

Thermodynamic and kinetic study of volatile compounds in biopolymer based dispersions



Vahid Samavati^{a,*}, Zahra Emam-Djomeh^b, Ali Mehdinia^c

^a Department of Food Science and Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Iran

^b Transfer Phenomena Laboratory, Department of Food Science and Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Iran

^c Marine Living Science Department, Iranian National Center for Oceanography, Tehran, Iran

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ABSTRACT

Partitioning and release of ethyl acetate and diacetyl from two matrices with a different composition was studied by applying static head space gas chromatography. Two matrices with a different composition have been developed: one containing carbohydrates (Tragacanth gum) and in the second one, called complex matrix, a lipid (oleic acid) was added. The roles of carbohydrate (Tragacanth gum) and lipid (oleic acid) on the retention of all the aroma compounds were pointed out. Changes in the composition of matrices exhibited a considerable effect on the thermodynamic component as expressed by the air/liquid partition coefficient ($K_{a/l}$) values at equilibrium (20 °C). The kinetic study of the release from these matrices had shown a decrease of the initial rate of release (R_i) by reference with water. The rheological properties of all matrices were investigated and the flow behaviour of all matrices was successfully modelled with power law and Ellis models and power law model was found as the better model to describe the flow behaviour of dispersions.

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1. Introduction

Aroma release has an important influence on the sensory characteristics and hence consumer's preference of foods. The retention of aroma compounds in food matrices is important for the perception of food products (De Roos, 2003). A modification of the food composition may favour or hinder the release of some aroma compounds and consequently may conduct to a distortion of the initial aroma profile (Seuvre, Philippe, Rochard, & Voilley, 2007).

In aqueous systems, the retention of aroma compounds can be modified by physicochemical interactions between macromolecules such as proteins and polysaccharides, lipids and aroma compounds (Guichard, 2006; Seuvre, Diaz, & Voilley, 2000; Seuvre, Philippe, Rochard, & Voilley, 2006). The nature of the different non-volatile constituents such as proteins, lipids, carbohydrates, and salts have a great impact on the retention of the aroma compounds by the food matrices (Bakker, 1995; De Roos, 1997; Fisher & Widder, 1997; Godshall, 1997; Van Ruth, de Vries, Geary, & Giannouli, 2002; Van Ruth, King, & Giannouli, 2002).

* Corresponding author at: Department of Food Science, Technology and Engineering Faculty of Agricultural Engineering and Technology, University of Tehran, P.O. Box: 4111, 31587-11167 Karadj, Iran. Tel.: +98 261 224 8804.

E-mail addresses: vahidsamavati@gmail.com (V. Samavati), emamj@ut.ac.ir (Z. Emam-Djomeh), mehdinia@inco.ac.ir (A. Mehdinia).

Many studies have been carried out in simple systems composed of water, proteins, lipids and carbohydrates (Fisher & Widder, 1997; Godshall, 1997; Karaïskou, Blekas, & Paraskevopoulou, 2008; Roberts, Stephen Elmore, Langley, & Bakker, 1996; Terta, Blekas, & Paraskevopoulou, 2006). These works showed that both components and food structure may control flavor distribution and release from the different phases of food. The affinity of the volatiles for these phases as well as the nature and the amount of the dispersed phase (oil or water), the nature and the area of the oil–water interface and the type of emulsifier/stabilizer used a reconsidered to influence the aroma release from emulsified systems (Andriot, Harrison, Fournier, & Guichard, 2000; Rabe, Krings, & Berger, 2003; Karaïskou et al., 2008; Meynier, Lecoq, & Genot, 2005; Miettinen, Tuorila, Piironen, Vehkalahti, & Hyvönen, 2002; Seuvre et al., 2006; Doyen, Carey, Linforth, Marin, & Taylor, 2001; Van Ruth, de Vries, et al., 2002; Van Ruth, King, et al., 2002).

Polysaccharides are widely employed in the food industry due to their thickening, stabilizing and gelling properties in products such as salad creams, beverages and jellies. Polysaccharides influence the volatility of the molecules of the aroma compounds and their partitioning between different phases (Baines & Morris, 1987; Wilke & Chang, 1955). According to Baines and Morris (1987), the main effect of polysaccharides is an increase of the viscosity that hinders the process by which volatile molecules are brought from the interior of the sample to the surface. Roberts et al. (1996) found

Table 1
Composition of each medium.

