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INFLUENCE OF THERMODYNAMIC AND KINETIC FACTORS ON THE RETENTION AND RELEASE OF AROMA COMPOUNDS IN LIQUID FOOD SYSTEMS – A REVIEW

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Key words: aroma compound, thermodynamic and kinetic factors, partition coefficient, mass transfer coefficient

This paper briefly presents the main results of theoretical and empirical studies, found in available literature, that can be helpful for understanding physical and chemical stability of the aroma compounds in liquid food systems. As the main parameters, which affect retention and release rate of odorants, are reported thermodynamic and kinetic factors in relation to equilibrium partition coefficient between gas and liquid phases and mass transfer coefficient in gas and liquid phases. Moreover, the review introduces interactions between volatiles and basic food components *i.e.* lipids, proteins and carbohydrates as well as the influence of environmental factors such as: ionic strength, pH and temperature, on the volatility and release of odorants.

INTRODUCTION

Aroma compounds are low-molecular-weight organic food components (molecular mass <400 Da) with vapour pressures sufficiently high for these molecules to be partially present in the gas state [Wedzicha & Couet, 1996; Landy *et al*., 1996]. Volatile molecules responsible for aroma are perceived when they are directly sniffed by the nose or released into the mouth cavity during mastification and carried into the nose retronasally [Taylor *et al*., 2001; Giroux *et al*., 2007]. Only aroma compounds released in sufficiently high concentrations, above their detection thresholds, will be detected by olfactory receptors and even slight variation in the food composition can change the perceived flavour [Deibler *et al*., 2002; Boland *et al*., 2004]. In principle, food matrices are multicomponent, multiphasic and thermodynamically unstable colloidal dispersions, mostly composed of: liquid, solid and gaseous phases [Philippe *et al*., 2003; Seuvre *et al*., 2006]. Moreover, many natural and processed liquid foods exist either partly or wholly as emulsions or have been in an emulsified state at some time during their existence [Druaux & Voilley, 1997; Charles *et al*., 2000; Aguilera, 2005; Dalgleish, 2006]. Products in liquid state, affect retention and release of flavour compounds, due to different composition, microstructure and texture [Seuvre *et al*., 2000; van Ruth *et al*., 2002; de Roos, 2003; Giroux *et al*., 2007]. Moreover, the nature of the different non-volatile constituents *e.g*. proteins, lipids and carbohydrates, has a great impact on the quantity of aroma molecules released in the headspace [de Roos, 1997; Fisher & Widder, 1997; Godshall, 1997]. Furthermore, physicochemical properties of the flavour compounds *e.g*. molecular weight, molar volume, solubility and hydrophobicity as well as concentration of salts, pHs and temperature should be considered [Druaux & Voilley, 1997; Lubbers *et al*., 1998; Seuvre *et al*., 2006]. The aroma compounds are retained in the food matrix mainly due to chemical interactions *e.g*. hydrogen, hydrophobic, ionic or covalent bonding [Harrison & Hills, 1997; Reineccius, 2006]. On the other hand, food composition affects aroma release as flavour compounds may be dissolved, adsorbed, entrapped, encapsulated or diffusion limited by food constituents [van Ruth *et al*., 2000]. Besides, to understand better the phenomenon controlling aroma molecules release in complex media, the relationship between food composition and structure as well as texture has to be taken into account [Harrison *et al*., 1997; Seuvre *et al*., 2000; de Roos, 2003]. Many approaches to measure odorants release or retention in food products have been developed over the last 15 years. However, there is still a lack of sufficient studies which allow to identify all factors that affect physical and chemical stability of volatiles in food.

This article will review available theoretical and empirical studies concerning influence of liquid phase depending on its composition, texture and microstructure, on the retention and release of aroma compounds.

MAIN FACTORS AFFECTING ODORANTS RETENTION AND RELEASE

Foods usually contain ingredients exhibiting significantly differentiated physicochemical properties and also mostly vary with texture and microstructure [Druaux & Voilley, 1997; Aguilera, 2005; Dalgleish, 2006]. Moreover, odorants are representing different polarities, volatilities and other physicochemical properties [Reineccius, 2006; Seuvre *et al*., 2007].

