today, the normal tool to use is a balloon whisk, where the number of wires and beating rate influences the oil droplet size in the emulsion, in addition to the degree of air incorporation. While butter sauces are normally made using hand power, hand-made sauces represent too much variation for research purposes. In this study, hollandaise sauces were standardized using an induction stand mixer (Kenwood Cooking Chef, Kenwood Electronics Europe B.V., Uithoorn, The Netherlands, http://www.kenwood.com). An immersion blender (Bamix Gastro 200, bamix of Switzerland, Switzerland, http://www.bamix.com) was used to finish one of the sauces (Mayonnaise). The application of these machines resulted in more rigorous beating of the emulsions than what is normal when making butter sauces by hand. One might therefore expect smaller oil droplets and maybe also more incorporated air in these sauces compared to hand-made ones. To ensure the relevance of the model sauces, trained chefs were involved in the sauce development phase. The aim was to make model sauces resembling professional hand-made sauces.

Sauce recipe

All sauces were made using the same ingredients and amounts, in order to compare preparation methods (see Table 1).

If one assumes that the egg yolk contains approximately 49% water (Belitz et al., 2009), the total water content in sauce ingredients was 23,8% (water content in the clarified butter was disregarded), which is sufficient water phase ratio to

Table 1
Sauce ingredients. This combination of ingredients was used in all sauces. The recipe contains, in total, 856 g of ingredients.

Ingredients	Amount (grams)
Egg yolk	130
Wine reduction	120
Clarified butter (warm or cold)	580
Lemon juice	20
Salt	6

ensure emulsion stability. During preparation, the sauces were heated to different temperatures, and the actual water content varied therefore slightly between sauces, due to evaporation (Table 4). If all droplets in an emulsion have the same size, they can, at the most, occupy about 74% of the volume (This, 2010). This corresponds to a continuous phase percentage of 26. In normal, culinary emulsions, oil droplets vary in size, and subsequently, the requirements to water phase percentage is lower than in an ideal emulsion. It is possible to use as little as 5% water in emulsions (This, 2010), but it will be unstable and very susceptible to separation due to evaporation of water.

The original Carême and Escoffier recipes call for addition of water during sauce preparation, a technique used by many chefs. In this study enough water to yield stable emulsions was used from the start of the procedures, in order to standardize the sauce-making.

Model sauce procedures

Five sauces were made in this project, and detailed procedures are shown in Table 2. The sauces were named Carême, Escoffier, Mayonnaise, Sabayon WB (WB for “warm butter”) and Sabayon CB (CB for “cold butter”). Two of the sauces used Carême's and Escoffier's methods as inspiration. The Carême sauce was based on heat-treated egg yolks, before cold butter was added to the sauce. The sauce was made using a flexible beater (Kenwood AT502, accessory to the Kenwood Cooking Chef KM070 machine) to imitate the action of a wooden spoon. The Escoffier sauce was also made with the flexible beater (AT502), and melted butter was added to the sauce before the cooking of egg yolks. As Escoffier's recipe did not specify the tool for sauce emulsification (Escoffier, 1921, 2009), the flexible beater may incorporate less air into the sauce than was intended by Escoffier. In either way, the recipe results in a sauce less airy than a sabayon-based butter sauce, as the egg yolks were not coagulated by heat before adding butter. Carême and Escoffier sauces were both deep yellow sauces, with a thinned custard-like texture.

The Mayonnaise sauce was made as a mayonnaise-type butter sauce. All ingredients were held at 50 °C, a temperature above the melting range of butter and below heat-denaturation of egg proteins (Vega and Mercadé-Prieto, 2011). An immersion blender was used to emulsify the sauce, because many chefs use immersion blenders to make more stable mayonnaises than can be made by hand (due to stronger mechanical treatment). The mayonnaise sauce was a thick and dense sauce, with whitish yellow color and some large air bubbles.

Sabayon-based butter sauces are made based on the thick and warm foam of egg yolks, called a sabayon, and then butter is incorporated. Two versions of this method were made; Sabayon CB, where the added butter was cold, and Sabayon WB, were the incorporated butter held 65 °C. The sabayon egg foam was made using a whisk (Kenwood Power whisk 45,002, balloon whisk, accessory to the Kenwood Cooking Chef KM070 machine). Both sauces were very airy, light sauces, with pale yellow color.

Flavoring ingredients salt, wine reduction and lemon juice were added to all sauces to provide a realistic sensory profile of the model sauces. Table salt and lemon juice may influence egg yolk properties, but the ingredients were added in similar ways to all sauces, in order to compare. All sauces were analyzed fresh, as texture and flavor may change with time, which means that less than 2 min passed between preparation and startup of analysis. Because of the different procedures, temperatures varied with 8 °C right after production.

The amount of mechanical treatment subjected to the five hollandaise sauces was calculated based on product information from Kenwood (Kenwood Electronics Europe B.V., Uithoorn, The Netherlands, http://www.kenwood.com) and Bamix (bamix of Switzerland, Switzerland, http://www.bamix.com). Approximate numbers of total turns were calculated from the revolutions per minute numbers for the different machine speed settings (See Table 2). These numbers give an indication of the amount of mechanical treatment applied to the sauce types. This information was useful in relation to airiness and particle size measurements. Some of the total turn numbers are high, and higher than what one can expect when making sauces by hand.

Preferences of culinary professionals

Experience and knowledge of professionals is valuable information for researchers studying a specific field. In gastronomy, food and beverage professionals are the ones with hands-on experience. Information about butter sauces and how professionals produce them was highly relevant for this study. Chefs were therefore contacted. A detailed questionnaire about butter sauce ingredient choices, preparation techniques and experience was prepared. This questionnaire was distributed to chefs from the Culinary Institute of Norway ($n=5$, average age 27, average years of experience 10.6, Gastronomisk Institutt, Stavanger, Norway), the Norwegian Junior Culinary Team ($n=5$, average age; 23, average years of experience; 6.6, Juniorkokkelandslaget, http://www.nkl.no) and the Norwegian Culinary Team ($n=6$, average age; 27.7, average years of experience; 10.2, Kokkelandslaget, http://www.nkl.no), in addition to other experienced chefs ($n=2$, average age; 40.5, average years experience; 21.5). In total, 18 chefs answered the questionnaire (average age; 27.6, average years of experience; 10.6). All of the chefs were Norwegian, but 11 out of the 18 chefs had worked abroad for various amounts of time.

Table 2
Sauce procedures. The table shows the details of the five sauce preparation methods. All sauces were made adding the ingredients in the same order. It is noteworthy that the order of ingredient addition is not constant among chefs.

