Flavor Release from Salad Dressings: Sensory and Physicochemical Approaches in Relation with the Structure

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The effect of process and formulation on sensory perception and flavor release was investigated on salad dressing models. Oil/vinegar emulsions ($\phi = 0.5$, droplet size > 10 μm) with thickeners and a whey protein concentrate were prepared with different fat droplet sizes and different distributions of fat droplet size. The effect of the amount of emulsifier was also tested. Sensory profile analysis was performed by a trained panel and flavor release quantified by dynamic headspace analysis. When the droplet size is increased, the lemon smell and citrus aroma significantly increase, whereas the egg note, mustard, and butter aroma significantly decrease. The concentrations of alcohols and acids significantly increase when droplet size increases, whereas those of other compounds such as limonene or benzaldehyde significantly decrease. The dispersion of the droplet size has a small effect on flavor perception, and the effect of the increase of the amount of emulsifier is noticed only by instrumental analysis.

Keywords: *Emulsion; structure; sensory analysis; flavor release*

INTRODUCTION

Current consumers are looking for products ready for use such as dressings. Dressings and sauces are oil-in-water emulsions stabilized with thickeners. Sensory parameters affecting the acceptability of these sauces are mainly texture and flavor. However, few data have been reported on the effect of process or formulation on the sensory perception of dressings. Recently, Wendin et al. (1997) showed the effect of fat content, flavor compounds, and thickener content on the texture and flavor of mayonnaise by sensory and physicochemical analysis.

As many food products are emulsions (e.g., ice cream, cheese, margarine, and milk), many results have been reported in the literature on flavor release from model emulsions. In oil-in-water emulsions, volatile compounds distribute themselves between at least three different phases, the aqueous phase, the oil phase, and the interface. Flavor release from emulsions is mainly dependent on the affinity of volatile compounds for the liquid phases but could also be affected by the structure of the emulsions. The structure is characterized by the nature of the dispersed phase (water or oil), the surface area of the lipid−water interface, and the nature and amount of the surface-active agent adsorbed at the interface. Salvador et al. (1994) observed a higher release rate of diacetyl from an oil-in-water emulsion than from a water-in-oil emulsion with the same oil content and the same emulsifier. They supposed that the difference observed was due to difference in the mass transfer rates between the interface. Several authors tested the incidence of an increase of oil−water interfacial surface area by comparison of the dispersed and the same nondispersed biphasic system (Land, 1978; Le Thanh et al., 1992; Dubois et al., 1996; Landy et al., 1996). The results show that the effect of the state of dispersion depends on the nature of the volatile but especially on the nature of the surface-active agent. When proteins are used as an emulsifier, interactions could occur between volatile compounds and proteins at the interface or in the aqueous phase. Adsorption of the protein at the interface could either mask the aroma binding sites or facilitate the access for aroma to the binding sites of the proteins (Espinoza-Diaz, 1999). The consequence is an increase or a decrease of the volatility of the aroma interacting with the considered protein. Proteins adsorbed at the interface can also act as a barrier and decrease the amount of aroma transferred through the oil−water interface (Harvey et al., 1995; Rogadcheva et al., 1999). Increase of the interfacial surface area could be obtained by a decrease of the fat droplet size of the emulsions. Druaux et al. (1996) showed an effect neither of the droplet size (0.5 and 6.1 μm) nor of the protein concentration at the interface on the volatility of diacetyl in emulsions with 0.05% *n*-dodecane. The release of flavor from emulsion has been theoretically described by McNulty and Karel (1973), Overboosh et al. (1991), and Harrison et al. (1997), but factors such as droplet size or surfactant properties were not considered in these models.

Results of the literature show a slight effect of the structure on flavor release in emulsions, but in the majority of the studies, the droplet size of the emulsions

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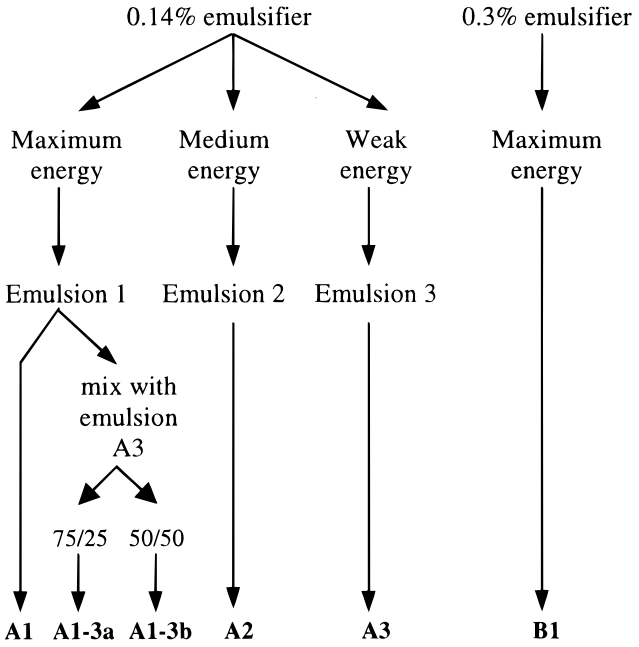

Figure 1. Process of the model salad dressings.

is <10 μm and the oil volume fraction <15%. Therefore, the objective of this study was to investigate the influence of the structure on flavor release from a real food emulsion, salad dressing with droplet size >10 μm and oil volume fraction = 50%, by physicochemical and sensory analyses. Six emulsions were produced to test three parameters: droplet size, distribution of the fat droplet size, and concentration of emulsifier at the oil−water interface.