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In addition, many of these characteristics may be changed when food is processed or stored for a long time in specific environmental conditions. The phenomenon of volatiles release and retention is extremely complex and therefore, there is a need to elucidate the main factors affecting these processes [Lubbers *et al*., 1998; Taylor *et al*., 2001]. De Roos [2003, 2006], Geary *et al*. [2004] and Terta *et al*. [2006] reported that there are two major parameters that control the rate of aroma release from foods, namely the volatility of the odorants in the product base (thermodynamic factor) and the resistance to mass transfer from product to air (kinetic factor). To evaluate influence of these factors on the quantity and release rate of odorants, static and dynamic headspace analyses have been developed [Kolb & Ettre, 1997; Haahr *et al*., 2000; Pigott & Schaschke, 2001]. Juteau *et al*. [2004] suggested that only static measurements allow a determination of thermodynamic and kinetic parameters with a good precision.

Thermodynamic factor

The vapour phase is in equilibrium with the liquid food system (product) if there is no effective mass transport at the product-air interface [Landy *et al*., 1996; Marin *et al*., 2000]. Under these conditions the partition coefficient (K_{GL}) is defined as the ratio of the concentration of the volatile in the gas phase to its concentration in the liquid phase and also is a measure of the volatility of the flavour compound in the product [de Roos, 1997; Nahon *et al*., 2000; Malone *et al*., 2000; Philippe *et al*., 2003]. The partition coefficient (K_{GL}) is given by:

$$K_{GL} = C_G / C_L \tag{1}$$

where: C_G and C_L, aroma compound concentrations in gas and liquid phases, respectively.

Kolb & Ettre [1997], Ebeler *et al*. [1988] and van Ruth *et al*. [2000] reported that in the so-called ideal dilute solution (usually <0.1%) when each dissolved analyte molecule is surrounded by solvent molecules, Henry's law prevails and, at equilibrium, the partial pressure of the aroma compound in the headspace is proportional to the odorant concentration in the liquid phase:

$$p_i = H \times x_i \tag{2}$$

where: p_i, partial pressure of the aroma compound; H, Henry's law constant; x_i, mole fraction of the aroma compound in the solution.

Moreover, Kolb & Ettre [1997], Marin *et al*. [2000] and Meynier *et al*. [2005] suggested that at given temperature the partition coefficient (K_{GL}) is proportional to the Henry's law constant (H) and that it depends on the food matrix composition and/or structure. The parameter K_{GL} is a fundamental value in gas chromatography in general, and also in headspace sampling.

In liquid food systems composed of aqueous and lipid phases, the distribution of the odorant over the oil and water phases after equilibration is given by the oil-water partition coefficient (K_{OW}) [de Roos, 1997; Harrison *et al*., 1997; Philippe *et al*., 2003; Seuvre *et al*., 2006]:

$$K_{OW} = C_O / C_W \tag{3}$$

where: C_O and C_W, aroma compound concentrations in oil and water phases, respectively.

The hydrophobicity is determined as the logarithm of the liquid-liquid partition coefficient (log *P*) generally, between octanol, oil or *n*-butanol and water [Brauss *et al*., 1999; Jouenne & Crouzet, 2000b]. The higher log *P* value, the more lipophillic (hydrophobic) is the aroma compound [Reineccius, 2006]. Leland [1997] reported that most flavour compounds are at least moderately lipophilic, and the lipophilicity increases with molecular weight within a homologous series. The non-volatile food constituents *e.g.* proteins, lipids and carbohydrates significantly influence on the retention of the flavour molecules [Druaux & Voilley, 1997; Seuvre *et al*., 2006; Giroux *et al*., 2007]. Lipids are part of many products and may act as a solvent of the majority of odorants and also modify microstructure and texture of food [Haahr *et al*., 2000; Roberts *et al*., 2003; Nongonierma *et al*., 2007]. The influence of oil concentration on the gas-emulsion partition coefficient has been demonstrated by Harrison *et al*. [1997]:

$$K_{GE} = K_{GC} / 1 + (K_{DC} - 1) \times \Phi_D \tag{4}$$

where: K_{GE}, K_{GC} and K_{DC}, equilibrium partition coefficients between: gas and emulsion phases, gas and continuous phases and dispersed and continuous phases, respectively; Φ_D, volume fraction of the dispersed phase.