Operations (time from start)	Sauce				
	Carême	Escoffier	Sabayon WB	Sabayon CB	Mayonnaise
0	130 g egg yolks in bowl Flexible whisk Stir speed 1		130 g egg yolks in bowl Balloon whisk (power whisk) Stir speed 4		
10 s	Addition of 120 g water phase (wine reduction)				
1 min	Temperature set to 80 °C.				Temperature set to 50 °C, add warm butter (50 °C)
2 min	Heating. After this step the temperature in the egg yolk mixture is 66–67 °C	Add warm butter (65 °C)	Heating. After this step the temperature in the sabayon is 66–67 °C	Heating. After this step the temperature in the sabayon is 66–67 °C	
3 min					Remove bowl from mixer and transfer contents to bowl in water bath (50 °C)
3:30 min					Use **immersion blender** at full speed, while turning anti clockwise, to make emulsion
4 min			Reduce whisk speed to setting 2. Add warm butter (65 °C).	Reduce whisk speed to setting 2. Add 30 g cold butter (3 °C) every 15 seconds	
5 min	Add 30 g cold butter (3 °C) every 15 seconds				
5:30 min					Add lemon juice and salt to sauce. Stir
6 min		Heat and whisk sauce to increase temperature	Add lemon juice and salt to sauce. Stir		Sauce finished
6:30					
7 min			Pass sauce through a sieve to a new bowl. Sauce finished		
8 min		Add lemon juice and salt to sauce. Stir		Heat and whisk sauce to increase temperature	
9 min		Pass sauce through a sieve to a new bowl. Sauce finished			
10 min	Heat and whisk sauce to increase temperature			Add lemon juice and salt to sauce	
11 min				Pass sauce through a sieve to a new bowl. Sauce finished	
12 min	Add lemon juice and salt to sauce. Stir				
13 min	Pass sauce through a sieve to a new bowl. Sauce finished				
Temperature in finished sauce	51 °C	57 °C	57 °C	51 °C	49 °C
Approximate numbers of total turns	68,200	47,300	57,300	89,500	79,500

Sauce ingredients

Eggs

Egg yolks were isolated from free-range 1–6 days old eggs (Gudmestad's farm, 4365 Nærbø, Norway). The hens were of Dekalb breed, and eggs from the same livestock were used throughout the project. Eggs were shelled and the yolks were separated from the albumen by hand, and adherent albumen was removed using filter towel. The yolks were mixed gently to punctuate the membranes, using a balloon whip, and further passed through a sieve to remove remaining chalaza. Egg yolk was weighed out and placed in the refrigerator (at 3 °C) under cling film until use. Shelling of eggs took place the same day that the yolks were used. According to literature, a typical egg yolk contains the following: lipids: 32.6%, proteins: 16.6%, carbohydrates: 1.0%, minerals: 1.1% and water 48.7% (all percentages are of total weight, breed not specified) (Belitz et al., 2009).

Butter

Whole, room tempered or cold, melted or clarified butter can be used in butter sauces. Whole butter contains about 1% proteins, 1% carbohydrates (mainly lactose) and about 14% water. Whole butter used in butter sauce therefore contributes to thinning of the water phase. The minor proportion of milk proteins may influence emulsification. Home-clarified butter contains traces of proteins and carbohydrates in addition to water. Many chefs prefer to use clarified butter, as not to thin the sauce, but others use whole butter, either warm or cold, to ensure sauce stability (to keep the ratio between dispersed and continuous phase constant) while adding butter to the sauce. Both salted and unsalted butter made from fresh or fermented cream can be used in a butter sauce. Sodium chloride in salted butter may influence egg yolk properties.

In this study, one type of butter was used in all sauces, to be able to compare products. Industrially clarified butter was chosen, as an industrial product ensures minimal product variation. Carbohydrates, milk proteins and water were eliminated from the butter during production, and only milk fat remained. Industrially clarified butter ("Klaret smør", TINE SA, 0021 Oslo, Norway, http://www.tine.no), was available in 4 l (3.6 k) buckets. According to the producer, the butter completely melts in the temperature range 30–32 °C. The clarified butter contained 0.2% water. Clarified butter for heating (50 °C or 65 °C) was packed in heat-resistant piping bags (kee-seal™ultra, Keeplastics AB, Norrköping, Sweden, http://www.keeplastics.se) and vacuum-sealed. Heat-resistant piping bags (resistant between −30 and 110 °C) were used, for easy temperature control and handling. Butter for sauce recipes requiring cold butter was only divided into small cubes (approximately 1 cm × 1 cm) and placed in a container covered with cling film until use. Both butter bags and cubes were stored in the refrigerator (3 °C) until use. Butter in piping bags was warmed in a temperature-controlled water bath until external temperature was reached in the butter. Two temperatures, 50 °C and 65 °C, were used according to the different sauce procedures.

Lemon juice

Spanish Primofiore lemons (Fruani S.L., Alicante, Spain, http://www.fruani.com) were packed 15 days before juicing. Lemon juice was obtained by juicing the lemons (Philips Juicer HR 2752, Philips, http://www.philips.com). The juice was filtered by passing it through a sieve, and then through a cloth sieve, removing all small pips and most of the pulp. The lemon juice was vacuum packed on a chamber vacuum machine (Helmut Boss, Bad Homburg, Germany, http://www.vacuum-boss.com), and frozen (−22 °C) until use. Upon use, juice was gently thawed at room temperature, weighed out and stored in small containers under cling film in the refrigerator (3 °C) until use. Juice from the same lot of lemons was used in all sauces. The pH of the lemon juice was 2.31 ± 0.00 ($n=3$, measured by SG8 SevenGo pro™, Mettler-Toledo AG, Schwerzenbach, Switzerland, http://www.mt.com).

Reduction

A reduction, made on dry white wine and white wine vinegar, was chosen for the aqueous phase in the sauces. Dry Chablis wine (Domaine Séguinot-Bordet, http://www.seguinot-bordet.com, Appellation Chablis Contrôlée (Chardonnay grapes)), Chablis, France, (http://www.seguinot-bordet.fr), was used to make a wine reduction together with white wine vinegar (Martin Pouret, Fleury Orléans, France, http://www.martin-pouret.com). The vinegar was made on wine from Sauvignon blanc and Chenin Blanc grapes (from Loire and Bordeaux areas) by the traditional Orléans vinegar method.

The wine and vinegar reduction was prepared in a stand mixer (Kenwood Cooking Chef, Kenwood Electronics Europe B.V., Uithoorn, The Netherlands, http://www.kenwood.com). Reduction was made in large batches, enough to prepare 4 butter sauces. For each batch, 750 g wine and 250 g white wine vinegar was used. Initial weight of the liquid was 1000 g, and it was reduced to approximately 600 g during 25 min (Settings on Kenwood Cooking Chef stand mixer: 110 °C, stir speed 2, balloon whisk). After this time the reduction was removed from the bowl and transferred to a container placed in an ice bath. The reduction was cooled down to 10 °C and weighed. The average reduction weighed 594.4 g (SD = 13.47, $n=23$), which corresponds to a degree of evaporation of 40.6%. Cold wine reduction was vacuum packed (Boss chamber vacuum machine, Helmut Boss, Bad Homburg, Germany, http://www.vacuum-boss.com) and frozen (−22 °C) until use. Reduction was thawed in room temperature, weighed out and stored in small containers under cling film in the refrigerator (3 °C) until use. The pH in the reduction was 3.04 ($n=3$, SD = 0) (measured by SG8 SevenGo pro™, Mettler-Toledo AG, Schwerzenbach, Switzerland, http://www.mt.com).

Salt

Fine-grained, iodine free salt (Jozo Salt, Akzo Nobel Functional Chemicals BV, Hengelo, Netherland, http://www.jozosalt.com) was used in all sauces.

Analyses

Water content

To determine water content in sauces, samples were weighed out in suitable steel containers, and dried in an oven at 105 °C until constant weight (> 12 h). After heat treatment, containers were weighed again. Each sauce was made in duplicates, and triplicate samples were analyzed from each batch.

