Review Article
Factors affecting retention and release of flavour compounds in food carbohydrates

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Abstract: Much has been researched over many decades about the retention and release of flavour compound in foods. Nowadays, carbohydrates such as sugar and polysaccharide are also increasingly used in food industry in term of main product and food additive. Furthermore, polysaccharides are the most common matrices used to entrap flavour compounds. Many studies have shown that carbohydrates influence the retention and release of volatile flavour compounds. Thus, an understanding of behaviors of an interaction between food carbohydrates and flavour compounds is required for suitable flavour retention and release during processing and eating. It is useful to improve new food flavouring and develop new carriers for flavour encapsulation. In this review, flavour carbohydrate interactions are described. In addition, some factors affecting retention and release of flavour compounds in carbohydrates such as physicochemical properties of flavour compounds, type of carbohydrates and their concentration were reviewed.

Keywords: flavour, retention, release, carbohydrate

Introduction

At this moment, food flavour is of great interest because consumers are depending on better-tasting food. Typically, food aroma is an equilibrium mixture of aroma compounds. All aroma compounds are relatively small (< 400 Da), usually organic compounds (Landy *et al.,* 1996). The chemical structures of aroma compounds however vary widely; they include acids, neutral compounds, sulfur and nitrogen compounds, alcohols, aldehydes, ketones, hydrocarbons, and esters. The release of aroma compounds from foods is determined by the partition coefficient between the air phase and food matrix and, in the retronasal case, by the partition coefficient between the water phase (saliva) and the food matrix. If an aroma compound is added to the water matrix in a closed system and allowed to reach equilibrium, it will distribute between the air and water phases according to its air-to-water partition coefficient (de Roos, 1997).

When food is eaten, flavour molecules are released from the food into the mouth and the volatile flavour compounds pass back up through to nasopharynx into the nose. A sufficiently high concentration of flavour molecules has to be released from the

food to stimulate the olfactory system and elicit a response. Flavour retention and release depend on the nature and concentration of volatile compounds present in the food, as well on as their availability for perception as a result of interactions between the major components and the aroma compounds in food (Bakker *et al.,* 1996).

Of the major food constituents, carbohydrates have generally the greatest influence on aroma compound release and retention. Carbohydrates are widely used in the food industry as sweetener, thickeners, stabilizers and gelling agents in products such as ice cream, beverages, jellies and sauces. In recent years, due to increased health consciousness amongst consumers, carbohydrates are increasingly being extended into the area of reduced fat products. Therefore, the formulation of new food products containing carbohydrate has led to an increased demand for knowledge of their mechanical and physical properties, including the flavour release and retention properties of carbohydrate. Carbohydrates are also claimed to affect the release and retention of the flavour compounds. However, these effects depend on many factors such as the physicochemical characteristics of the aroma compounds, type of

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carbohydrates and concentration of carbohydrate (Boland *et al.,* 2004; Arvisenet *et al.,* 2002; Secouard *et al.,* 2003). The aim of this review is to describe factor affecting retention and release of flavour compound in carbohydrate matrixes.

Flavour

Flavour is the combination of taste and odour. It may be influenced by sensations of pain, heat and cold and by tactile sensations when food is consumed (The British Standards Institution, 1975). Flavour is principally perceived by taste receptors in the mouth and the aroma receptors in the nose. Generally, flavour compounds are divided into two classes: flavour compounds responsible for taste and those responsible for odour. Flavours are also complex as they can be volatile or non-volatile and represent many different chemical classes. The flavour compounds which arouse the taste perceptions must dissolve in the saliva before they can be perceived. As a result, they interact with taste receptors located in taste buds on the tongue. The sensitivity to the four tastes is shown to be differentially distributed across the tongue. Flavour compounds responsible for odour are volatile compounds which are perceived by the odour receptor sites of the smell organ such as the olfactory tissue of the nasal cavity. They reach the receptors when drawn to the nose (nasal detection) and via the throat after release by chewing (retronasal detection) (Fisher and Scott, 1997). However, only volatile flavour compounds will be stated in this review article.