Harrison *et al*. [1997] also suggested that Equation 4 predicts an identical value for K_{GE} irrespective of whether the emulsion is oil-in-water (o/w) or water-in-oil (w/o). Moreover, with the assumption that the release rate is proportional to partition coefficient (K_{GE}), Malone *et al*. [2000] in relation to o/w emulsion concluded, that decrease of the oil content (Φ_D) causes increase of K_{GE} and also release rate of lipophilic odorants ($K_{DC}>1$). Conversely, for hydrophilic volatiles ($K_{DC}\approx1$), K_{GE} is independent of Φ_D and the rate of release is unaffected [Miettinen *et al*., 2003]. However, further empirical studies showed that Equation 4 is limited because some of the significant physicochemical properties of emulsion *e.g.* surface area of the lipid-water interface, nature and amount of the surface active agents adsorbed at the interface were not considered [Malone *et al*., 2000; Charles *et al*., 2000; van Ruth *et al*., 2002; Meynier *et al*., 2005; Bortnowska, 2009]. Moreover, Relkin *et al*. [2004] demonstrated that not only hydrophobicity of the flavour compounds and fat content but also its nature may affect aroma molecules retention. Proteins are acknowledged to decrease the headspace concentration of aroma compounds in products [Guichard, 2006]. In o/w emulsion containing proteins and odorants, the interactions between these components can occur at the oil-water interface or in aqueous phase. Adsorption of the proteins at the interface can either mask the aroma binding sites or facilitate the access for flavour compounds to the binding sites of the proteins [Charles *et al*., 2000; Guichard & Langourieux., 2000]. In principle, two different types of interaction can occur: reversible physical adsorption *via* van der Waals interaction, and chemical reaction *via* covalent or electrostatic linkages [Fisher & Widder, 1997; Lubbers *et al*., 1998; Fabre *et* *al*., 2002]. Reineccius [2006] suggested that losses of odorants that will react with protein functional groups *e.g.* -OH, $-NH_2$ or –SH, may be very extensive. Besides, in homologous series, the aroma binding on proteins increases with the carbon content of the aroma compound *i.e.* with its higher hydrophobicity [Lubbers *et al*., 1998; Pelletier *et al*., 1998]. By contrast, carbohydrates are generally limited in their influence on headspace volatiles [Godshall, 1997; Seuvre *et al*., 2007]. Polysaccharides offer more possibilities for chemical interactions than the simple sugars due to the diversity of functional groups available [Godshall, 1997; Boland *et al*., 2006]. Reineccius [2006] showed that the backbone of polysaccharides generally affords little opportunity for chemical binding, on the other hand the side chains of some carbohydrates offer ionizable groups *e.g.* $SO_3^{=}$, COO^-, NH_4^+ as well as peptides or proteins. Secouard *et al*. [2003] reported that the specific binding interactions of odorants with polysaccharides are often the consequence of: adsorption, complexation leading to entrapment in microregions, encapsulation and hydrogen bonds. Godshall [1997] suggested that molecular inclusion is a stronger form of interaction that was found between aroma compounds and starches as well as cyclodextrins, yet reversible under mild conditions. Moreover, González-Tomás *et al*. [2004] considered, that also covalent bond formation and hydrophobic interactions between polysaccharides and odorants may occur. Aqueous phase may contain also molecules such as: ethanol, acids, inorganic salts and food can be stored or processed at different temperatures. In principle, adding an organic solvent *e.g.