Airiness

The approximate amount of incorporated air in sauces was measured using a simple analysis setup: three numbered small cups were chosen and weighed. Sauces were prepared, and each sauce was put into the three cups and weighed. A dough scraper was used to remove excess sauce from the top of each cup, and this ensured equal filling of cups for all samples. The volume of each of the cups was measured by filling the cups with water, using the same method as for the sauces, and weighed. Based on these measurements, the airiness could be calculated by comparing weight of the sauce to the weight of water. The results are approximations, as the density of the sauce ingredients is slightly lower than the density of water. Two batches of each sauce were analyzed by triplicate samples. Approximate airiness is given as volume percentage.

Particle size distribution

Light scattering particle size distribution analysis was carried out (Mastersizer Hydro 2000G, Malvern Instruments, United Kingdom, http://www.malvern.com). Sauces were analyzed right after preparation, and were diluted, approximately 1:500, in warm water (55 °C) to prevent partial coalescence due to milk fat crystallization and in order to transport the oil droplets into the measuring cell. Batches were prepared in duplicates, and two samples were analyzed from each batch. Results were given as volume percentages and volume median diameters ($d(0.5)$).

Microscopy

All samples, except the Carême sauce, were stained with fluorescent dye (0.1 μg/ml) 0.001 w/v % Nile red (Sigma, USA) for microscopy. Nile red is a lipophilic stain and diffuses into the lipid phase of the sauces and visualizes the lipid droplet structure of the sauces. In the case of the Carême sauce, the spectral overlapping autofluorescence of the water phase was too high, and no clear image could be obtained when staining the samples with Nile red. Therefore, for this preparation, the autofluorescence of the water phase was used for the recording of the image and an inverted image is shown for better comparability.

Confocal laser scanning microscopy (CLSM) was performed on an inverted Leica TCS SP5 II (Leica Lasertechnik GmbH, Heidelberg, Germany) using excitation wavelength 514 nm, and two objectives (10.0 × HC PL APO, NA 0.4 (dry) and 40.0 × PL FLUOTAR, NA 1.00 (oil immersion)). Pinhole was set to 1 Airy unit, and image resolution was 1024 pixels × 1024 pixels and 512 pixels × 512 pixels. All samples were analyzed at 43 °C (temperature above the highest crystallization temperature of butter). During image acquisition each line was scanned 8 times and averaged. When necessary, the images were adjusted for brightness and contrast.

Color measurements

Sauce surface color was assessed (DigiEye full system, calibrated color-measuring system, VeriVide Ltd., Leicester, UK, http://www.verivide.com). Sauce was prepared, and right away poured into porcelain cups and placed in the system's standardized daylight (6400 K) box, where it was photographed (calibrated Nikon D80 digital camera, Nikon D80, 35 mm lens, Nikon Corporation, Japan, http://www.nikon.com). Pictures were analyzed and sauce color quantified (DigiPix software, VeriVide Ltd., Leicester, UK, http://www.verivide.com). Color was quantified according to the L^*a^*b system (standardized by Commission Internationale de l'Eclairage, International Commission on Illumination, CIE, http://www.cie.co.at) (Hunt, 1991), which is a tristimulus system, where color can be defined by three mathematical parameters (David Julian McClements, 2002). Results are given as color coordinate scores (a^* and b^*) and hue ($a^* > 0$: red color, $a^* < 0$: green, $b^* > 0$: yellow, $b^* < 0$: blue). Hue (H^*) is defined as the angle between color coordinates a^* and b^* ($H^* = \tan^{-1}(b^*/a^*)$, $H^* = 0°$: reddish hue, $H = 90°$: yellowish hue). Two batches of each sauce were analyzed by triplicate samples.

Analysis of volatiles

Content of volatile compounds in sauces and their key ingredients were analyzed right after preparation, and two batches of each sauce were analyzed by triplicate sampling. Sauce ingredients were analyzed in triplicate samples.

Samples of 20 g were placed in 100 mL flasks, and were put to equilibrium at 37 °C in a circulating water bath, while stirred at 220 rpm. 1 mL 4-methyl-1-pentanol (5 ppm) was added as internal standard. The lipid-containing samples were purged with nitrogen (inert gas) at 150 mL min^{-1} flow for 30 min, while water-based samples were purged for 20 min at 100 mL min^{-1}. Volatiles from samples were adsorbed on Tenax-TA traps (room temperature). Traps contained 250 mg of Tenax-TA with mesh size 60/80 and a density of 0.37 g mL^{-1} (Buchem bv, Apeldoorn, The Netherlands, http://www.buchem.com). All traps were dry-purged for 10 min, to remove trapped water before GC analysis, as this may cause analytical problems.

Trapped volatiles were desorbed using an automatic thermal desorption unit (ATD 400, Perkin Elmer, Norwalk, USA, http://www.perkinelmer.com). Primary desorption was carried out by heating traps to 250 °C with a flow (60 mL.min^{-1}) of carrier gas (H_2) for 15.0 min. The stripped volatiles were trapped in a Tenax-TA cold trap (30 mg held at 5 °C), which was subsequently heated at 300 °C for 4 min (secondary desorption, outlet split 1:10). This allowed rapid transfer of volatiles to a gas chromatograph-mass spectrometer (GC–MS, 7890A GC-system interfaced with a 5975C VL MSD with Triple-Axis detector from Agilent Technologies, Palo Alto, California, http://www.agilent.com) through a heated (225 °C) transfer line.

Separation of volatiles was carried out on a DB-Wax capillary column 30 m long × 0.25 mm internal diameter, 0.50 µm film thickness. The column pressure was held constant at 2.4 psi resulting in an initial flow rate of approximately 1.2 mL min^{-1} using hydrogen carrier gas. The column temperature program was: 10 min at 40 °C, from 40 °C to 240 °C at 8 °C min^{-1}, and finally 5 min at 240 °C. The mass spectrometer operated in the electron ionization mode at 70 eV. Mass-to-charge ratios between 15 and 300 were scanned. Volatile compounds were identified by probability based matching of their mass spectra with those of a commercial database (Wiley275.L, HP product no. G1035A). The software program, MSDChemstation (Version E.02.00, Agilent Technologies, Palo Alto, California, http://www.agilent.com), was used for data analysis. Peak areas were used as relative measures of amounts.

Descriptive sensory analysis

Descriptive analysis (DA) was conducted by a trained sensory panel ($n=11$, Nofima, Ås, Norway) according to Generic Descriptive Analysis as described by Lawless and Heymann (Lawless and Heymann, 2010). All assessors were selected and trained in accordance with ISO 8586-1 (ISO, 1993). The sensory laboratory was designed in accordance with ISO 8589 (ISO, 2007).

Sensory attributes were evaluated using an unstructured line scale with labeled endpoints ranging from no intensity (1) on the left side, to high intensity (9) on the right side. Each assessor evaluated all samples at individual speed using EyeQuestion v3.8.13 for direct recording of data (Logic8, Holland). Assessors were trained in evaluation of butter sauces. A list of 28 descriptors was developed during training sessions where both panel leader and assessors were present (Table 3). PanelCheck version 1.2.1 was used to evaluate panel performance (http://www.panelcheck.com). The sensory evaluation was performed in four sessions with a total of 10 sauces (five sauces in replicate). A dummy sample was served at the beginning of the test. A session consisted of two to three sauces served every 10 min. All samples were served with three digit random codes, monadically evaluated at individual speed and registered continuously. The samples were served in the same randomized order for all assessors, with all assessors evaluating the same samples simultaneously, due to practical restriction regarding sample preparation. Each sample consisted of 0.5 dl sauce served in warm (55 °C ± 1 °C) porcelain bowls with lids (55 °C ± 1 °C). The sauces were served with a plastic spoon. The sauces varied in serving temperature (cf. Table 2), but all sauces had temperatures well above butter

Table 3
Sensory attributes for hollandaise sauce. The sensory descriptors used to evaluate hollandaise sauce. Descriptors were translated from Norwegian to English after evaluation.