MATERIALS AND METHODS

Emulsion Preparation. The lipid phase (50%) was composed of sunflower oil. The aqueous phase was constituted of a whey protein concentrate (DMV, Videbaek, The Netherlands), xanthane (0.14%) (Kelco International, Chicago, IL), and a waxy modified starch (0.5%) (National Starch, Villefranche-sur-Saône, France) for stabilization. The acidic phase was composed of wine vinegar (8°), lemon concentrate (0.05%), and salt (2%). Three odorant compounds were added to the emulsions: allyl isothiocyanate (final concentration in the salad dressings = 150 ppm) in the lipid phase, phenyl-2-ethanol (20 ppm), and ethyl hexanoate (10 ppm) in the vinegar. They are responsible for mustard, floral, and fruity notes, respectively. Salad dressings were produced on a continuous pilot scale; the aqueous phase and the oil phase were mixed together, and then the acidic phase was added. The salad dressings were stored in 500 mL poly(ethylene terephthalate) (PET) flasks at 4 °C. Six emulsions were prepared as indicated in Figure 1. By modification of the energy of emulsification, three emulsions with different fat particle sizes (A1, A2, and A3) were made. Emulsions A1 and A3 were mixed together in two different ratios to give emulsions A1−3a (75:25, w/w) and A1−3b (50:50, w/w). One emulsion with a higher concentration of surface-active agent (B1) was produced with the maximum energy of emulsification. Therefore, it was possible to test the effect of the droplet size (comparison of A1, A2, and A3), the effect of distribution of fat droplet size (comparison of A1, A1−3a, and A1−3b), and the effect of surface-active agent concentration (comparison of A1 and B1).

Emulsion Characterization. A Malvern Mastersizer laser diffractometer (model S2-01, Malvern Instruments, Orsay, France) was used to determine the structural features of emulsion: median diameter [D (v, 0.5)], dispersion [D (v, 0.9) − D (v, 0.1)], and specific surface area (SSA). A solution of fungi α-amylase (20 mg/L; A-0273, Sigma, Saint-Quentin, France) was added to the emulsion to eliminate starch granules that could disturb the measurement. The amount of protein adsorbed at the interface, Γ (g/m^2 of oil−water interface), was determined from the difference of protein concentration between the one used for making the emulsion and the one obtained after centrifugation of emulsion. Before centrifugation, the emulsions were diluted to decrease the viscosity and the centrifugation treatment was adapted for each emulsion: 3500g for the finest emulsions and 500g for the coarse emulsions. The nitrogen content in the initial aqueous phase and in the aqueous layer was quantified by the general Kjeldahl procedure (International Dairy Federation, 1986). Viscosity was measured with a Rheomat 115 (Lamy, Paris, France). The apparent viscosity of emulsion was calculated at a shear rate of 50 s^{-1}.

Dynamic Headspace Analysis and Quantification by Gas Chromatography−Mass Spectrometry (GC-MS). Emulsions (20 g) were poured into a 500 mL flask. Internal standard, 2-methyl-1-pentanol (5 μL of a 1.6 mg/mL solution) was injected on the emulsion surface. Volatile compounds in the headspace were purged with nitrogen at 40 mL/min for 5 min at 25 °C and trapped on a Tenax TA trap (20−35 mesh). The desorption of the volatiles on a gas chromatograph was performed with the thermal desorption cold trap injector of Chrompack (CP-4010 PTI/TCT, Chrompack, Middelburg, The Netherlands). The Tenax trap was placed inside the desorption oven. Water was eliminated with a back-flush of nitrogen at 40 mL/min for 1 min. Volatile compounds were then desorbed from the Tenax trap with N_2 (40 mL/min) at 250 °C for 20 min. The desorbed volatiles were cryofocused on a fused silica trap cooled at −130 °C with liquid nitrogen. The cryotrap was held to 250 °C for 1 min, and volatile compounds were injected on GC-MS. The trap was then heated at 270 °C for 30 min using the back-flush system. Relative quantification of the volatile compounds was performed on a Hewlett-Packard 5890 series II GC, equipped with a DB-FFAP fused capillary column (30 m × 0.32 mm i.d., film thickness = 0.25 μm, J&W Scientific Inc., Folsom, CA) and coupled with a Nermag R10-10C mass spectrometer (Nermag, Argenteuil, France). The helium velocity was 35 cm s^{-1}. Detector temperature was 260 °C, and source detector was 150 °C. The oven temperature was held at 35 °C for 5 min and then programmed to 220 °C at 4 °C min^{-1}. Peak areas were estimated under the total ion current (TIC compounds) or under selected ion current (SIC compounds) in the case of coelution of compounds. Hydrophobicity of the volatile compounds was estimated by the log P value according to the method of Rekker (1977).