Medium	Composition	
	TG (wt%)	Oleic acid (v/v, %)
A	0	0
B ₁	0.5	0
B ₂	1	0
B ₃	1.5	0
C ₁	0.5	5
C ₂	1	5
C ₃	1.5	5

that adding thickeners to a system disturbs the balance of the released flavour profile as viscosity increases.

Tragacanth gum (TG) is a dried exudation obtained from the stems and branches of an Asiatic species of *Astragalus* (Balaghi, Mohammadifar, & Zargaraan, 2010). It has been used as a stabilizer, emulsifier, and thickener in the food, pharmaceutical, and cosmetic industries (Samavati, Emam-Djomeh, Mohammadifar, Omid, & Mehdinia, 2011). Tragacanth is one of the most acid-resistant gums, as well as one of the most efficient natural emulsifiers for acidic oil-in-water emulsions (Weiping & Branwell, 2000). In this study Asiatic species of *Astragalus* (*A. rahensis*) has been used.

Lipids are the food ingredients that have been shown to have a great impact at the sensorial level because they are an excellent solvent for the aroma compounds: lipids decrease the vapour pressure of numerous volatile compounds and then influence the aromatic perceived profile (Guinard, Wee, McSunas, & Fritter, 2002; Widder & Fischer, 1996). Nevertheless the release of the aroma compounds depends also on their physicochemical characteristics such as polarity, hydrophobicity and solubility (Relkin, Fabre, & Guichard, 2004).

In the literature there are a lot of studies showing flavour compound behaviour with food components using simple matrices. However, studies with complex matrices are more complicated. The aim of the present work is the better understanding of these phenomena by studying the aroma release from model matrices consisting of Tragacanth gum (TG), oleic acid.

2. Materials and methods

2.1. Materials

Oleic acid (C₁₈H₃₄O₂, purity 65–88%, $\rho = 0.889\text{--}0.895\text{ kg/m}^3$) were purchased from Merck Company (Merck, shuchardt OHG 85662, Hohenbrunn, Germany). Tragacanth gum was obtained from Shaheed Beheshti Medical University (Tehran, Iran). Then, gums pulverized, sieved and the collected powders (mesh size 200–500) were used. Ethyl acetate and diacetyl were purchased from Merck company (Hohenbrunn, Germany).

2.2. Emulsion preparation

The continuous phase of emulsions was prepared by dissolving suitable amounts TG (0.5, 1, 1.5 wt%) powders into distilled water at 35 °C, followed by stirring for 30 min in 10 000 rpm to ensure complete dispersion. Then, solutions were kept 24 h at room temperature to allow full hydration. The O/W emulsions were obtained by slowly mixing oleic acid (5%, v/v) TG solutions; oleic acid/TG solution mixture was finally emulsified with stirring by Ultra Turrax (IKA T25 Digital, Germany) in 15 000 rpm for 10 min. Final matrices were 1-distilled water (medium A) taken as the reference medium, 2-carbohydrate matrices containing TG (medium B) and 3-complex matrices (oleic acid in water emulsions consist of TG and oleic acid (medium D)). The composition of each sample presented in Table 1.

2.3. Static head space analysis

The different emulsions were flavoured with the ethyl acetate (purity > 97%) and diacetyl (purity > 98%) (merck, shuchardt OHG 85662, Hohenbrunn, Germany) at concentration of 300 ppm. The two compounds were chosen because their hydrophobicity is different to each other. Ethyl acetate has lower water solubility and is more hydrophobic (higher *n*-octanol/water partition coefficient log *P*) than diacetyl.