Class	Descriptors	Definition
Odor	Lemon (o)	Aroma of fresh lemons
	Vinegar (o)	Aroma of vinegar (7%) solution in water
	Egg (o)	Aroma of egg yolks
	Butter (o)	Aroma of butter
Taste/Flavor	Sourness	Taste of dilute aqueous solutions of acids
	Sweetness	Taste of dilute aqueous solutions of sucrose
	Saltiness	Taste of dilute aqueous solutions of sodium chloride
	Bitterness	Taste of dilute aqueous solutions of substances such as quinine and caffeine
	Acidic (lemon) (f)	Flavor of lemon
	Acidic (vinegar) (f)	Flavor of white wine vinegar
	Egg (f)	Flavor of egg yolk
	Butter (f)	Flavor of butter
Appearance	Color intensity	Surface color using NCS system as reference
	Whiteness	Surface color using NCS system as reference
	Particles	Presence of particles in sauce
	Glossiness	Degree of glossiness of emulsion surface due to bright reflection
	Airiness	Relates to the amount of incorporated air in sauce. Evaluated by looking at the sauce
	Viscosity	Mechanical texture attribute related to flow resistance
Texture	Smoothness	Geometric texture property related to the absence of perception of particle size and particles in a product
	Elasticity	Mechanical textural attribute relating to the recovery from a deforming force
	Fullness	Mechanical texture attribute related to flow resistance
	Creaminess	Relates to a creamy feeling in the mouth
	Meltability	Relates to the time it takes to make the sample liquid in the mouth
	Fatty	Surface textural attribute relating to perception of high fat proportion in a product.
	Astringency	Organoleptic attribute which produces a feeling of dryness and contractions in the mouth
	Pungent	Relates to sharp and pricking sensation of the mucus membranes in the nose and the mouth
	Mouth-coating	Relates to the degree of coating in the mouth
	Aftertaste	Flavor intensity of sample still present in the mouth 15 s after expectoration.

fat crystallization temperatures. The assessors were instructed to evaluate the appearance qualities of the sauces on the spoon, before smelling and tasting a spoonful to rate the rest of the attributes. All samples were expectorated, and unsalted crackers and lukewarm water was available for rinsing. Cucumber and melon cubes were available for mouth cleansing between sessions.

Statistical analysis

Panel Check 1.3.2. (Nofima, Norway, http://www.panelcheck.com) was used to evaluate the panel performance of the sensory panel. Tucker-1 plots were used to evaluate the consensus of sensory attributes among the assessors. General Linear model (Minitab Inc, USA) was used to study significant differences between products based on results from the different analysis methods. Tukey's Multiple Comparisons Test (Minitab Inc, USA) was applied to determine which products were significantly different. Significance was defined at $\alpha \leq 0.05$.

Multivariate data analysis (principal component analysis) was performed on data using Unscrambler®X v10.2 (Camo AS, Norway) to study the main sources of systematic variation in the average descriptive profiling data.

Results and discussion

The importance of preparation techniques in hollandaise sauce was studied by evaluating the outcome of the five different methods. Hollandaise sauce can be made with other techniques than the ones presented here, but the selected methods represent the span of available methods in the culinary literature, as they reflect combinations of ingredient states and ingredient addition points. Due to this starting point, less emphasis is made on explicitly evaluating the effect of single parameters, such as heating times or amount of mechanical treatment.

Culinary professionals (Norwegian chefs ($n=18$)) were asked to answer a detailed questionnaire about how they prepare hollandaise sauce and about their ingredient choices, in order to evaluate the relevance of the model sauces. *All* chefs answered that the preferred method for hollandaise and béarnaise production is to make a sabayon, and to add warm, clarified butter to it. The chefs preferred to make hollandaise sauce by hand, using a balloon whisk. All chefs answered that they use warm butter in hollandaise sauce, but 22.2% also add some of the butter water phase to the sauce. The answers from the questionnaire clearly showed that Escoffier and Carême sauce methods are not in common use among Norwegian chefs today. The chefs described optimal butter sauce texture using words such as "airy" (61.1%), "creamy" (61.1%), "thick" (22.2%) and "velvety" (16.7%). Carême used nutmeg in his sauce hollandaise, but none of the contacted chefs adds this spice to their hollandaise sauce. Some chefs reported that they season butter sauces with white pepper, cayenne pepper or Tabasco sauce, as alternatives to the common use of whole black pepper in the reduction.

In the following paragraphs, results from the different analyses are presented.

Water content and airiness

Water content and airiness was measured as these parameters describe emulsion and foam properties of the sauces (Table 4).

Water content measurements indicate the amount of water, which evaporated form the sauces during production. Surprisingly, Escoffier was the sauce with the highest evaporation, although this sauce had neither the longest heating time nor the highest number of revolutions. The results may be explained by the addition of warm butter (65 °C) from an early stage in the production, which quickly increased the temperature in the system. The stand mixer's protecting splashguard cover was used during all productions, which counteracted water loss through condensation of water. One can therefore expect that evaporation from hand-made hollandaise sauces would be greater than observed here. The amount of condensed water on the bowl and splashguard was not measured, and represents a source of error to the water content measurements. In butter emulsion preparation it is important to add enough water from the start to ensure emulsion stability through sauce production and through the period from production to service.

Airiness in sauces is believed to influence texture, perception and mouthfeel. The amount of incorporated air does not solemnly depend on the number of whisk turns, but also on the whisk type and state of ingredients. The Escoffier and Carême sauces were made using the Kenwood flexible beater, whereas Sabayon WB and Sabayon CB were made using the Kenwood Power whisk (balloon whisk). The flexible beater had only two wiper blades, which were quite thick, and the beater incorporated therefore less air into the sauce than the balloon whisk, having 16 wires. Accordingly, Carême and Escoffier sauces were the least airy sauces and Sabayon sauces were the most

Table 4
Water content and airiness. Water constituted 23.8% of the total ingredient weight before processing. Variation in water content was created by the different heat-treatment regimes. All sauces contained enough water to ensure stable emulsions. Airiness measurements showed that sauce textures vary from dense to foamy.

Sauce	Water content (weight %) in finished sauces (± SD, $n=9$)	Airiness (approximate volume %) (± SD, $n=6$)
Carême	21.95 ± 1.19	3.29 ± 1.06
Escoffier	20.51 ± 0.86	2.82 ± 0.86
Mayonnaise	22.32 ± 0.50	6.62 ± 0.82
Sabayon CB	21.67 ± 0.23	27.45 ± 0.59
Sabayon WB	21.45 ± 0.09	22.04 ± 1.95

airy. Sabayon CB had approximately 20% more incorporated air than Sabayon WB, probably due to the longer preparation time. The Mayonnaise had about 6.6% incorporated air, caused by the immersion blender. The blender dragged air into the sauce when vortex was created, resulting in higher airiness than Carême and Escoffier sauces.