Sensory Analysis. Sensory evaluation by quantitative descriptive analysis (QDA) was performed with a selected and trained panel consisting of 14 females and 2 males at ENSBANA, Dijon, France. They were selected for their capacity to recognize, memorize, and discriminate odors and to describe their perceptions when testing salad dressings. During training sessions (17 × 1.5 h), the list of smell and aroma attributes was developed using samples from the present experiment together with commercial salad dressings. To find the best standard to define each attribute, different standards were proposed to the panelists (Table 1). Panelists were trained to evaluate the intensity of each attribute on a continuous scale of 10 cm labeled with "no intensity" at the left and "strong intensity" at the right. Data acquisition was performed with FIZZ software (Biosystems, France). Salad dressings (25 mL) were presented in plastic cups, covered with polystyrene lids at 20−23 °C. Samples were randomized according to the Latin square design to take into account the serving order and carry-over effect of samples (MacFie et al., 1989). Four emulsions were evaluated per session, and three replicates were made in six sessions. One flask of emulsion was opened for each replication. Panelists were asked first to smell the emulsion and note the intensity of smell descriptors and, second, to put the emulsion into the mouth and evaluate the intensity of aroma attributes. Water and bread were used for cleaning the palate between the samples.

Statistical Analysis. The statistical analyses were performed with the Statistical Analysis Systems software (SAS

Table 1. List of Attributes and Standards

sensory perception	attributes	abbreviation	standards or definitions
smell	smell intensity	Sintensity	intensity of smell
	oil	Soil	sunflower oil
	olive oil	Solive	olive oil
	vinegar	Svinegar	alcohol vinegar diluted to 1/3
	wine vinegar	Swine	wine vinegar diluted to 1/8
	egg	Segg	hard-boiled egg yolk
	lemon	Slemon	fresh lemon juice
	red fruits	Sredfruits	mixed red fruits
	aromatic herbs	Saroherbs	Provence herbs diluted in 500 mL of Evian water
	shallot	Sshallot	3 shallots in 500 mL of Evian water
	mustard	Smustard	5 g of mustard in 500 mL of Evian water
	garlic	Sgarlic	$1^1/_2$ cloves of garlic in 500 mL of Evian water
	fresh herbs	Sfreshherbs	$^1/_2$ parsley + $^1/_2$ chive
aroma	aroma intensity	Aintensity	intensity of aroma
	oil	Aoil	sunflower oil
	olive oil	Aolive	olive oil
	vinegar	Avinegar	alcohol vinegar diluted to 1/3
	wine vinegar	Awine	wine vinegar diluted to 1/8
	shallot	Ashallot	3 shallots in 500 mL of Evian water
	egg	Aegg	hard-boiled egg yolk
	citrus fruit	Acitrus	mix of fresh citrus fruits juice
	red fruits	Aredfruits	mixed red fruits
	butter/cream	Abutter	mix of fermented milk and fresh cream
	mustard	Amustard	5 g of mustard in 500 mL of Evian water
	nut	Anut	crushed nut
	pepper	Apepper	1 g of pepper in 500 mL of Evian water

Institute, Inc., Cary, NC). For sensory analysis, a three-way analysis of variance (ANOVA; procedure, GLM) was applied with product, subject, and session as effects. The product effect was tested over product−subject interaction. For physicochemical analysis, a one-way ANOVA was applied with product as effect. An effect of product was defined as significant at $p <$ 0,05. When significant, a multiple comparison of means was performed with the Student−Newman−Keuls test. Pearson correlations (SAS) between sensory data, physicochemical data, and structure or viscosity were calculated (CORR procedure), using emulsions with formula A only.

RESULTS DISCUSSION

Effect of Droplet Size (Comparison of Emulsions A1, A2, and A3). Droplet size of the emulsions had a strong effect on both release and perception of volatile compounds.