* ethanol to the medium increases solubility of the flavour compounds, rendering them less available for interactions [Lubbers *et al*., 1998]. Moreover, ethanol can also cause the loss of some aldehydes by acetal formation but this binding is reversible releasing ethanol and aldehyde again at acid pH [Leland, 1997]. Fischer & Widder [1997] reported that the presence of ethanol appears to trigger modifications in the protein conformation, reducing the number of accessible binding sites for aroma compounds. The inorganic salts can induce salting-out effect, which sometimes is exploited by flavour analysts for its ability to drive the volatile compounds into the gas phase [Kolb & Ettre, 1997; Leland, 1997]. Besides, the increase in protein solubility with an increase in ionic concentration induces a decrease in the binding of odorants [Lubbers *et al*., 1998; Guichard, 2006]. Aqueous acidic medium may change aroma compounds volatility because they in this medium may decompose as a result of acid-catalyzed hydratation and rearrangement reactions [de Roos, 1997; Leland, 1997]. Reineccius [2006] considered that volatility of the aroma compounds also depends on their chemical structure *e.g.* volatile acids at pHs below their pKa, being in the protonated form may be more abundant in the headspace. In contrast, odorants in the ionized form below their pKa *e.g.* amines or pyrazines, are more soluble in water and therefore exhibit less volatility. In addition, pH may also influence protein-aroma compounds interactions. Lubbers *et al*. [1998] reported that at a given pH, the ionization state of proteins differs with their isoelectric point, which causes conformational changes. The effects of pH on retention of aroma compounds by proteins have been shown by: Jouenne & Crouzet [2000a,b], Heng *et al*. [2004], Guichard & Langourieux [2000] and others. Guichard [2006] suggested that the results, regarding volatiles – proteins interactions, are often difficult to compare due to different protein batches and differences in experimental conditions. In principle, volatility of odorants increases with higher temperature of the system [Kolb & Ettre, 1997; de Roos, 2006]. Moreover, the rise in temperature leads also to significant changes regarding physicochemical properties of food ingredients *e.g.* an increase in the unfolding of the proteins can induce new binding sites or increase their accessibility for interactions with aroma compounds [Fisher & Widder, 1997; Lubbers *et al*., 1998]. Proteins and carbohydrates are biopolymers that lately have been used as fat mimetics [Akoh, 1998]. Knowledge of the effects of macromolecule flavour binding on the release rates could therefore assist in designing low-fat substitutes that give the same flavour release profiles as the original high-fat food. Harrison & Hills [1997] developed a mathematical model that describes flavour release from aqueous solutions containing flavour-binding polymers. This model was used to predict equilibrium partitioning properties of hydrophilic diacetyl and hydrophobic heptan-2-one as the function of the binding constants. These authors concluded that an increase of flavour-binder interactions resulted in a lower final headspace aroma concentration. The perceived flavour may also be affected by sorption, microencapsulation and crystallization. De Roos [2000] reported that in suspensions the same processes can in general take place as in solutions (odorants binding) and in emulsions (odorants absorption). The main difference is the rate of equilibration, which is often much slower in suspensions than in emulsions due to the low rate of diffusion in solids. Microencapsulation is the method that improves physical and chemical stability of odorants [de Roos, 2003; Reineccius, 2006]. The capsules (5-300 μm in diameter) used in foods, can be made of: sugars, gums, proteins, dextrins, starches and lipids [Soottitantawat *et al.* 2005; Aguilera, 2005]. Only the dry capsule wall protects sufficiently well the sensitive ingredients against adverse reactions and prevents the loss of volatiles [Druaux & Voilley, 1997; Loksuwan, 2007]. Regarding crystallization in the aqueous or lipid phase, de Roos [2000] reported that if this process takes place, the volumes available for phase partitioning become smaller (solutes are excluded from the crystal lattice) and as the consequence, equilibria will shift until the solute concentrations in the fluid parts of the phases are distributed according to the partition coefficients.