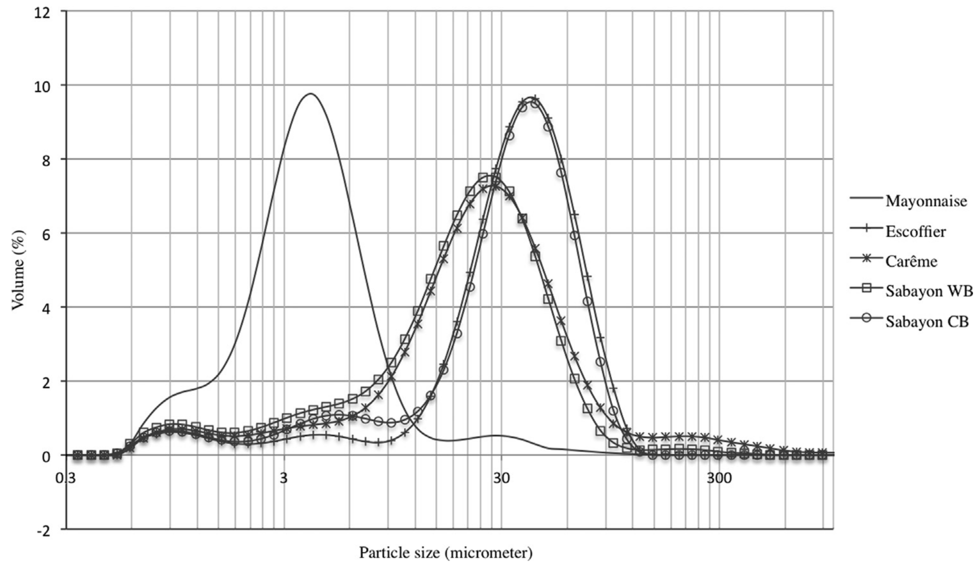

Fig. 1. Particle size distribution. The technique measured the size of oil droplets (butter) in sauces. Sauces were grouped into three significantly different sauce groups, where Mayonnaise had the smallest droplets.

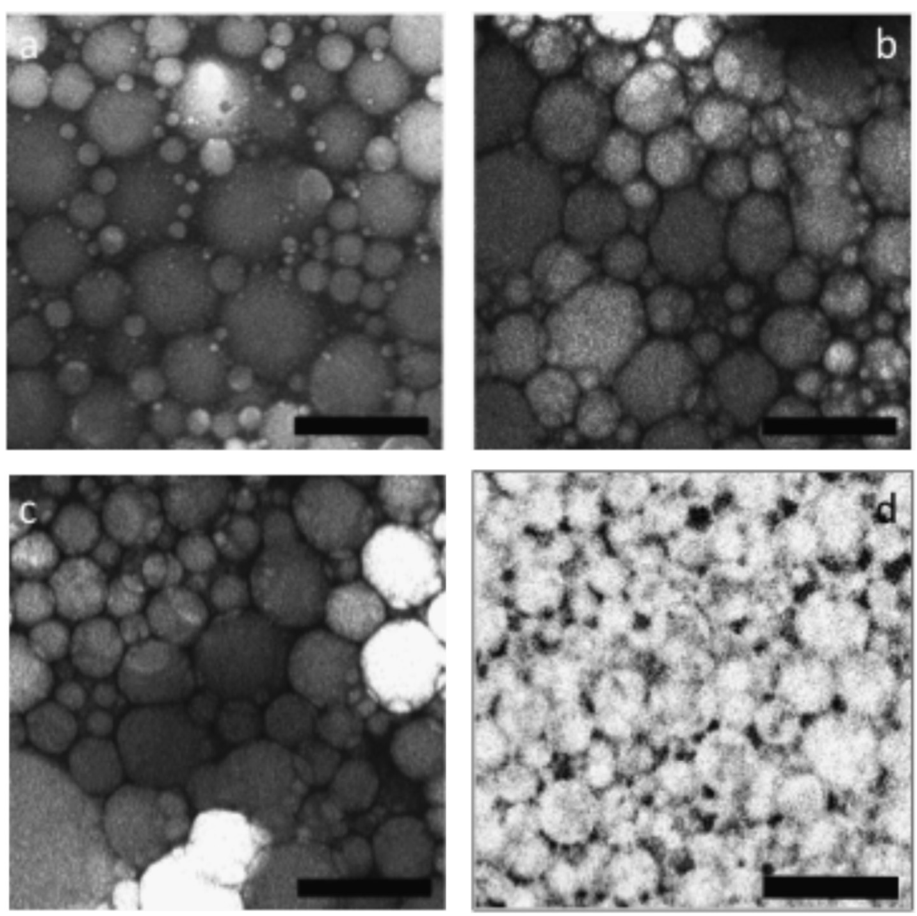

Fig. 2. Confocal laser scanning micrographs showing the lipid droplet size distribution of Sabayon WB (a), Sabayon CB (b), Escoffier (c) and Carême (d) sauces. All four sauces were polydisperse emulsions with Escoffier showing the largest, and Carême showing the lowest variation in size distribution. The brighter appearance of Carême is due to the fact that the image is a result of inversion of the autofluorescence recording of the water phase. Bar equals 50 μm.

Particle size distribution

Particle size distribution was performed to get an understanding of the distribution and size of oil droplets in the different emulsions. As hypothesized, the results (Fig. 1) show that the mayonnaise had the smallest oil droplets, due to powerful treatment of the immersion blender. The four remaining sauces were grouped in two significant different groups ($p < 0.05$), where Carême and Sabayon WB had the smallest droplets ($d(0.5)_{Car} = 24.95 \pm 1.50$ μm, $d(0.5)_{SabWB} = 21.53 \pm 1.98$ μm, $p = 0.65$). Escoffier and Sabayon CB had also similar profiles ($d(0.5)_{Esc} = 36.49 \pm 1.98$ μm, $d(0.5)_{SabCB} = 34.36 \pm 1.77$ μm, $p = 0.93$). Sauces having similar preparation times did not group together. Carême is believed to have smaller droplets than Escoffier due to longer preparation. The situation was reversed regarding the sabayon sauces. It is hypothesized that the slow speed used to incorporate butter into the sabayon sauces did not favor smaller droplet formation, and resulted in droplet coalescence in addition to increased air incorporation.

Microscopy

Images obtained by confocal laser scanning microscopy gave a clearer insight into the polydisperse nature (i.e. variations in droplet size) of the emulsions. According to Fig. 2, the Carême sauce showed the smallest variation in droplet size, followed by Sabayon WB, Sabayon CB and Escoffier sauces. The Mayonnaise showed a higher number of small lipid droplets, accompanied by a limited number of large lipid droplets (Fig. 3). The Mayonnaise presented more homogenous lipid droplet sizes than was observed in the other sauces' micrographs.

Although the micrographs supplied information about droplet sizes and the polydisperse nature of the emulsions, they did not contribute with particulars about sauce airiness. Air droplets can only be observed in the overview image of the Mayonnaise at lower resolution (Fig. 3a). This is due to the fact that it is almost impossible to get satisfactory images at higher resolution, when light has to travel through air. Emulsion imaging is challenging due to the extreme differences in refractive indices of the two phases, water and fat.