Aroma compounds were analysed on an Agilent HP6890 series gas chromatograph equipped with PTV injector, an MPS-2 Multipurpose Sampler (Gerstel, Germany), a HP5973 MSD detector (Mass Selective Detector-Quadrupole type) and an EC-5 MS capillary column (50 m × 0.25 mm × 0.25 μm i.d.; coating thickness 0.25 μm). For equilibrium measurements the samples were incubated at 20 °C until thermodynamic equilibration of the samples (25 ml vials containing 10 ml of the flavoured model system) was reached. Preliminary experiments at different equilibrium times were conducted to ensure that the analysis for each sample was performed at equilibrium. A time period of 3 h was sufficient to reach equilibrium for each matrix and flavour compound. For kinetic measurements the samples (25 ml vials containing 10 ml of the flavoured model system) were incubated at 20 °C for 60, 120, 300, 600, 900, 1800, 3600, 5800, 7200 and 10 800 s and then head space analysis was done.

Peak areas obtained by static head space analysis were converted to concentrations using calibration curves. Linear correlation coefficients were found to range from 0.994 to 0.999 for both analytes. The mass partition coefficient between gaseous phase and matrix was calculated:

$$K_{\text{mass}} = \frac{C_g}{C_m}, \quad (1)$$

where *C_g* and *C_m* are, respectively, the flavour mass fractions (w/w) in the gas and in the matrix phase.

2.4. Viscosity measurements

The viscosity of suspensions was measured using of oscillatory rheometer (MCR 301, Anton Para Co. Germany) at 0.1–500 s^{−1}. Couette geometry with a cup (33.93 mm diameter) and a bob system (32.05 mm diameter, 33.29 mm length) was used. All measurements were performed in 20 °C. The power law equation allows the calculation of the consistency index *K* and the flow behaviour index *n*.

$$\text{Power-law model } \eta = k\dot{\gamma}^{n-1} \quad (2)$$

2.5. Statistical analysis

All the flavour released data were subjected to multivariate analysis of variance (MANOVA) and least significant difference Tukey test to determine significant differences between the different custards (SAS 9.1.3 software). A significance level of *P* < 0.05 was applied.

3. Results and discussion

3.1. Rheological investigation

The flow curves of various matrices have been plotted as a function of shear rate (Fig. 1). The viscosity-shear rate profiles obtained for all samples were similar; that is, each had a characteristic Newtonian plateau at low shear rate followed by a shear thinning region. The apparent viscosity at a given shear rate increased progressively with an increase in TG concentration from 0.5 to 1.5%. The

Table 2
Rheological characteristics of each medium (20 °C).

Rheological properties				
Medium	Viscosity ($\gamma = 1 \text{ s}^{-1}$) (Pa s)	Flow index (n)	Consistency index (K)	R^2
A ^a	0.0010	1.000	0.001	0.995
B ₁	0.0028	0.881	0.003	0.997
B ₂	0.0065	0.807	0.012	0.993
B ₃	0.0153	0.692	0.028	0.996
C ₁	0.0061	0.810	0.011	0.998
C ₂	0.0135	0.731	0.027	0.995
C ₃	0.0220	0.652	0.039	0.994

^a Keys for the matrices are in Table 1.

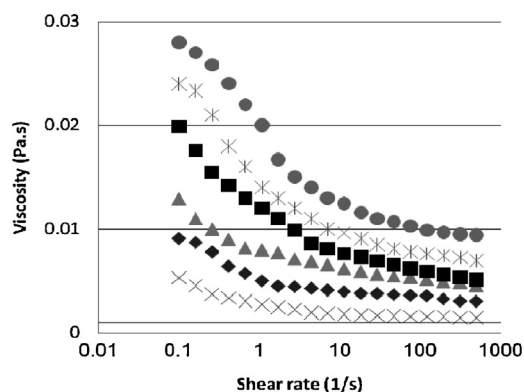


Fig. 1. Flow curves of various matrices.

deformation of the flocculated droplets could result in their becoming elongated and aligned with the shear field, which results in a reduction of the viscosity (Floury, Desrumaux, & Lardieres, 2000). Moreover, the apparent viscosity reaches a constant value at high shear stress, either because all of the flocs are completely disrupted so that only individual droplets remain or because the number of flocculated droplets remains constant since the rate of floc formation is equal to that of floc disruption (Campanella, Dorward, & Singh, 1995). This type of shear-thinning behaviour has been widely reported for suspensions containing rigid particles (Chanamai & McClements, 2000; Liu & Masliyah, 1996; Tadros, 1994) and for polydisperse emulsions (Campanella et al., 1995; Pal, 1996; Pal, Yan, & Masliyah, 1992).