Flavour property in food depends on both the nature of the foods and the flavour compounds present. Flavour delivery depends on the availability of the flavour compounds in the gas phase and, therefore, on the affinity of the flavour compounds for the food matrix. Various properties of the flavour compounds determine the interactions with food components such as molecular size, functional groups, shape and volatility. Properties such as molecular weight, vapour pressure, boiling point, octanol-water partition coefficient (log P) have been used to predict the volatility of the compounds under a static condition (Taylor, 2002).

Food-flavour interaction

Flavour-matrix interactions in food products have been widely investigated with respect to influences on flavour release and perception. Defining key matrix parameters that influence the release of flavour compounds from foods would provide useful information to control the flavour response of food products and allow for the effective use of flavour materials (Schober and Peterson, 2004). Food matrix components can bind, entrap or encapsulate volatile and nonvolatile flavour compounds if the "binding sites" of food components are still available. As a result, the interactions reduce the rate of flavour release and also affect the flavour intensity and quality of foods. This influences the consumer overall acceptance. The mechanism of binding between flavour compounds and food matrices can be classified into three categories (McGorrin, 1996) (1) Binding (Binding means the inclusion, adsorption, absorption and retention of flavour compounds onto nonvolatile substrates). (2) Partitioning (Partitioning means the distribution of flavour compounds between phase such as the oil, water and gas phases). (3) Release (Release means the availability of flavour compounds from the bulk foods into the gas phase for sensory perception). The type of interaction depends on the physicochemical properties of flavour compounds and food components. Flavour also changes with time and processing conditions. There are four main groups of flavour compound interactions in food matrices compounds (McGorrin, 1996; Solms *et al.,* 1973;; Le Thanh *et al.,* 1992), including (1) covalent bonding (this is irreversible bonding such as the interaction between aldehyde or ketone and amino group of proteins). (2) hydrogen bonding (this is occurs between polar or volatile alcohol and heteroatom (N,S,O) of food components) (3) hydrophobic bond (this is weak and reversible bonding such as van der Waals bond between apolar compounds and fat molecules). (4) physical binding (for example inclusion complexes, which occurs between flavour compounds and starch or starch derivatives)

Flavour carbohydrate interactions

Carbohydrates are divided into three categories: (1) monosaccharides, (2) oligosaccharides and (3) polysaccharides. Carbohydrates change the volatility of flavour compounds relative to water, but the effect depends on the interaction between the particular flavour and carbohydrate molecules (Godshall, 1997). Generally, mono- and disaccharide exhibit a salting out effect, which cause an increase in volatility of flavour relative to water. Voilley *et al* (1977) studied the change in concentrations of acetone and octanol in gas phase above aqueous solutions containing sucrose and found that sugar increases the vapour pressure of the volatile flavour compounds. Similar result was obtained by Marinos-Kouis and Saravacos

Table 1. Classification and properties of crystalline amylose-flavour complexes

Type of V-amylose	Example of ligands	General properties
V6I or Vh	Ethanol Decanol Hexanal Lactones	The small molecules could be entrapped only into the cavity of the helix. The thermostability of the complexes increases with increasing chain length of the ligand.
V6II or Vbutanol V6III or Visopropanol	Butanol Isopropanol	The molecule could be entrapped between helices (intra-inter helices inclusion).
	Thymol Menthone Linalool Ethyl hexanoate	The molecule could be entrapped between helices (intra-inter helices inclusion). Some studies proposed a sevenfold helix.
V8	α-Naphthol	Amylose complex with the largest helix diameter. The ligand is included in the helix and between helices. It allowed for the inclusion of bulky molecules.