Sauce color and particles

Color measurements were performed in artificial daylight, and gave clear indications on emulsion appearance (Fig. 4). The color measurements separated the emulsions into four significantly different groups. Mayonnaise was the palest sauce, due to extensive light scattering explained by its small oil droplets (Chantrapornchai et al., 2008), confirming the particle size measurements. The sabayon sauces did not significantly differ in color (H^*: $p = 0.29$). These emulsions appeared paler in color than Escoffier and Carême sauces, probably due to the high amount of incorporated air, as the bubbles contributed to light scattering. In this case, incorporated air was more important for emulsion color than droplet size alone. The slightly higher amount of incorporated air and smaller oil droplets can explain the paler color of the Carême sauce compared to Escoffier sauce.

An important difference between sauce procedures was the addition of cold (Carême and Sabayon CB) versus melted, warm butter (Escoffier, Sabayon WB and Mayonnaise). The

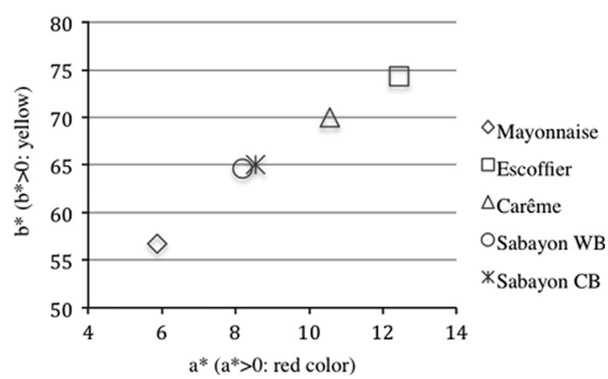

Fig. 4. Color measurements of sauces. Measurements were obtained by using the DigiEye system. Sauces were separated into four significantly different groups.

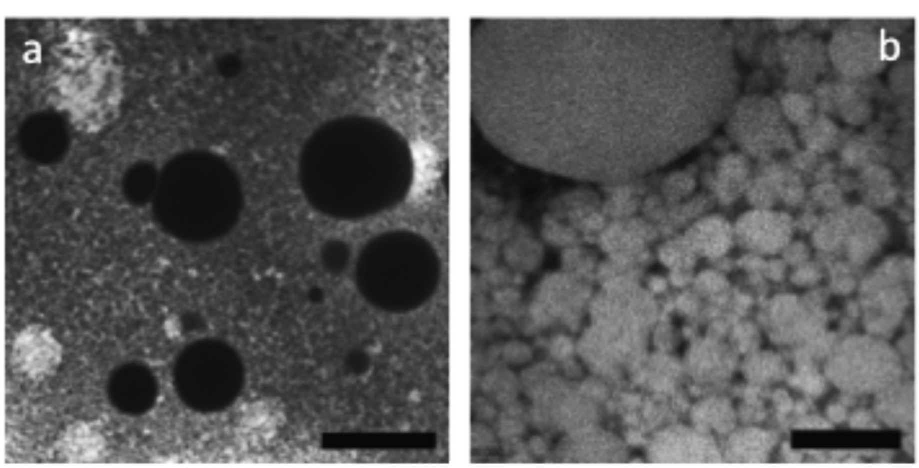

Fig. 3. Confocal laser scanning micrographs of Mayonnaise at two different resolutions. The overview shown in Fig. 2a, demonstrates the presence of a limited number of large bright lipid droplets together with large air bubbles (black). The many hardly visible small lipid droplets can first be recognized as such by increasing the resolution approximately 20 × as shown in Fig. 2b. Bar in image a equals 250 μm and 12,5 μm in image b.

most heat-treated sauces (Escoffier, Carême, Sabayon CB and Sabayon WB) were all passed through a sieve before service. This was done because of particle formation in the sauces. Due to high temperatures at the bottom of the bowl, a film of coagulated egg yolk covered the bottom during preparation. This film was not transferred to the next bowl, but particles from this film were probably released into the sauces. In addition, during production it became clear that the cold butter sauces, Carême and Sabayon CB, had larger particle formation than the other sauces (unmeasured findings). It seems that a coagulation of tiny particles took place in the sauce when the warm egg mixture came in contact with the cold butter. This is an argument for choosing warm butter in hollandaise sauce production.

Analysis of volatiles

The results from the analyses presented above show that the five sauces were structurally different. Analysis of volatiles was performed to investigate whether these structural differences influenced aroma release from sauces, possibly resulting in different sauce aromas. Sauce ingredients were also analyzed, in order to evaluate the influence of ingredients on sauce aroma.

As aroma compounds can be either lipophilic or hydrophilic, the amount of fat in an emulsion is important when it comes to flavor release. Many aroma compounds are lipophilic, and will be retained in the lipid phase of an emulsion. If one assumes that the egg yolk contains approximately 33% lipids (Belitz et al., 2009), all the sauces in this study contained about 73% fat (before evaporation of water), which is very high in a food context (whole butter contains about 85% fat).

Volatile analysis detected 50 aroma compounds in the butter sauces (results not shown). For 16 of these compounds, the concentrations varied significantly between sauces. These compounds represent about ⅓ of the number of volatiles found in the sauces. These aroma differences might be caused by different matrix structures or different production of volatiles during processing. Volatiles present in significantly different concentrations are seen in Table 5.

The content differences of volatiles between sauces could be due to structural variations between sauces and the degree of heat-treatment during production. All of the compounds in Table 5 were present in sauce ingredients, where they were found in similar or higher concentrations than in the sauces. The heat treatment (process) seems therefore not to be the origin of any *new* aroma compounds varying significantly between sauces. Based on these results one cannot, on the other hand, rule out that production of any of the 16 volatile compounds did not take place during sauce production. It is, nonetheless, clear that the process is responsible for differences in concentration between sauces.

Ingredients were analyzed in order to determine their aroma-related contribution to the sauces. In general, lemon juice was the source of aldehydes and terpenes. Regarding the significant differences shown in Table 5, lemon juice contributed almost exclusively with the following compounds: α-pinene, limonene, γ-terpinene and β-ocimene. All these compounds were found in the highest concentrations in the sabayon-based sauces. For the latter three compounds, the sabayon sauces had significantly higher concentrations of these compounds than the other sauces. High amount of incorporated air is one factor distinguishing these sauces from the others, and one may therefore suggest that airy sauces promote lemon aroma release.

Table 5
Significant differences in volatiles between sauces. Volatile compounds present in significantly different concentrations in sauces are listed in this table. Different superscript letters in rows indicates significant difference ($p \leq 0.05$). Area values are presented as averaged ($n=6$) raw areas/1000. Regarding method of identification, "MS" refers to compounds identified by probability based matching of mass spectrum with the Wiley database and "RI" refers to identification confirmed by comparison with retention index from literature. The column named "Source(s)" indicates in which ingredients the compounds in question was found. Ingredients are listed in order of abundance.