As oil-phase volume fraction increased, low-shear viscosity increased and flow curves shifted upwards to higher viscosities due to the increase in the packing fraction of oil droplets. The viscosity of emulsions, at low shear rate, was greater than unity and increased with increasing the oil concentration.

Table 2 shows the parameters obtained with power law model for various matrices. The consistency index (K) value in power law model increased with increase in oil volume fraction and TG

Table 3
Partition coefficient ($K_{a/l}$) of flavour compounds between gaseous phase and different matrices (20 °C).

Medium	$K_{a/l}$	
	Diacytyl	Ethyl acetate
A [#]	0.077 ^a	0.094 ^a
B ₁	0.070 ^b	0.079 ^b
B ₂	0.062 ^c	0.069 ^c
B ₃	0.055 ^d	0.062 ^d
C ₁	0.065 ^b	0.068 ^c
C ₂	0.057 ^d	0.060 ^d
C ₃	0.051 ^e	0.055 ^e

a–b: For each column, same letters indicate no significant differences ($P < 0.05$).

[#] Keys for the matrices are in Table 1.

concentration, which indicated that increasing oleic acid volume fraction and TG concentration enhanced droplet interactions and the emulsions were more structured.

The flow behaviour index (n) decreased when oil volume fraction and TG concentration increased indicating a marked shear thinning effect at higher concentration of oil phase and TG with pronounced effect of TG concentration, which suggested that shear thinning behaviour was mainly due to the presence of TG.

3.2. Aroma retention measurement

3.2.1. Flavour partitioning at equilibrium

The percentage of retention ($R\%$) of each compound in the different matrices was determined using the following equation (Philippe et al., 2003):

$$R\% = \frac{K_{a/l}^{\text{water}} - K_{a/l}^{\text{matrix}}}{K_{a/l}^{\text{matrix}}} \times 100(\%) \quad (3)$$

According to Terta et al. (2006) any variation of $K_{a/l}^{\text{matrix}}$ with respect to the reference $K_{a/l}^{\text{water}}$ is an indication of interaction between the aroma compound and the matrix components. A positive percentage value indicates an aroma compound retained by the matrix and a negative value a compound released by the matrix. In this work all of the percentages of retention for both aroma compounds were positive values that indicated an aroma compound retention by the matrices. The partition coefficients (K_{mass}) of flavour compounds between gaseous phase and matrices for two aroma compounds are presented in Table 3. Ethyl acetate showed the higher retention in all matrices. The retention of both aroma compounds increased with TG concentration in carbohydrate and complex matrices (Figs. 2 and 3). The difference in retention between the two aroma compounds was attributed to their different physicochemical properties. Ethyl acetate is a non-polar compound ($\log P = 0.7$) whereas diacytyl is polar ($\log P = -1.5$).

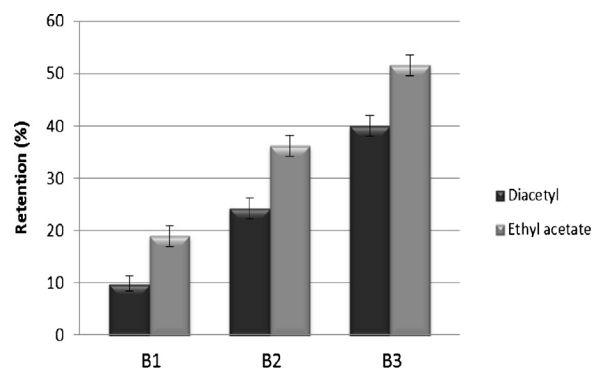


Fig. 2. Retention of diacytyl and ethyl acetate in carbohydrate matrix (20 °C) (B₁ = 0.5 wt% TG, B₂ = 0.5 wt% TG, B₃ = 1.5 wt% TG).