Source: Adapted from Conde-Petit *et al.* (2006) and Jouquand *et al.* (2006)

(1975) cited in Godshall (1997) who found that higher volatility was obtained when higher concentrations of sucrose were added. Polysaccharides influence aroma release through vapour pressure reduction or by influencing mass transfer rate. Complex carbohydrates offer many more possibilities for chemical interaction than the simple sugar due to the diversity of functional groups available. In model systems, polysaccharides generally induce a reduction in aroma release caused by an increase in viscosity and/or by molecular interactions with flavour compounds. For polysaccharides especially, starch is the most common matrix used to entrap flavour due to its structure (Goubet *et al.,* 1998). In particular, its linear fraction, amylose, has the ability to form complexes with small ligands (such as fatty acids, emulsifiers, alcohols, ketones, aldehydes, phenols, benzene, hydrocarbon, iodine), known under the generic name of V amylose, with a variety of small ligands (Figure 1). The best-known and best described complex is Vh amylose, which is obtained with linear alcohols and monoacyl lipids. It consists of a sixfold left-handed helix repeating at 0.80 nm, in which the complexing agent is included. Complexes are the "combination of ligand and ligand induced helicated amylose", and the ligands can be included in the cavity of amylose helices or in interhelical spaces. It results from nonspecific interactions between the ligand and amylose. These complexes are reversible. They are formed during the gelatinization of starch or during the subsequent cooling. Hydrogen bonds are weakened during the gelatinization process. This complex is described as a helical inclusion complex with amylose forming a helix around the hydrophobic chain of flavour molecules while amylopectin binds with water. The hydrocarbon or lipophilic part of the flavour molecules can be retained in the hydrophobic regions inside the starch helix due to hydrogen atoms and the polar part of the flavour molecules are outside the helix due to the hydroxyl groups (Arvisenet *et al.,* 2002). Additionally, different starches can have different capacities due to the percentage of amylose content. Starch with high amylose content tends to bind greater amounts of flavour compounds.