Volatiles	Identification method	Source(s)	Carême	Escoffier	Mayonnaise	Sabayon CB	Sabayon WB	p
2-Propanone	MS, RI	All (Egg yolk, butter, lemon juice, reduction)	2570^{a}	2576^{a}	1251^{b}	1830^{ab}	1540^{b}	0.02
2,3-Butanedione (diacetyl)	MS, RI	Reduction, butter	8542^{b}	7811^{b}	10830^{a}	8438^{b}	7829^{b}	0.03
α-Pinene	MS, RI	Lemon juice, (butter)	57^{b}	48^{b}	55^{b}	119^{a}	86^{ab}	0.03
Limonene	MS, RI	Lemon juice, (butter)	225^{b}	226^{b}	210^{b}	698^{a}	647^{a}	< 0.01
γ -Terpinene	MS, RI	Lemon juice	13^{b}	15^{b}	11^{b}	43^{a}	42^{a}	< 0.01
β-Ocimene	MS, RI	Lemon juice, (butter)	32^{b}	32^{b}	34^{b}	103^{a}	102^{a}	< 0.01
3-Hydroxy-2-butanone (acetoin)	MS, RI	Reduction, butter	22300^{b}	30428^{a}	27911^{a}	27322^{a}	28973^{a}	0.02
1-Hydroxy-2-propanone	MS	Reduction	451^{c}	917^{a}	626^{abc}	555^{bc}	831^{ab}	0.02
Benzaldehyde	MS, RI	All (reduction, lemon juice, egg yolk, butter)	57^{c}	78^{ab}	88^{a}	59^{c}	66^{bc}	< 0.01
Butanoic acid	MS, RI	All (reduction, butter, egg yolk, lemon juice)	171^{b}	1333^{a}	580^{b}	538^{b}	787^{ab}	0.02
Acetophenone	MS, RI	Reduction, egg yolk, butter (similar concentrations)	31^{b}	65^{a}	59^{a}	28^{b}	51^{a}	< 0.01
Diethyl succinate	MS, RI	Reduction	33^{b}	50^{a}	41^{ab}	32^{b}	38^{b}	< 0.01
Benzeneethanol	MS, RI	Reduction	585^{b}	1160^{a}	618^{b}	702^{b}	1080^{a}	< 0.01
δ-Octalactone	MS, RI	Butter	18^{abc}	31^{a}	16^{bc}	10^{c}	23^{ab}	0.04
Phenol	MS	All (lemon juice, reduction, butter, egg yolk)	75^{ab}	94^{a}	95^{a}	57^{b}	60^{b}	< 0.01
δ-Nonalactone	MS	Butter	12^{abc}	20^{ab}	10^{bc}	4^{c}	22^{a}	0.01

Table 6
Descriptors representing significant differences. The sensory panel evaluated the sauces significantly different ($p < 0.05$) with respect to these descriptors. Tukey's test results are shown as superscript letters. ANOVA results showed that butter odor varied significantly between sauces, but post-testing by Tukey's test did not find significant differences between sauces.

Descriptor class	Descriptor	Carême	Escoffier	Mayonnaise	Sabayon WB	Sabayon CB	p
Odor	Butter (o)	4.49^{a}	4.46^{a}	3.36^{a}	3.35^{a}	3.53^{a}	0.02
Appearance	Color intensity	6.84^{a}	7.04^{a}	4.67^{c}	5.24^{bc}	5.65^{b}	< 0.01
	Whiteness	3.79^{c}	3.54^{c}	5.98^{a}	5.35^{ab}	5.11^{b}	< 0.01
	Glossiness	6.78^{ab}	7.35^{a}	7.14^{a}	6.31^{b}	6.84^{ab}	< 0.01
	Airiness	3.71^{b}	3.37^{b}	5.59^{a}	6.20^{a}	5.95^{a}	< 0.01
	Viscosity	5.16^{a}	3.59^{b}	4.02^{ab}	4.64^{ab}	3.89^{ab}	0.03
Flavor	Acidic (vinegar) (f)	4.39^{b}	4.85^{ab}	5.70^{a}	5.43^{ab}	5.44^{ab}	0.03
	Butter (f)	4.95^{ab}	5.10^{a}	4.04^{b}	4.34^{ab}	4.28^{ab}	0.02
Texture	Smoothness	7.15^{ab}	7.60^{a}	6.86^{ab}	6.60^{b}	6.80^{ab}	0.02
	Creaminess	4.07^{b}	3.51^{b}	6.03^{a}	6.57^{a}	6.08^{a}	< 0.01
	Meltability	5.76^{a}	5.96^{a}	4.45^{b}	4.75^{b}	4.89^{b}	< 0.01
	Fattiness	5.10^{a}	5.06^{a}	4.88^{ab}	4.23^{bc}	4.11^{c}	< 0.01
	Mouth-coating	3.71^{b}	3.55^{b}	4.74^{a}	4.30^{ab}	4.15^{ab}	0.02

Wine and vinegar reduction added, in particular, esters to the butter sauces, but when considering the differences in concentration, the reduction was the main source for the following compounds: 2,3-butadione, 3-hydroxy-2-butanone, 1-hydroxy-2-propanone, acetophenone, diethyl succinate and benzeneethanol. Results did not give a clear general pattern regarding expression of individual reduction volatiles in the different sauces, probably because the different chemical structures of the volatiles. 2,3-Butadione (diacetyl) and 3-hydroxy-2-butanone (acetoin) are associated with butter aroma, and the industrially clarified butter did contribute with these compounds, but to a lower extent than the reduction. Butter also contributed with δ-octalactone and δ-nonalactone. These compounds, and acetoin, were found in the highest concentrations in the Escoffier and Sabayon WB sauces (warm butter added to both sauces), and may indicate a stronger butter aroma in these sauces compared to the rest. Diacetyl was found in the highest concentrations in the Mayonnaise. As this sauce had the lowest degree of heat-treatment, diacetyl was probably lost to the surroundings during production of the warm butter sauces, due to its low boiling point (87–88 °C (Burdock, 2010)).

Based on volatile analysis results, lemon juice and reduction were the main contributors of aroma in butter sauces. Of the ingredients, the volatile components of egg yolk contributed the least to statistical differences between sauces.

Descriptive analysis (DA)

Sensory attributes used to evaluate butter sauces are listed in Table 3. Norwegian descriptors were used by the panel, and translated to English by the authors for article use (The standard for sensory analysis vocabulary, NS-ISO 5492 (ISO, 1999) was consulted).

Results from the descriptive analysis of sauces are listed Table 6. Only descriptors evaluated significantly different (ANOVA) for sauces are presented. Results from the sensory evaluation are showed in the Fig. 5. The PCA plot show that most of the variance was explained by the first component (PC1 = 87%). The sauces were separated into two groups along the first component; Carême and Escoffier on one hand, and the sabayon sauces and Mayonnaise on the other. The most important descriptors for this separation were color intensity, whiteness, creaminess and airiness.

The separation of the sauces into the two groups reflects a historical shift, as the recipes for Carême and Escoffier sauces were published in the19th and 20th century, whereas the Sabayon technique represents the hollandaise sauce style preferred by most chefs today. One can therefore characterize the sauces to the left in Fig. 5 as "historic" and the sauces to the right as "modern", which shows that the development in sauce-making techniques having taken place in the past 100–200 years also significantly influences sauce perception.

Only one odor characteristic was found to be significantly different between sauces according to ANOVA analysis. Tukey's test did, on the other hand, not find significant differences when comparing differences between the means. One can therefore conclude that there were no major differences in the perceived aroma (ortho-nasal evaluation) between sauces. This may be due to the high amount of fat in these sauces. In addition, lemon juice was added to all sauces, which may have masked subtle sauce aroma differences. On the other hand, sauces were evaluated significantly different in two flavor attributes; butter(f) and acidic (vinegar)(f). These attributes may represent a combination of taste and aroma (retro-nasal) perception.