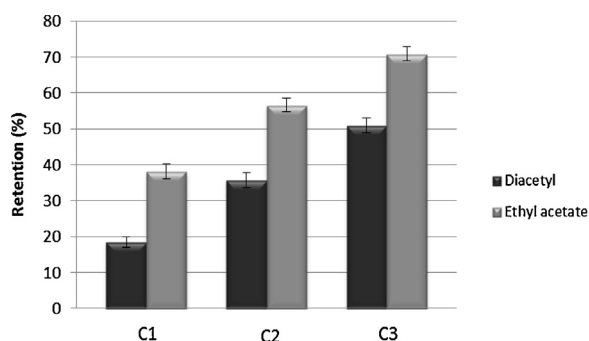


Fig. 3. Effect of complex matrices on the retention of diacetyl and ethyl acetate (20 °C) (C₁ = 0.5 wt% TG + 5% oleic acid, C₂ = 1 wt% TG + 5% oleic acid, C₃ = 1.5 wt% TG + 5% oleic acid).

According to Rosenberg, Kopelman, and Talmon (1990) and Terta et al. (2006), polar compounds are more soluble in water and can also diffuse more easily through the matrix, which can explain the significant lower retention of diacetyl from the matrices. Additionally, as many authors report, the higher relative volatility is, the lower the retention. It is reported that increase in hydrocolloid content influenced the diffusion of volatile molecules in the liquid phase probably through binding and/or physicochemical interactions between them and the hydrocolloids (Terta et al., 2006).

It also is explained by this fact that the two aroma compounds belong to different chemical groups should also play a role in their degree of retention from the matrices (Terta et al., 2006). Bylaite, Adler-Nissen, and Meyer (2005) have suggested that the ordered conformation of some hydrocolloids giving a structure may create a “hydrophobic cavity” which can entrap aroma compounds.

Different authors studied the release of various aroma compounds with various matrices and reported an effect of the viscosity on flavour release and perception (Carr et al., 1996; Yven, Guichard, Giboreau, & Roberts, 1998; Kalviainen, Roininen, & Tuorila, 2000).

To illustrate the effect of viscosity on retention of both aroma compounds the calculated percentage values of retention were plotted against increasing viscosity of matrices. Fig. 4 shows the effect of viscosity on both aroma compounds retention. The viscosity dependency of ethyl acetate retention is higher than that of diacetyl (Fig. 4). Both carbohydrate and complex matrices were more viscous than water and thus the diffusion of molecules was reduced. This effect was more important on the ethyl acetate. These results are in agreement with those reported by Roberts et al. (1996) who demonstrated that non-polar compounds were most affected by a change in viscosity.

In order to investigate the effect of the composition of the matrices and that of the rheological behaviour on the release and/or

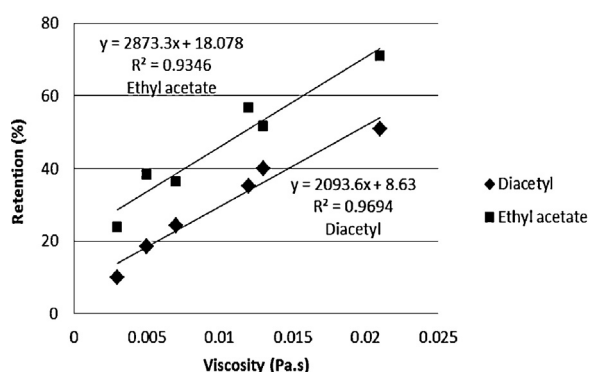


Fig. 4. Aroma retention of diacetyl and ethyl acetate as function of matrix viscosity at 20 °C at equilibrium condition.