Effect on flavor release depended on the hydrophobicity of the volatile compounds. The release of the most hydrophilic compounds is higher in the emulsion with the larger droplet size (Table 3; Figure 2a). These compounds, alcohols, acids, diacetyl, and acetoin, come from the vinegar (Charles et al., 2000). Their concentrations should be higher in the water phase than in the oil phase. The increase of droplet size is associated with a decrease of viscosity (Table 2). Viscosity is known for its suppression action on the release of volatile compounds as shown for xanthan by Rankin and Bodyfelt (1996) and for a xanthan−starch mixture by Odake and Roozen (1996). These decreases can be attributed to binding of flavor compounds to the thickeners and/or to inhibition of the transport of flavor compounds from within the solution to the surface (Roberts et al., 1996). Hydrogen bondings were found between xanthan and hydrophilic compounds (Yven et al., 1998). However, in the present study, as concentration of thickeners is the same, the decrease in flavor release of hydrophilic compounds cannot be explained only by molecular interactions between aroma and thickeners. Odake et al. (1998) showed that the release of diacetyl measured by dynamic headspace analysis was higher in an oil-in-water system without than with polysaccharides,

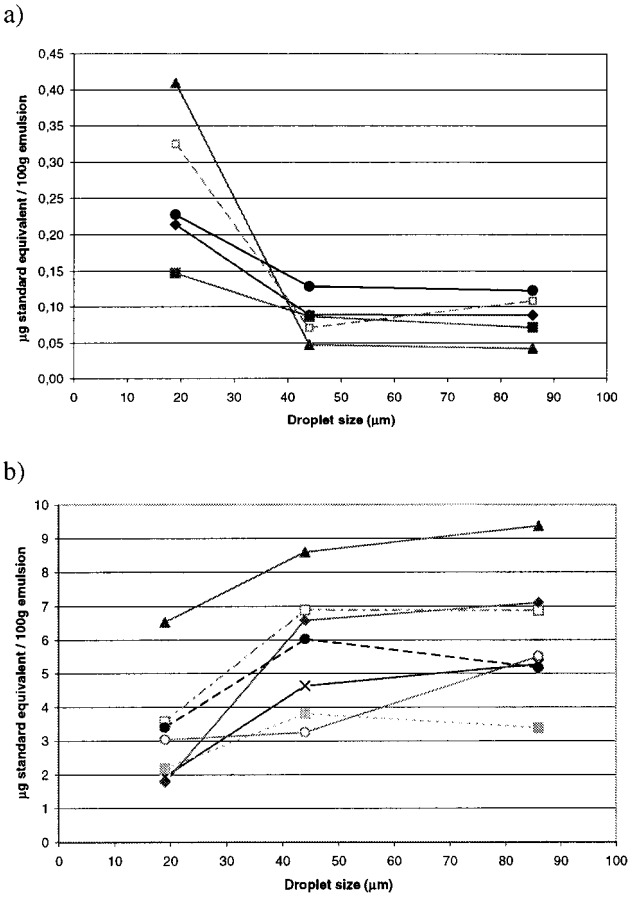

Figure 2. Effect of droplet size on flavor release from model salad dressings: (a) ▲, phenol (log $P = 1.5$); □, diallyl sulfide (×10) (log $P = 2.4$); ●, hexanal (log $P = 2.4$); ◆, benzaldehyde (log $P = 1.5$); ■, limonene (/10) (log $P = 4.7$); (b) ▲, 2-methyl-1-butanol (/10) (log $P = 1.3$); □, 2-methyl-1-propanol (/10) (log $P = 0.65$); ◆, 3-methylbutanoic acid (log $P = 1.07$); ●, acetoine (/10); ×, 1-propanol (log $P = 0.25$); ■, propanoic acid (log $P = 0.25$); ○, diacetyl (log $P = -2.0$).

because of the smaller viscosity of the emulsion system. Thus, the decreased flavor release of hydrophilic com-

Table 2. Structural Features and Viscosity of the Model Salad Dressings

dressing	D (v, 0.5) (μm)	surface area (m^2/mL)	dispersion (μm)	protein adsorbed at interface (mg/m^2 of interface)	viscosity (Pa·s)
A1	19.3	29.8	21.8	1.7	0.70
A2	44.6	16.1	38.9	2.7	0.51
A3	86.6	6.1	80.0	6.8	0.36
A1−3a	21.4	26.7	103.8	nd[a]	0.54
A1−3b	44.2	21.1	112.2	2.2	0.46
B1	17.9	34.0	18.58	3.1	0.62

[a] nd, not determined.

pounds may be explained by resistance to mass transfer in the aqueous phase of the dressings when the droplet size decreases.