The analysis of volatiles demonstrated significant differences in concentration for 16 compounds. However, the specific impact of each of these differences on the total aroma profile detected by the human nose is unclear. Volatile analysis fractionates the aroma into its individual compounds, and measures their total concentration, which is quite different compared to how the human nose works analyzing the combination of all aroma compound present in gaseous state. High fat content will decrease the vapor pressure of aromatic molecules from food matrices such as sauces and aroma compounds show significantly higher odor thresholds in fatty

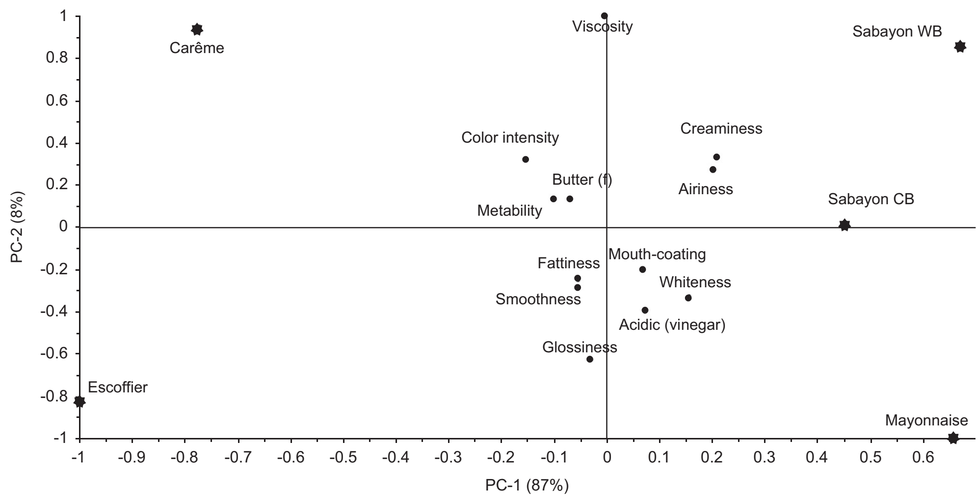

Fig. 5. Principal component analysis (PCA) bi-plot of sensory results. 95% of the variance was explained by the first two components. Only significant descriptors are plotted. "Historic" (Carême and Escoffier) sauces to the left and «modern» sauces (Sabayon WB, Sabayon CB and Mayonnaise) to the right. Stars and dots represent sauces and descriptors respectively.

products. This may explain why the assessors did not find significant odor differences between the samples, as detection of aromatic differences is suppressed in fatty foods and larger differences in aroma content would be needed.

The results from the sensory analysis were compared to the other analyses. Airiness measurements did not directly correspond to the DA results. The assessors rated the Mayonnaise sauce very high in airiness, and Tukey's test found no significant difference between the airiness of Mayonnaise and the Sabayon sauces based on the DA results. This is in contrast to the airiness measurements, where Mayonnaise was found only to contain approximately 6.5% air. Airiness was assessed by looking at the sauce, which may explain the findings, as Mayonnaise had some large air bubbles on the surface created by the immersion blender. The texture of the two sauce types was nonetheless quite different, because Mayonnaise represented a dense structure, and the Sabayon sauces could be characterized as foamy. Better training of the sensory panel regarding this attribute would probably have given different results.

Escoffier and Carême sauces were evaluated more deep yellow in color than the other sauces, which was in accordance with the color measurements. Sabayon WB was evaluated between Mayonnaise and Sabayon CB both in color intensity and whiteness. DA did not result in significant separation of sauces into four groups like the color measurements, but humans do not exhibit preciseness when quantifying color of objects (Hunter and Harold, 1987).

The attribute «color intensity» was correlated with butter flavor in the sensory analysis results (see Fig. 5). Analysis of volatiles did not yield any clear answers regarding buttery character of the sauces, as butter aroma is produced by several volatiles and *different* sauces presented high concentrations of volatiles associated with buttery odor. We hypothesized that Escoffier and Sabayon WB might have the strongest butter aroma based on volatile analysis results. In contrast, sensory evaluation resulted in Carême and Escoffier sauces being attributed the strongest butter flavor. The assessment of Carême and Escoffier sauces as the most butter-flavored sauces may indicate that the deep yellow color of the sauces biased the assessment of butter flavor in the sensory analysis.

Sensory analysis results showed no significant difference regarding sauce particles, which is consistent with the sifting of the sauces, but DA showed a non-significant trend in which Carême and Sabayon CB were attributed the highest scores with respect to particles. The observation of higher particle formation in cold butter sauces could probably have been determined with DA analysis, but it was agreed that passing the sauces through a sieve before serving was the best solution, due to culinary practice and because presence of tiny particles in the sauce could impart the evaluation of other descriptors.

Concluding remarks

According to the results presented, of the five methods investigated in this study chefs of today seek hollandaise sauce properties best represented by the Sabayon WB procedure. Airiness was one of the most important properties for the chefs, and was best obtained by building butter sauces on sabayons, as the foam structure was more or less conserved in the butter sauce. The stability of the foam is probably caused by the coagulation of egg yolk proteins, which stabilizes the air bubbles.

Sauces with less incorporated air and/or larger oil droplets may be associated with higher butter flavor ("historic" sauces), but this may also be caused by an optical illusion, created by their deeper yellow color. On the other hand, it was observed that presence of air bubbles counteracted the impression of fattiness in the sauce, in spite of the high butter content, which may be appealing to modern palates. Airiness was also associated with creaminess in hollandaise sauce, which was another important sauce quality for chefs. Droplet size seemed not to influence other parameters than sauce color. Nor did the impact of the process significantly influence the aroma profiles of sauces, although some significant variations in the volatile profiles were observed instrumentally.

People may talk about the «authentic» or «original» recipe or way to make a dish. For some iconic dishes origin is known, but for the majority, the food or product changes to varying degrees over time. Dishes are not stationary products and evolve therefore, due to shifting of trends, changes in ingredient choice and new equipment or procedures. Hollandaise sauce was invented a very long time ago, in fact so long that historians do not agree where and when it was first made. Some of its historical evolution has been illustrated by the results in this study. It seems that the properties chefs look for in a hollandaise sauce has changed a lot since the days Carême occupied the kitchen. Although chefs of today prefer airy hollandaise sauces, changes in terms of preferred taste and texture are likely to continue. The latest development includes chefs starting to replace some of the butter in butter sauce with plant oils (unsaturated fat) to meet today's nutritional demands. By doing this, the texture of a sabayon hollandaise is likely to be conserved, as the sauce is served well above melting points of butter and butter/oil mixtures. However, nutritional properties, flavor profiles and chemical and physical stability will be altered.

The present study demonstrates that the preparation procedure significantly influenced textural parameters and appearance of hollandaise sauces. Traditionally, cooking has mainly focused on the composition of ingredients and its impact on the gastronomic outcome. The present study shows that gastronomical outcome to a large extent can be manipulated by the choice of procedure. Sauce making can be controlled in order to obtain specific sauce properties, for example to match a certain fish, meat or vegetable dish. The sauces explored in this study, were all made using the same ratios of ingredients, and results indicate that the process influenced aroma properties, as measured instrumentally. Nonetheless, as shown by the sensory analysis, the aroma differences created by the various procedures were too subtle to be perceived. Flavor seems therefore to be best controlled by amount and type of ingredients in butter sauce.

Based on these findings, it is possible to control many aspects of sauce appearance and texture by manipulating the sauce making process, and this, combined with the savoir-faire of an experienced chef regarding ingredients and their aromas, may lead further in the search for sauce perfection.

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