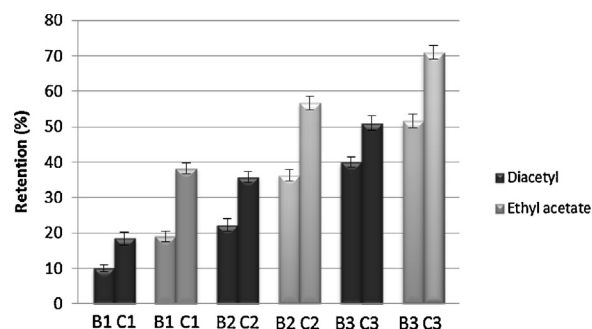


Fig. 5. Effect of oleic acid (v/v%) on the retention of diacetyl and ethyl acetate (20 °C) (B₁ = 0.5 wt% TG, B₂ = 1 wt% TG, B₃ = 1.5 wt% TG, C₁ = 0.5 wt% TG + 5% oleic acid, C₂ = 1 wt% TG + 5% oleic acid, C₃ = 1.5 wt% TG + 5% oleic acid).

the retention of aroma compounds, the two matrices have been developed having the same rheological behaviour (matrices B₂ and C₁).

As can be seen from Fig. 5, the degree of both aroma compounds retention in B₂ and C₁ matrices was not significantly different showing that the viscosity was the determinant for its retention in matrices. On the other hand, the equiviscous matrices of TG (1%, w/w) and TG/oleic acid mixture (TG 0.5% (w/w)/oleic acid 5%, v/v) exhibited the same aroma release. This observation revealed that diacetyl and ethyl acetate release behaviour, was strongly governed by steric interactions.

The presence of oleic acid in complex matrices resulted in higher retention of both aroma compounds. However, diacetyl is a polar compound and its interaction with oleic acid (a non-polar compound) is not considerable, but, its retention is affected by oleic acid in complex matrices. This effect could be explained by this fact that the viscosity of matrices is affected by the presence of oleic acid and increase in viscosity result in higher aroma retention. In general, the effect of matrices on retention of both aroma compounds is the combination of physical and chemical phenomena. Additionally, the viscosity enhancement with increasing TG and oleic acid concentrations decreases the diffusion rate of both aroma compounds through the interface of the solution.

3.2.2. Effect of carbohydrate on thermodynamic component

Partition coefficients ($K_{a/1}$) of both aroma compounds between gaseous phase and polysaccharide solutions were determined using Eqs. (1) and (2) (Table 3). For both aroma compounds, partition coefficient values were lower in the presence of TG (carbohydrate matrix) than in water alone.

The higher solubility of diacetyl explains its lower affinity for the gaseous phase and thus a lower partition coefficient ($K = 0.077 \pm 0.004$) compared to ethyl acetate ($K = 0.094 \pm 0.003$). The same tendency was reported by many investigators who observed that the polar compounds exhibited in their solutions lower partition coefficients than the less polar because of their greater water solubility (Seuvre et al., 2006) whereas air/liquid partition coefficient for pure water system increased for compounds possessing a longer carbon chain due to the increased hydrophobicity of the molecule (Andriot et al., 2000).

The formation of local hydrophobic zones may then be favoured by the over-lapping of high polymer chains, thus explaining the enhanced retention of aroma compounds through hydrophobic interactions. The formation of such hydrophobic zones was already proposed to explain the decrease of aroma compound volatility (α -pinene, ethyl-2-methyl butyrate, 1,8-cineole) in guar and carboxymethylcellulose solutions (Roberts et al., 1996).

3.2.3. Effect of oleic acid volume fraction on thermodynamic component

Oleic acid was implicated in the retention: the ratios increased with the hydrophobicity of aroma compounds, this effect of retention was observed before (De Roos, 1997; Piraprez, Herent, & Collin, 1997).

As Table 3 shows, the oleic acid significantly influenced the volatility of the two aroma compounds. Both compounds showed an increase in retention with increased oleic acid volume fraction, which was more pronounced in the case of the non-polar compound, ethyl acetate. The partition coefficient of ethyl acetate exhibited its highest value for water followed by the values for carbohydrate matrices (18–51% reduction) and complex matrices (31–40% reduction).

Likewise, the partition coefficient of diacetyl seemed to be greatest from water while a decrease of 10–29% and 19–51% was evident for carbohydrate and complex matrices, respectively. The hydrophobicity of the volatile molecules in addition to their solubility seems to be the key aspects for the equilibrium between the emulsion and the air phase. The observed effect of the lipid fraction is in accordance with other studies on a number of alcohols, ketones, esters, aldehydes etc., which demonstrated a profound effect of the lipid content of foods on aroma release (Karaïskou et al., 2008; Miettinen et al., 2002; Van Ruth, de Vries, et al., 2002; Van Ruth, King, et al., 2002).