Generally, six glucose units per turn are present in an amylose complex (V6). For V6 types, two trapping modes could be suggested: intra helices inclusion V6I and intra–inter helices inclusion V6II, V6III (I, II and III represent varying volume between helices in the crystalline stacking). For V6I, the small molecules could be entrapped only into the cavity of the helix and for V6II and V6III, the molecules could also be entrapped between helices. Characteristics X-ray diffraction patterns of V6I, V6II are shown in Figure 2(A) (Jouquand *et al.,* 2006). Bulky or branched ligands require a large cavity such as a conformational rearrangement of the amylose chain, which can lead to a helix with seven or eight glucose units per turn (Zaslow, 1963). Additionally, a large molecule such as phenolphthalein can be complexed by amylose when one phenyl ring of phenolphthalein is included into the amylose helix whereas the other two interact with the surface of the amylose helix (Kubik and Wuff, 1993). Some examples of flavour amylose complexes, formed with different number of glucose units per turn, are illustrated in Table 1. It seems to be a common aspect of these amylose complexes that expanded helices with a large diameters display a
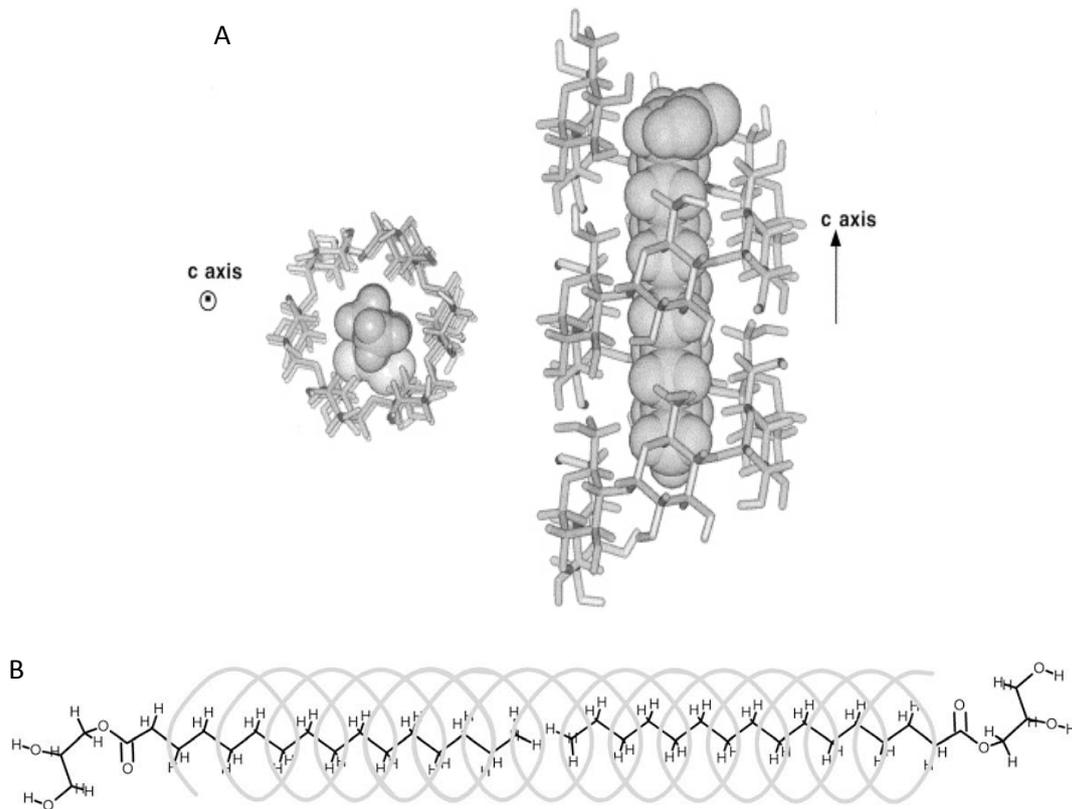
Figure 1. Molecular modelling representation of amylose–fatty acid complexes showing the inclusion of the aliphatic part (C12) of the fatty acid inside the hydrophobic cavity of the amylose single helix (A) and a complex of amylose with monopalmitin molecules (B) (Source: Buleon *et al.,*1998 and Copeland *et al.,* 2009)
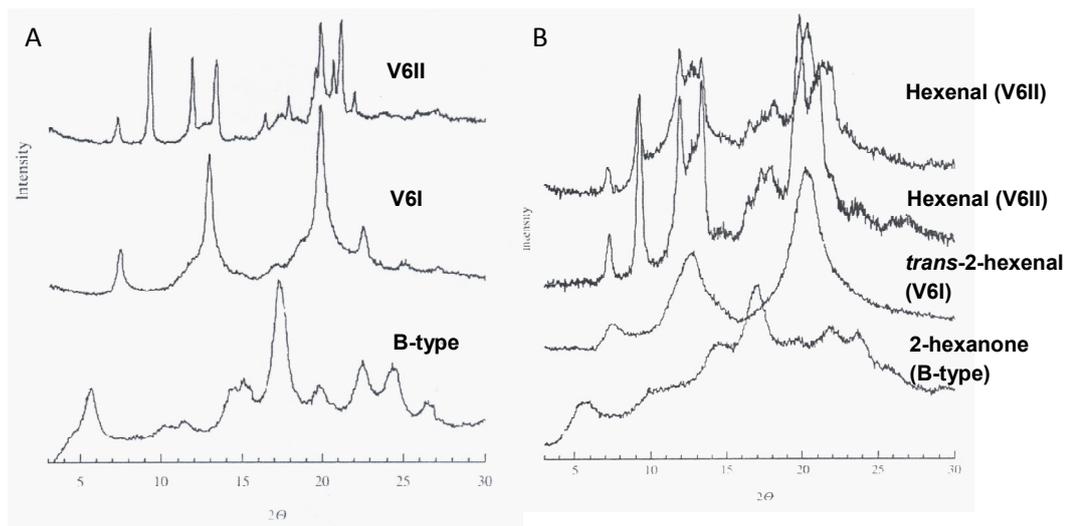

Figure 2. X-ray diffractogram of V6 structure (A) and amylose-flavour complexed (B) (Source: Jouquand *et al.,* 2006)

greater binding capacity (Solms and Guggenbuehl, 1990). However, this reason seems to be slow and not possible for amylose with less than 250 glucose units (Kubik and Wuff, 1993). Moreover, Polysaccharides, such as dextrins and gums, are known to interact with flavour compounds, and are used to stabilize flavours in food preparations (Taylor, 2002). Dextrin can reduce the activity coefficients of flavour compounds in water and, accordingly, gas/liquid partition coefficients. The binding is of hydrogen bond type, which results in competition of flavour compounds for the binding sites (Goubet *et al.,* 1998). Gums, such as xanthan and guar gum, are generally used as thickeners and also exhibit interactions with flavour compounds. The type of compound affects the extent of binding. As competition between flavour compounds with respect to binding to these gums has been observed, the binding mechanism is likely to be of a more general hydrogen bound nature (Taylor, 2002).