On the contrary, release of some hydrophobic compounds, such as phenol, limonene, 2-methylpropyl acetate, or hexanal, for example (Table 2; Figure 2b), is higher when the fat droplet size is the smallest. According to McNulty and Karel (1973), the release of hydrophobic compounds in the headspace is performed in two steps: transfer from oil to water and then transfer from water to vapor. When droplet size of the emulsion increases, the total oil−water interfacial surface area increases (Table 2). The increase of the interfacial surface area may enhance the rate of transfer of the hydrophobic compounds from oil to water. Decrease of droplet size was also associated with a decrease of the quantity of proteins adsorbed at the interface (Table 2). Druaux et al. (1996) noticed no effect of the droplet size nor an increase of the protein concentration at the interface on the volatility of diacetyl and 2-nonanone in emulsions with 0.6% *n*-dodecane. On the contrary, Landy (1998) showed an effect of the state of dispersion on the volatility of ethyl butanoate and ethyl hexanoate in emulsions with 5% sodium caseinate but no effect in emulsions with 0.5% sodium caseinate. These authors suggested that the difference was due to high affinity of the two esters for the adsorbed protein when the concentration of protein at the interface is higher. Espinoza-Diaz (1999) observed that the volatility of 2-nonanone was higher in an emulsified system compared to the nonemulsified system with β-lactoglobulin (3%). The authors postulated that, for this protein, the adsorption at the interface modifies the binding sites of the aroma compounds to the protein and that protein in the aqueous phase could also interact with 2-nonanone. In this study, the surface-active agent is a whey protein concentrate, containing β-lactoglobulin and α-lactalbumin. Many hydrophobic compounds interact with β-lactoglobulin and α-lactalbumin (Pelletier et al., 1998; Sostmann and Guichard, 1998), and the interactions with α-lactalbumin are smaller than those with β-lactoglobulin (Jasinski and Kilara, 1985). At pH 3, α-lactalbumin is better adsorbed at the interface than β-lactoglobulin (Dalgleish, 1997). Therefore, the better release observed for most hydrophobic compounds from the finest emulsion cannot be explained by specific interactions of the aroma compounds with interfacial protein.

Proteins present at the interface could decrease the rate of transfer from oil to water. For example, the presence of β-lactoglobulin at the miglyol−water interface increases the resistance to the transfer of benzaldehyde across the lipid layer (Rogacheva et al., 1999). In this study, the protein concentration at the oil−water interface is smaller for the emulsions with the smaller droplet sizes (Table 2), which may also explain why the release of hydrophobic compounds is higher from the emulsion with the smaller droplet size.

Variation of the droplet size influenced also the sensory profile of the emulsions. Droplet size had a significant effect ($p < 0.05$) on the intensity of 9 of 26 terms (Table 3). The intensity of *egg smell*, *egg aroma*, *aroma intensity*, *mustard aroma*, and *butter aroma* increased when droplet size decreased from 86 to 20 μm, whereas those of *lemon smell* and *citrus aroma* were smaller in the fine emulsion. *Olive oil smell* and *olive oil aroma* intensities were significantly higher in emulsion A2. *Mustard aroma* is due to allyl isothiocyanate (AITC). As the oil−water partition coefficient of AITC is equal to 50 (unpublished results), its concentration in the lipidic phase is more important in the fat than in the aqueous phase. The rate of transfer of this compound from the oil to the water phase seems to increase when the oil−water interfacial surface area increases. This is in agreement with the results obtained by Overboosh et al. (1991), which showed that mastication of an oil containing an emulsifier enhanced release of 2-pentanone. This enhancement was associated with a decrease of droplet size when the oil was mixed with saliva.

The other notes could not be explained by only one volatile compound; no direct correlations were found between one sensory attribute and one volatile compound. The butter note is mainly due to diacetyl, acetoin, and acids (Schieberle et al., 1993). In this case, results obtained by physicochemical and sensory analysis are opposite: these compounds are better released from the coarse emulsion, whereas perception of the butter note is greater in the finest emulsion. In the mouth, several factors such as dilution with saliva and mastication have to be taken into account. In a cream type dressing, Odake et al. (1998) have calculated that diacetyl is more concentrated in the aqueous phase and that its release decreased when dressings were diluted with saliva. These authors also suggested that viscous products that coat the inside of the mouth and the teeth have more release than less viscous products due to the increase of the product−air interface. This is in agreement with other sensory results obtained on these salad dressings: the emulsion with the smallest fat droplet size was judged to more heavily coat the inside of the mouth.

Influence of the Distribution of Fat Droplet Size (Comparison of A1, A1−3a, and A1−3b). The mix of emulsions A1 and A3 led to bimodal emulsions with larger dispersion (Table 2). The two populations of droplets present in the initial emulsions A1 and A3 were present in these emulsions (Figure 3). The proportion of fat dispersed in the smaller fat droplets (19 μm) was significantly ($p < 0.05$) greater in the A1−3a emulsion (23%) than in the A1−3b emulsion (15%). Emulsion A1 was more viscous than the mixed emulsions A1−3a and A1−3b.

The effect of the distribution of fat droplet size on flavor release was more pronounced when determined by dynamic headspace than by sensory analysis. Results obtained by headspace analysis are in agreement with our hypothesis concerning release of hydrophilic and hydrophobic compounds. Alcohols, acids, and diacetyl were better released from emulsion A1−3b, which was the less viscous (Table 2). On the contrary, benzaldehyde, 2-methylpropyl acetate, and phenol were better