Kinetic factor

When the phase equilibria are disturbed by air flowing over the surface of the product, mass transport takes place from product to air in an attempt to restore the equilibria and it results in concentration gradients in the liquid and vapour phase [de Roos 2006]. De Roos [2003] and Aguilera [2005] suggested that according to the Fick's first law the rate of the unidirectional diffusion from the liquid to vapour phase is determined by the concentration gradients in each of these phases and by the respective mass transfer coefficients in the liquid and gas phase. The mass flux (J) in either phase is expressed by the following equations:

$$J_L = k_L \times (C_L^{\,i} - C_L) \qquad (5)$$

$$J_G = k_G \times (C_G - C_G^i) \quad (6)$$

where: J_L and J_G, mass fluxes in liquid and gas phases, respectively; k_L and k_G, mass transfer coefficients in liquid and gas phases, respectively; C_G^i and C_L^i, odorant concentrations at the interface in gas and liquid phases, respectively; C_G and C_L, odorant concentrations in gas and liquid phases, respectively.

Marin *et al.* [2000] and de Roos [2003] suggested that in general, mass transfer coefficient k determines the rate at which equilibrium can be achieved. The reciprocal of parameter k is defined as the resistance to mass transfer and in liquid phase is dependent on its texture and microstructure. De Roos [2000] reported that depending on the mechanism of mass transport, flavour compounds release can be described by: stagnant-film model, penetration theory and non-equilibrium partition model. The first model assumes that mass transport of volatiles through the boundary layers at the interface is by molecular diffusion as well as that the mass transfer coefficient $k_L = D_L/\delta_L$ varies with the first power of the diffusion coefficient (D_L) and the reciprocal of the effective thickness of the stagnant layer at the interface (δ_L). The second model is based on the assumption that mass transport of odorants is by eddy or during fixed time by molecular diffusion and predicts that mass transfer coefficient $k_L = 2(D_L/\pi\, t_e)^{1/2}$ varies with the square root of the diffusion coefficient. The penetration theory of interfacial mass transfer was applied by Harrison *et al.* [1997] to model flavour release from liquid emulsions with the assumption that the rate limiting step is the transfer of flavour compounds across the emulsion-gas interface. The mass flux (J_L) from a product across the interface is given by:

$$J_L = 2\,(D_L/\pi\, t_e)^{1/2} \times (C_L^i - C_L) \quad (7)$$

where: D_L, diffusion coefficient of odorant in the liquid phase; t_e, time that each surface element is exposed to the interface between liquid and gas phases; C_L^i and C_L, odorant concentrations in liquid phase at the interface and in liquid bulk phase, respectively.

The non-equilibrium partition model assumes that mass transport of volatiles takes place only by eddy diffusion. De Roos [2000] suggested that this model is mainly applicable to highly agitated systems where molecular diffusion is too slow to have a significant effect on flavour release and perception however, it was also applied to less agitated systems such as cake dough during baking. According to de Roos [2006] two different mechanisms of odorants diffusion may be considered by estimation of mass transfer coefficients. The first is eddy or convective diffusion which is completely independent of odorant type and size. The second diffusion mechanism is the molecular or static diffusion, which varies with the molecular size of aroma compounds. However, since odorants have similar size, the differences in molecular diffusion are also small. This author concluded, that the mass transfer coefficients (k_L) of aroma compounds in simple liquid and semi-solid monophasic systems do not differ much as long as no specific binding or absorption by food ingredients is taking place. Moreover, de Roos [2003] suggested that according to the stagnant-film and penetration theory models it is often assumed that the resistance in the product phase controls flavour compounds release and that the resistance in the gas phase can be neglected *i.e.* no concentration gradient in the gas phase. However, when the mass transfer coefficients in both phases are comparable *i.e.* differ by a factor of less than 10, the resistances in liquid and gas phases have to be taken into account. If the concentration gradients at the gas-liquid interface can be neglected, the mass flux through the bounduary layers (J) is the same at any distance from the interface [Marin *et al.*, 2000; de Roos, 2000]:

$$J = k_o \times (C_G - K_{GL} C_L) \quad (8)$$

where: k_o, overall mass transfer coefficient, calculated from the equation $1/k_o = 1/k_G + K_{GL}/k_L$; C_G and C_L, aroma compound concentrations in gas and liquid phases, respectively; K_{GL}, gas-liquid partition coefficient; k_G and k_L, mass transfer coefficients in gas and liquid phases, respectively.

Release of volatiles from liquids containing aroma-binding macromolecules was studied by Jouenne & Crouzet [2000a] and Guichard & Langourieux [2000]. Harrison & Hills [1997] developed a mathematical model, based on the assumptions that transport of volatiles across the gas-liquid interface can be described by the penetration theory of interfacial mass transfer and the rate of exchange of aroma compounds between the bond and unbound states is always at equilibrium and can be described by the first-order chemical kinetics. It was found, that increase of flavour-binder interactions led to decreased release rates of odorants however, the rate limiting step for volatiles release was not the chemical binding step but the transport of odorants across the liquid-gas interface. Yoshii *et al.* [2001] reported that incorporation of hydrophobic flavour compounds into powders by encapsulation provides their controlled release. It was suggested that with the empirically determined release characteristics of encapsulated volatiles, it is possible to estimate their storage period and controlled release application in food. The mass flux through hydrated capsule wall is given by de Roos [2003] as:

$$J_{HC} = k_{wall} \times (C_O / K_{OW} - C^o_W) \quad (9)$$

where: J_{HC}, mass flux through the hydrated capsule wall; K_{OW}, oil-water partition coefficient; k_{wall}, mass transport coefficient in the capsule wall; C_O and C^o_W, concentrations of the aroma compound in the oil and aqueous phase outside of the capsule wall, respectively.