Factors affecting retention and release of flavour compounds in food carbohydrates

Flavour release from food matrix and the subsequent delivery of flavour to the olfactory and gestation receptors is greatly dependent on the type of food ingredients and physicochemical properties of flavour compounds (Goubet *et al.,* 1998; Terta *et al.,* 2006). Factors affecting retention and release of flavour compounds in food carbohydrate are depending on (1) physicochemical properties of flavour compounds (2) type of carbohydrates and (3) concentration of carbohydrates. All detail regarding to these factors effecting will be stated here.

Physicochemical properties of flavour compounds

When the same carbohydrate is used as a carrier, it has been observed that the retention rate varies according to the aroma compound encapsulated. This can lead to an unbalanced aroma (Goubet *et al.,* 1998). Several physicochemical characteristics of the volatile compound could partly explain these differences such as molecular weight, chemical group and polarity.

Molecular weight

Generally, high molecular weight flavour compounds will retain in carbohydrate martrix more than low molecular flavour compound. This behavior has been observed for esters spray-dried with gum arabic (Rosenberg *et al.,* 1990 cited in Goubet *et al.,* 1998). Several solid contents and concentrations of

ester were tested and ethyl hexanoate (MW = 144) was always better retained than ethyl butyrate (MW = 116). Furthermore, when stored at different relative humidities (range from 11 to 97%), ethyl hexanoate was always more efficiently entrapped than ethyl butyrate. The similar trend has been noticed for a mixture of 16 aroma compounds encapsulated on glucose, maltose, or corn syrup solids of 28.5 and 41.4 dextrose equivalent (DE, reducing power expressed as grams of glucose per 100 g of dry matter) (Voilley, 1995). The retention rate of isoamyl butyrate (MW = 158) or *n*-butyl- pentanoate (MW = 158) was higher than that of ethyl butyrate (MW = 116) or ethyl propionate (MW = 102) on all carriers, except on maltose and corn syrup solid (DE 28.5). On maltose, 24% of ethyl butyrate remained encapsulated against 23.5% for isoamyl butyrate. Whatever the carrier, the amount of ethyl butyrate (MW = 116) encapsulated was greater than that of ethyl propionate (MW = 102). Except for the two cases mentioned above, retention increased with the molecular weight of the aroma compound in the following order: ethyl propionate (MW = 102) < ethyl butyrate (MW = 116) < *n*-butyl pentanoate, isoamyl butyrate (MW = 158). These results could be explained by the greater ability of low molecular weight compounds to diffuse through the matrix during drying. Indeed, since the molecule is not linear, molecular weight and molecular size are linked and this latter is the primarily factor determining diffusion. When the molecular weight of the volatile flavour compounds and its molecular size increases, the slow diffusion rate is obtained. As a consequence the aroma compound does not reach the matrix surface as readily. Retention of high molecular weight flavorants is also favored (Goubet *et al.,* 1998; Reineccius, 1988).