Table 3. Quantities of Volatile Compounds Released from Model Salad Dressings with Different Structures (Micrograms of Standard Equivalent/100 g of Emulsion)[a]

	dressing					
volatile compound	A1	A2	A3	A1−3a	A1−3b	B1
methyl acetate	57.9 (5.8)[a]	60.1 (7.2)[a]	61.3 (6.9)[a]	75.1 (10.8)[a]	76.3 (12.4)[a]	78.8 (8.0)[a]
ethyl acetate	241.2 (20.6)[b]	458.1 (122.4)[ab]	287.4 (74.5)[b]	568.6 (57.2)[a]	466.3 (29.9)[ab]	615.2 (177.4)[a]
2-methylpropyl acetate	1.9 (0.2)[b]	2.3 (0.3)[ab]	0.0 (0.0)[c]	0.0 (0.0)[c]	2.0 (0.6)[b]	3.1 (0.5)[a]
2-methylbutyl acetate	2.1 (0.3)[a]	2.2 (0.2)[a]	1.6 (0.5)[a]	2.3 (0.3)[a]	2.4 (0.0)[a]	3.0 (0.6)[a]
ethyl hexanoate	23.0 (2.4)[a]	26.9 (2.9)[a]	19.6 (2.7)[a]	30.1 (2.9)[a]	25.6 (6.2)[a]	26.9 (1.3)[a]
ethyl 2-hydroxypropanoate	0.9 (0.6)[a]	0.9 (0.8)[a]	1.4 (0.1)[a]	1.2 (0.3)[a]	0.6 (0.0)[a]	1.1 (0.0)[a]
acetone	9.56 (1.0)[a]	11.1 (3.3)[a]	8.4 (0.5)[a]	14.4 (0.7)[a]	15.8 (6.0)[a]	20.7 (0.1)[a]
diacetyl	3.0 (0.5)[b]	3.2 (0.5)[ab]	5.5 (1.7)[a]	4.9 (0.8)[a]	3.9 (1.4)[ab]	5.1 (0.1)[a]
acetoine	33.9 (1.3)[c]	60.2 (9.8)[b]	51.6 (11.7)[bc]	77.0 (0.3)[a]	31.9 (2.6)[c]	50.7 (5.1)[bc]
hexanal (SIC: 44)	0.2 (0.0)[abc]	0.1 (0.0)[c]	0.1 (0.4)[c]	0.1 (0.0)[bc]	0.2 (0.0)[ab]	0.3 (0.0)[a]
benzaldehyde (SIC: 106)	0.2 (0.0)[a]	0.0 (0.0)[b]	0.0 (0.0)[b]	0.1 (0.0)[b]	0.2 (0.0)[a]	0.2 (0.0)[a]
1-propanol	1.9 (0.2)[b]	4.6 (0.3)[a]	5.2 (0.3)[a]	4.4 (0.7)[a]	1.6 (0.2)[b]	2.1 (0.6)[b]
1-butanol	0.0 (0.0)[c]	0.0 (0.0)[b]	0.2 (0.0)[b]	0.2 (0.0)[c]	0.0 (0.0)[a]	0.0 (0.0)[c]
2-butanol	1.5 (0.2)[a]	1.9 (0.3)[a]	1.9 (0.8)[a]	1.8 (0.4)[a]	1.4 (0.2)[a]	2.0 (0.5)[a]
2-methyl-1-propanol	35.8 (5.4)[b]	68.8 (6.5)[a]	68.7 (13.0)[a]	63.4 (10.9)[a]	46.9 (11.2)[ab]	61.3 (11.3)[a]
mix of 3- and 2-methylbutanol	65.2 (6.9)[b]	85.8 (1.8)[ab]	93.7 (14.3)[a]	108.7 (15.4)[a]	86.6 (17.5)[ab]	97.8 (3.8)[a]
2-phenylethanol	2.7 (0.3)[a]	2.8 (0.7)[a]	3.7 (1.0)[a]	2.5 (0.3)[a]	2.3 (0.0)[a]	4.6 (1.1)[a]
phenol (SIC: 94)	0.4 (0.0)[a]	0.0 (0.0)[b]	0.0 (0.0)[b]	0.0 (0.0)[b]	0.3 (0.1)[ab]	0.3 (0.1)[a]
propanoic acid	2.1 (0.7)[bc]	3.8 (0.5)[a]	3.3 (0.8)[ab]	4.2 (0.6)[a]	1.9 (0.0)[c]	2.4 (0.2)[bc]
butanoic acid (SIC: 60)	0.0 (0.0)[b]	0.0 (0.0)[b]	0.1 (0.0)[a]	0.1 (0.0)[a]	0.0 (0.0)[b]	0.0 (0.0)[b]
2-methylpropanoic acid (SIC: 73)	0.0 (0.0)[c]	0.0 (0.0)[c]	0.2 (0.0)[b]	0.5 (0.1)[a]	0.1 (0.0)[bc]	0.2 (0.0)[b]
3-methylbutanoic acid	1.7 (0.3)[b]	6.5 (2.1)[a]	7.1 (1.6)[a]	6.0 (0.2)[ab]	2.0 (0.3)[b]	2.2 (0.07)[b]
AITC	875.1 (158.6)[b]	936.2 (22.8)[b]	843.0 (95.6)[b]	1442.6 (169.3)[a]	1230.4 (311)[ab]	1365 (162)[a]
ITC (SIC: 99)	2.6 (0.1)[b]	4.8 (0.0)[ab]	2.9 (2.1)[b]	7.9 (0.5)[a]	5.8 (1.8)[ab]	5.7 (0.9)[ab]
diallyl sulfide (SIC: 114)	0.0 (0.0)[a]	0.0 (0.0)[a]	0.0 (0.0)[a]	0.0 (0.0)[a]	0.0 (0.0)[a]	0.0 (0.0)[a]
D-limonene	1.4 (0.9)[ab]	0.8 (0.1)[b]	0.7 (0.0)[b]	0.8 (0.2)[b]	2.3 (0.3)[a]	1.8 (0.4)[a]