Diffusion coefficient in the liquid and gas phase

The mass transfer coefficient is a function of the diffusivity [Harrison *et al.*, 1997; Nahon *et al.*, 2000; Reineccius, 2006]. The typical molecular diffusivities of small molecules are about 10^{-5} and 10^{-9} $m^2\,s^{-1}$ in the gas and aqueous phase, respectively. It indicates that the resistance to mass transfer is much higher in the liquid than in the gas phase [de Roos, 2000; Weel *et al.*, 2004]. The Wilke & Lee [1955] method was used by Seuvre *et al.* [2007] to calculate diffusion coefficients of volatiles in the vapour phase:

$$D_{A\text{-}B} = [3.03 \times (0.98 / M_{AB}^{0.5}) 10^{-3}\, T^{1.5} / P M_{AB}^{0.5} \sigma_{AB}^{\ 2} \Omega_D] \times 10^{-4} \quad (10)$$

where: $M_{AB} = 2\,[(1/M_A) + (1/M_B)]^{-1}$; M_A and M_B, molecular weight of solute A and solvent B, respectively; P, pressure;

T, temperature; σ_{AB}, characteristic length $=1.18\times V_A^{1/3}$; V_A, molar volume of solute A at its normal boiling temperature; Ω_D, collision coefficient (function of temperature and energy of molecular attraction).

Roberts *et al*. [1996], Piringer [2000] and Terta *et al*. [2006] suggested that the basis for estimating diffusion coefficients of volatiles in liquid systems is the Stokes-Einstein equation:

$$D = kT / 6\eta\pi a \qquad (11)$$

where: k, Boltzmann constant; T, temperature; η, viscosity and a, radius of the molecule.

According to this equation, even a small increase in viscosity, *e.g*. 2-3-fold, should result in a corresponding decrease in diffusion rate of odorants. However, Bylaite *et al.* [2003] did not observe any decrease in aroma diffusivity in pectin-thickened systems even though the viscosity was increased 1000-fold. These authors suggested that hydrocolloid was still very diluted and that the immobilized water was loosely bound, even at high "macroscopic" viscosities. The Stokes-Einstein equation was derived for special situation in which the solute is much larger than the solvent molecule. Nevertheless, many authors have used this form as a starting point in developing empirical predictions [Piringer, 2000]. Seuvre *et al*. [2007] reported that diffusion coefficient ($D_{A\text{-}B}$) of odorant in water phase can be calculated with the Wilke and Chang estimation method which is an empirical modification of the Stokes-Einstein relation:

$$D_{A\text{-}B} = 7.4 \times 10^{-12} \times (\varphi M_B)^{0.5} \times T / \eta_B V_A^{0.6} \qquad (12)$$

where: A, diffusing solute (flavour compound); B, solvent; M_B, molecular weight of solvent B; T, temperature; η_B, viscosity of B; V_A, molar volume of solute A at its normal boiling temperature; φ, association factor of solvent B.

Since experimental determination of the mutual liquid diffusion coefficients at infinite dilution is rather complicated, it is important to estimate the coefficients under various temperatures from one available coefficient at a certain temperature. Chaohong & Yongsheng [1997] suggested that the following equation can be applied:

$$D_{A\text{-}B}(T_2) / D_{A\text{-}B}(T_1) = \exp\left[B \times (1/T_1 - 1/T_2)\right] \qquad (13)$$

where: $D_{A\text{-}B}(T_2)$ and $D_{A\text{-}B}(T_1)$, diffusion coefficients at temperatures T_2 and T_1, respectively; B, parameter calculated by a group contribution method [Chaohong & Yongsheng, 1997].

The influence of temperature and viscosity of the medium on the diffusion coefficients of flavour compounds exhibiting different hydrophobicity was reported by Seuvre *et al.* [2007].

CONCLUSIONS

The most important problem in the researches regarding flavour stability, is understanding all factors that may affect retention and release of aroma compounds in products composed of typical food ingredients and exhibiting different texture and microstructure. It seems that the considered in this article thermodynamic and kinetic factors are in principle sufficient to determine volatility and release rate of flavour compounds. However, there is still a need to further study odorants behaviour in foods and more physicochemical properties of aroma molecules and matrices should be taken into consideration. Moreover, the relations found between composition, microstructure as well as texture of food and stability of the aroma compounds should be exploited in simplified mathematical models which could be applied by the preparation of food products exhibiting desirable by consumer odour intensity and profile.

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