Chain length

Chain length of flavour compounds is another factor that influence on retention and release of flavour compounds. Long chain length molecules will be retained more than short chain molecules. The 'Thijssen selective diffusion' theory can be applied in these cases. According to this theory, moisture continuous to evaporate (although at slower rate), while evaporation of longer molecular size volatiles are diffusion limited (Bhandari *et al.,* 2001). Maga and Kim (1990) found that flavour compounds of C6, C8 and C10 of alcohols, aldehydes and acids bound more to high amylose starch (55%) than to low amylose starch (20%). Furthermore they observed the increase in retention of flavours with increasing ligand chain length. Kim and Maga (1994) found that for C6, C8, C10 acids, alcohols and aldehydes,
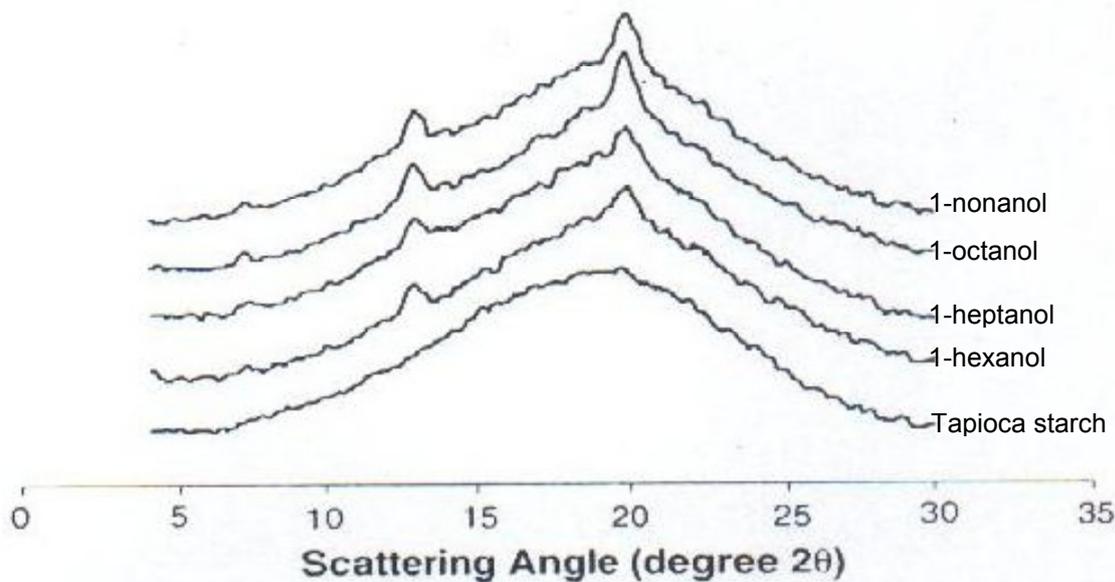
Figure 3. X-ray diffractogram of different tapioca-aliphatic alcohol complexes. (Source: Adapted from Itthisoponkul *et al.,* 2007)

retention increased with increasing chain length at three extrusion temperature conditions (115, 125 and 135°C), suggesting that lowering the chain length results in more flavour diffusion into the extrudate. In addition, Itthisoponkul *et al.* (2006) monitored inclusion complexes of tapioca starch with flavour compounds (primary alcohols having various chain lengths) were studied by X-ray diffraction. The flavour molecules, aliphatic alcohols containing between 6 and 10 carbons, were chosen to study the effect of chain length on complex formation with amylose. Freeze-dried tapioca starch dispersion without addition of flavour compounds served as a reference. The crystalline structure of tapioca-flavour complexes was characterized as shown in Figure 3. Crystallinity and complexing index (CI) were used to determine the degree of starch-flavour complexes. It was found that the X-ray diffraction patterns in the presence of aliphatic alcohols showed reflections at 7.6°, 13.1° and 20.1°. This scattering angles corresponding to those described for the Vh amylose, which is obtained with linear alcohols. Therefore, it can be assumed that the linear alcohol from 6 to 10 carbon atoms were included in the sixfold left-handed helix of amylose. Moreover, the percent of crystallinity was corresponding to the complexing index. The crystallinity and complexing index increased with increased chain length of alcohol. 1-Hexanol gives the lowest percent crystallinity and complexing index. On the other hand, 1-nonanol yields the highest percent crystallinity and complexing index. The crystallinity of 1-hexanol, 1-heptanol, 1-octanol and 1-nonanol is 4.57, 6.29, 7.45 and 7.85%, respectively.