The lipidic medium could induce a decrease of flavour compounds not only because of the affinity of aroma compounds for lipids but also because of the consistency of the lipidic medium (Seuvre et al., 2007).

The oleic acid had a significant influence on aroma release as with adding oleic acid (5%, v/v) in complex matrices the rates of release of both volatiles decreased (Table 3). This reduction was expected since oleic acid addition was accompanied by an increase in the viscosity of the matrices. The viscosity of the medium is an important parameter that influences the diffusion of volatile molecules since the Stokes–Einstein equation predicts that the diffusion is dependent on the square root of the viscosity. For diacetyl the effect of oleic acid was clearly observable with a mean decrease of 2.8–10% for all matrices containing oleic acid.

The effect of oleic acid on aroma release of both aroma compounds did not significantly increase with increase in TG concentration. The synergistic effect of oleic acid and TG on aroma release of diacetyl and ethyl acetate was not observed in this study. For example, this increasing effect was for matrix with 0.5% (w/w) TG (C₁) 8% and for matrix with 1.5% (w/w) TG (C₃) 10%.

3.3. Release kinetics of the aroma compounds

To study the influence of the nature of the aroma compound and the influence of the matrices on the kinetic of release, the K_{mass} kinetic curves were drawn (Fig. 6).

These measurements are realized in the three media (water, carbohydrate matrix and complex matrix). From water, the more hydrophobic aroma compound, ethyl acetate, presented the higher released quantity. The same order of quantities of released aroma compounds from the carbohydrate and complex matrices was observed. For the two compounds the effect of the complex matrix (containing oleic acid) was significant but with a greater retention for ethyl acetate.

By calculating the slope of initial part of the curves, information on the aroma compound diffusion through the liquid–gas interface can be obtained. The slope of initial parts of the release curves of ethyl acetate and diacetyl from matrices are displayed in Table 4. The determination coefficient (R^2) values were ranged from 0.98 to 0.99 indicating a good fit.

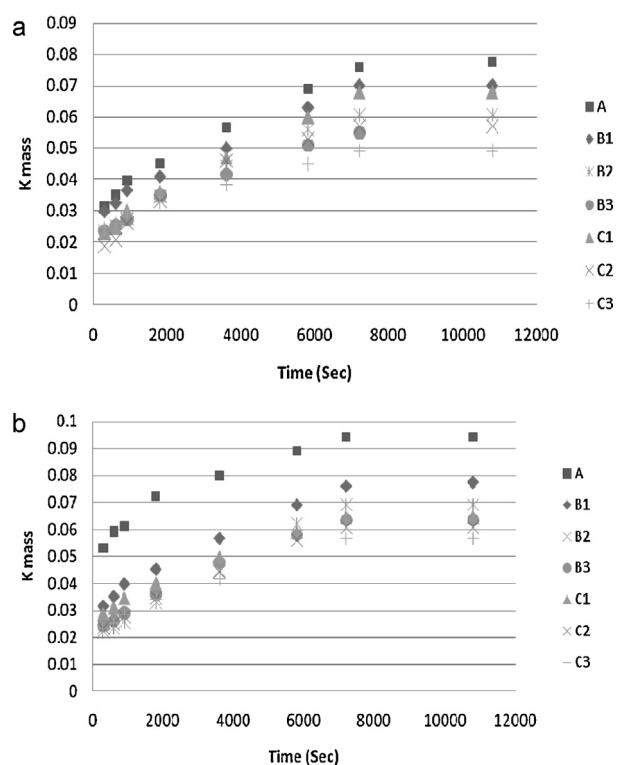


Fig. 6. Release of aroma compounds from various matrices at 20 °C: (a) ethyl acetate and (b) diacetyl. Release of aroma compounds from various matrices at 20 °C: (a) ethyl acetate, (b) diacetyl (A = distilled water without TG and oleic acid, B₁ = 0.5 wt% TG, B₂ = 1 wt% TG, B₃ = 1.5 wt% TG + 5% (v/v) oleic acid, C₁ = 0.5 wt% TG + 5% (v/v) oleic acid, C₂ = 1 wt% TG + 5% (v/v) oleic acid, C₃ = 1.5 wt% TG + 5% (v/v) oleic acid).