[a] Mean (standard deviation). Quantities with different letters are different at a 5% level.

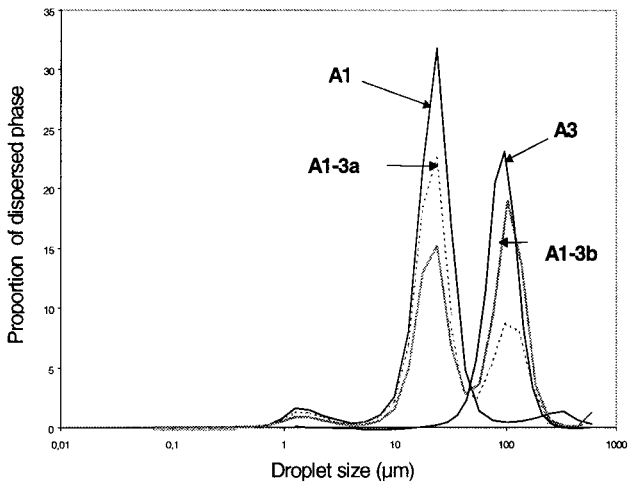

Figure 3. Droplet size distributions of model salad dressings A1 (maximum energy of emulsification), A3 (minimum energy of emulsification), A1−3a (mix of A1 and A3, 75:25 w/w), and A1−3b (mix of A1 and A3, 50:50 w/w).

released from emulsion A1, which had the greater oil−water interfacial surface area.

Only two sensory attributes, *smell egg* and *aroma egg*, were better perceived in emulsion A1. The presence of one population of fat droplets of larger diameter decreased the perception of these notes. As no good correlation between sensory analysis and volatile compounds was found, it is not possible to explain this result.

Influence of Surface-Active Agent Concentration (Comparison between A1 and B1). Differences were observed between physicochemical and sensory analysis results. No effect of the formulation was observed on sensory perception, whereas release of most of the volatile compounds was higher in the emulsion with the higher amount of surface-active agent. These last results were unexpected. No change in droplet size, dispersion, and viscosity was noticed when emulsifier concentration increased from 0.14% (A1) to 0.3% (B1), but the concentration of protein adsorbed at the oil−water interface increased (Table 2). As aroma compounds are known to interact with protein, we were expecting a smaller release from emulsion B1. Moreover, the increase of proteins adsorbed at the interface should

Table 4. Intensity of Sensory Attributes of Model Salad Dressings with Different Structures[a]