Additionally, Bylaite *et al.* (2004) studied flavour release in λ-carageenan matrix. Flavour release was determined in λ-carageenen solution by static headspace gas chromatography in term of air partition coefficient (K_{aw}). Aroma compounds such as aldehydes, esters, ketones and alcohols were used in this study. The results revealed that K_{aw} increased with increasing C number in molecules within each homologous series. The partition and release of 21 aroma compounds (alcohols, aldehydes, ketones and esters) were evaluated in pectin gel as studied by Hansson *et al.* (2003). It was found that K_{aw} tended to decrease when the longer carbon chain was obtained. Boland *et al.* (2006) studied flavour release (different chain length of esters) in pectin gel. It was revealed that as the chain length of esters increased (ethyl iso-pentanoate C-7, ethyl hexanoate C-8, cis-3-hexenyl acetate C-8, methyl anthranilate C-8, benzyl acetate C-9, styrallyl acetate C-10), there was a decrease in the air/gel partition coefficients. These data show the higher affinity of larger, more hydrophobic flavour compounds for the gel matrices. This can be due to binding/trapping of the flavour compounds.

Chemical groups

Comparison of the retention of several classes of aroma compounds, published by different authors (Rosenberg *et al.,* 1990; Le Thanh *et al.,* 1992; Voilley, 1995;). Among the chemical functions reviewed, alcohols are usually the best retained compounds by carbohydrates they can easily from glycosidic linkage with carbohydrate (Goubet *et al.,*

1998). Propanol and 1-hexanol have been shown to be better sorbed on β-cyclodextrins than diacetyl (a diketone) and ethyl acetate (an ester) (Le Thanh *et al.,* 1992). A mixture containing these aroma compounds was sorbed on β-cyclodextrins. It was observed that 2-propanol and 1-hexanol represented respectively 12 and 9% of the total of the volatiles sorbed, whereas diacetyl and ethyl acetate represented respectively 7 and 5% of the total amount of volatiles (Le Thanh *et al.,* 1992). Kim and Maga (1994) studied the retention of volatile compounds, with varying chemical group (acids, aldehydes and alcohols), in high amylose starch during extrusion. Total retention was the greatest for alcohols and lowest for aldehydes. In another study, benzylic alcohol has been shown to be the most retained volatile during the freeze-drying of glucose, maltose, or corn syrup solids (DE 28.5 and DE 41.4) flavored with a mixture of 16 flavour volatile compounds (Voilley, 1995). The retention rate of benzylic alcohol varied between 45 and 83%, depending on the carrier considered, but was always higher than those of the four esters (ethyl propionate, ethyl butyrate, isoamyl butyrate, and n-butyl pentanoate), which varied between 0.5 and 49.5%, or those of the three acids (butyric, caproic, and lactic acids), which were lower than 7%. The same trend, a higher retention of alcohols than other compounds, has also been observed when encapsulating a mixture of 10 volatiles in β-cyclodextrins. Linalool was the most retained compound among the mixture including five esters, two aldehydes, β-decalactone and butyric acid (Fleuriot, 1991 cited in Goubet *et al.,* 1998). Its retention rate, expressed as the amount of encapsulated compound on the added amount, was equal to 44%, whereas those of the other compounds were lower than 33%. A decreasing retention rate in the order alcohol (eugenol) > aldehyde (cinnamaldehyde) > ketone (3-octanone) > acid (nonanoic acid) has been also reported in β-cyclodextrins-complexed (Anantha and Milford, 1997). It was found that ketones seem to be less retained than alcohols, similarly to esters and more efficiently than acids. In another study it has been shown that more octanol (81%) and octenol (61%) than octanone (46%) were encapsulated in freeze-dried of maltodextrins (DE 10) (Bangs and Reineccius, 1981). It can be noticed that ketone was less retained than alcohols. These results are in agreement with those obtained by Maier (1972). The sorption of ketones by various food components, including carbohydrates, was lower than those of alcohols of comparable chain length. Jouquand *et al.* (2006) studied the retention of C6-aroma compounds with amylose complexes in starch dispersions. Four aroma compounds including hexanol, 2-hexanone, t-2-hexenal and hexanal were