The behaviour of diacetyl was different from ethyl acetate. The release curves of diacetyl from water and from both the carbohydrate and complex matrices are nearer than that from release curves of ethyl acetate. Diacetyl has a great affinity for water (high water solubility) and a weak log P ($= -1.5$). The effect of oleic acid on this compound was not strongly marked.

Ethyl acetate presented the shorter equilibrium time whereas diacetyl took a long time to reach the equilibrium. The most hydrophilic compound (diacetyl) which presents affinity for the water molecules was the compound with the slower rate of release (R_i) and the faster equilibrium time. For the hydrophobic compound, the repulsion by the water molecules is immediate, from where a high initial apparent rate of release. But the release is progressive in time, thus the time to reach the equilibrium is longer. Similar results have been reported by Seuvre et al. (2007).

For diacetyl, when comparing the slopes of initial part of release curve for water and matrix containing only TG, a

Table 4

Slope values calculated from the initial part of the release curves of diacetyl and ethyl acetate in different matrices (20 °C).

Medium	Slope ($\times 10^{-3}$)	
	Diacetyl	Ethyl acetate
A [#]	0.191 $\pm$ 0.004 ^a	0.112 $\pm$ 0.006 ^a
B ₁	0.172 $\pm$ 0.005 ^{bc}	0.091 $\pm$ 0.005 ^{bc}
B ₂	0.163 $\pm$ 0.004 ^c	0.082 $\pm$ 0.004 ^c
B ₃	0.122 $\pm$ 0.003 ^d	0.073 $\pm$ 0.006 ^{cd}
C ₁	0.161 $\pm$ 0.003 ^c	0.081 $\pm$ 0.002 ^c
C ₂	0.132 $\pm$ 0.004 ^d	0.067 $\pm$ 0.005 ^d
C ₃	0.102 $\pm$ 0.003 ^e	0.044 $\pm$ 0.006 ^e

a–b: For each column, same letters indicate no significant differences ($P < 0.05$).

[#] Keys for the matrices are in Table 1.

significant decrease was observed while a further decrease following the addition of oleic acid was noticed. This could be explained by the presence of TG, which even at a low level induces a transition from a macromolecular solution to a structured system. This system affects the diffusion rate of diacetyl molecules and, consequently, the initial slopes of the release curve.

For the two compounds the effect of the complex matrix (containing oleic acid) was significant but with a greater retention for ethyl acetate. From experiments performed on matrices containing only TG, decrease of the slope of initial part of release curve was evidenced (11–48%), which was probably the result of hydrogen bond formation between the diacetyl and the matrix. Similar result was reported by Karaïskou et al. (2008).

Likewise, in compare with water the release rate of ethyl acetate was slower in carbohydrate matrices. Also, addition of oleic acid (5%, v/v) in carbohydrate matrix (C₁) resulted in a 22% slope decrease, which was further continued with increasing carbohydrate content to 67% for the maximum TG added matrix C₃. The equilibrium time of both aroma compounds were a little longer than those in water. These observations were partially in agreement with Haahr, Bredie, Stahnke, Jensen, and Refsgaard (2000).

4. Conclusions

The degree of retention of ethyl acetate and diacetyl in matrices containing increasing levels of TG or oleic acid was affected by their physicochemical characteristics and the nature and concentration of the hydrocolloid. For both matrices (carbohydrate and complex) the aroma compounds were retained but with a higher retention in complex matrix which contained oleic acid. Ethyl acetate was mostly affected by hydrocolloid addition. Two effects can influence their transfer to headspace. The first refers to the fact that retention of aroma compounds from matrices reduces their quantity, which is available for release in the gaseous phase. This lower concentration of available volatiles affects both the release rate, as well as their concentration in the headspace under equilibrium, as expressed by the partition coefficient. Additionally, the viscosity enhancement with increasing TG and oleic acid concentrations decreases the diffusion rate of both aroma compounds through the interface of the solution.

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