	dressing						mean
attribute	A1	A2	A3	A1−3a	A1−3b	B1	SE
Sintensity	53.2[a]	53.6[a]	45.0[a]	48.3[a]	53.0[a]	48.7[a]	3.4
Svinegar	34.8[a]	33.7[a]	37.3[a]	34.5[a]	34.4[a]	30.4[a]	5.1
Swine	47.3[a]	47.3[a]	45.1[a]	51.8[a]	55.4[a]	52.0[a]	3.6
Smustard	50.4[a]	55.1[a]	47.3[a]	50.1[a]	50.4[a]	51.3[a]	2.4
Sshallot	34.7[a]	36.0[a]	40.0[a]	40.0[a]	34.6[a]	27.7[a]	3.8
Segg	35.8[a]	23.9[b]	19.0[b]	25.5[b]	21.8[b]	38.2[a]	2.8
Soil	24.4[a]	16.7[a]	25.9[a]	21.1[a]	20.7[a]	24.3[a]	2.1
Solive	16.3[b]	28.5[a]	21.0[b]	18.0[b]	14.0[b]	15.5[b]	1.5
Slemon	23.4[b]	33.2[a]	33.1[a]	25.3[ab]	22.9[b]	27.1[ab]	2.9
Sredfruits	19.9[a]	23.2[a]	22.8[a]	21.0[a]	19.8[a]	26.3[a]	2.8
Saroherbs	15.0[a]	20.9[a]	17.3[a]	11.8[a]	10.3[a]	14.7[a]	2.6
Sgarlic	41.3[a]	38.2[a]	35.4[a]	40.2[a]	38.0[a]	40.0[a]	2.4
Sfreshherbs	27.7[a]	28.2[a]	16.1[a]	24.2[a]	30.2[a]	28.6[a]	2.4
Aintensity	55.9[ab]	60.8[a]	47.1[b]	52.3[ab]	57.3[ab]	60.9[a]	2.8
Avinegar	30.4[a]	31.4[a]	37.2[a]	29.6[a]	23.3[a]	25.5[a]	3.1
Awine	59.9[a]	61.4[a]	49.5[a]	56.4[a]	60.2[a]	60.3[a]	2.0
Amustard	58.6[a]	53.1[ab]	44.0[b]	52.2[ab]	55.7[ab]	64.6[a]	2.8
Apepper	35.3[a]	31.4[a]	30.3[a]	32.3[a]	25.1[a]	30.5[a]	3.3
Anut	17.6[a]	21.8[a]	25.6[a]	19.3[a]	20.6[a]	27.5[a]	3.6
Ashallot	46.1[a]	40.8[a]	43.5[a]	40.0[a]	39.8[a]	36.9[a]	2.9
Agarlic	42.3[a]	36.0[a]	40.6[a]	37.2[a]	45.3[a]	46.2[a]	3.0
Aoil	25.1[a]	22.3[a]	30.8[a]	23.9[a]	24.5[a]	22.5[a]	2.3
Aolive	23.4[b]	38.8[a]	24.4[b]	20.9[b]	24.6[b]	20.3[b]	2.8
Aegg	37.6[a]	22.9[b]	14.8[b]	24.7[ab]	27.4[ab]	39.0[a]	2.6
Acitrus	34.4[ab]	45.9[a]	49.0[a]	40.5[ab]	34.9[ab]	28.3[b]	3.0
Aredfruits	33.5[a]	35.0[a]	32.4[a]	30.8[a]	30.9[a]	32.8[a]	3.5
Abutter	35.0[a]	20.0[ab]	11.8[b]	25.5[a]	31.2[a]	36.9[a]	2.3

[a] Intensities were measured on a 100 cm unstructured scale. Intensities with different letters are significantly different at a 5% level.

Table 5. Correlation Values between Flavor Release and Emulsion Characteristics for Salad Dressings with the Same Formulation (A1, A2, A3, A1−3a, and A1−3b)

	log *P*	*D* (v, 0.5)	specific surface area	viscosity
Slemon		*0.80*	*−0.91**	*−0.66*
Acitrus		*0.91**	*−0.97**	*−0.82*
diacetyl	−2.0	0.77*	−0.67	−0.86
1-propanol	0.25	0.87*	−0.89*	−0.81
2-methyl-1-propanol	0.65	0.79	−0.89*	−0.88*
1-butanol	0.8	0.69	−0.68	−0.76
3-methylbutanoic acid	1.07	0.84	−0.89*	−0.84
2- and 3-methyl-1-butanol	1.3	0.49	−0.51	−0.79
Aintensity		*−0.88**	*0.74*	*0.74*
Amustard		*−0.98***	*0.96**	*0.94**
Aegg		*−0.90**	*0.95***	*0.98***
Segg		*−0.65*	*0.75*	*0.88**
Abutter		*−0.96***	*1**	*0.90**
benzaldehyde	1.5	−0.80	0.84	0.72
phenol	1.5	−0.80	0.88*	0.88*
diallyl sulfide	2.4	−0.72	0.79	0.71
hexanal	2.4	−0.82	0.86	0.63
limonene	4.7	−0.73	0.70	0.55

[a] Significant correlations ($n = 5$): *, $p < 0.05$; **, $p < 0.01$.

reduce the rate of transfer of hydrophobic compounds from the oil phase to the water phase. The differences observed by physicochemical analysis do not induce significant differences in sensory perception.

Correlations between Flavor Release and Emulsion Characteristics (Table 5). The release of hydrophobic compounds (log $P > 1.5$) was negatively correlated with *D* (v, 0.5) and positively with the interfacial surface area and viscosity. The opposite was observed for hydrophilic compounds (log $P < 1.3$).

Positive correlations were also found between sensory attribute *citrus aroma* and *D* (v, 0.5), whereas *intensity aroma*, *mustard aroma*, *egg aroma*, and *butter aroma* are negatively correlated with *D* (v, 0.5) but positively with the interfacial surface area and viscosity.

Considering these correlations obtained on model salad dressings with the same amount of emulsifier but not the same structure, it seems that the flavor release in salad dressings is mainly dependent on the droplet size of the emulsion.

Conclusion. The modification of the structure of salad dressings has an effect on both flavor release and sensory perception. The release of hydrophobic compounds seems to be more related to the droplet size of the emulsions and the release of hydrophilic compounds to viscosity. In the mouth, phenomena seem to be more complex as structure and texture must be taken into account. This study pointed out the necessity of complementary study in simpler systems to better understand the respective influence of droplet size, concentration of protein at the interface, and viscosity on flavor release from salad dressings.

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