used to studied. It was found that 2-hexanol, hexanal showed X-ray diffractogram that characterized for V6II and trans-2-hexenal showed V6I as shown in Figure 2(B). However, 2-hexanone presented B-type starch diffractogram, which showed that 2-hexanone did not from complex with amylose. For these four compounds, the chemical function had an impact on the formation of the V type of amylose. It seems that the ketone function was able to prevent the formation of complexes with amylose. Moreover, potato starch was also studied. The X-ray diffractogram obtained without aroma compounds showed the characteristic of the B type. In the presence of 2-hexanone, the X-ray diffraction diffractogram also showed B-type indicating that ketone can not form complex with potato starch, whereas hexanol and hexanal appear to be of the V6II type. The X-ray diffractogram of potato starch-trans-2-hexenal complex displayed an amorphous spectrum with traces of V6I type amylose. Bylaite *et al.* (2004) studied influence of λ-carageenan on the release of volatile flavour compound (aldehydes, ketones, esters and alcohols). Flavour release was determined by air-water partition coefficient (K_{aw}). Among homologous series, esters showed the highest volatility, followed by aldehydes, ketones, with alcohols as the least volatile series. These finding are in agreement with the studies by Buttery *et al.* (1969) who also reported esters and aliphatic aldehydes to be the most volatile substance class, with methyl ketone, and alcohols the least volatile. Moreover, Bylaite *et al.* (2004) found that Kaw depends on the presence of functional groups and also influenced by the position of functional group in a molecule. Aldehydes with a $-CH_3$ group (methylalkanals) were more volatile than those with a straight chain (alkanals). Ketones with functional keto group at the third position within the molecule (3-pentanone, 3-heptanone, 3-nonanone) had higher K_{aw} than those having a keto group at the second carbon atom (2-pentanone, 2-heptanone, 2-nonanone). The volatility of ketones was significantly suppressed when two keto groups were present in the molecule such as the series of 2,3-alkanedione less volatile than the 2-alkanones.

Log P or Hydrophobicity of flavour compounds

Log P or logarithm of octanol water coefficient indicates the relative hydrophobicity (positive value)/ hydrophilicity (negative value) of compound. The octanol-water partition coefficient is a measure of the equilibrium concentration of a compound between octanol and water that indicates the potential for partitioning into organic matter (a high octanol-water

partition coefficient indicates a compound which will preferentially partition into organic matter rather than water). The octanol-water partition coefficient is inversely related to the solubility of a compound in water. Therefore, Log P of flavour compounds indicates the hydrophobic properties (Taylor, 1998). The hydrophobicity of aroma compound is another factor that affecting retention and release of flavour compounds. The retention of polar (hydrophilic) volatiles is expected to be very low. The greater solubility of polar compounds in water results in higher diffusivity through the matrix compared with nonpolar compounds (Bhandari *et al.,* 2001). Terta *et al.* (2006) studied the retention of aroma compounds by gum arabic and propylene glycol alginate solutions. Partitioning and release of limonene and trans-2-hexenal from gum arabic and propylene glycol alginate solutions were studied by applying static headspace gas chromatography. The difference in retention between the two aroma compounds was attributed to their different physicochemical properties. Limonene is a non polar compound (log P = 4.57) whereas trans-2-hexenal is quite polar (log P = 1.58). It was found that limonene presented higher retention than trans-2-hexenal. Polar compounds are more soluble in water and can also diffuse more easily through the matrix, which can explain the significant lower retention of trans-2-hexenal from the aqueous polysaccharide solutions (Rosenberg *et al.,*1990). Moreover, Juteau *et al.* (2004) studied flavour release from ι-carrageenan matrixes by static headspace analysis. Ethyl butanoate (Log P = 1.70) and ethyl hexanoate (Log P = 2.83) were used as aroma compounds. It was found that ethyl butanoate has a higher solubility and a lower log P value than ethyl hexanoate. The loss of ethyl hexanoate was significantly greater in water (29.8%) than in gels (6.2%). The same tendency, but non significant, was observed with ethyl butanoate (9.9% in water and 7.3% in gels). The differences between ethyl hexanoate and ethyl butanoate can be explained by a higher hydrophobicity and a lower solubility of the former.

Type of carbohydrates

Many studied have shown that polysaccharides influence the rate and intensity of flavour release in foods. The influence on retention and release of flavour compounds related to types of carbohydrates and polysaccharides. Interaction between flavour compounds and polysaccharides play an important role in the flavour perception of food products and consequently their acceptability to consumers. Thus, a fundamental understanding of aroma-starch
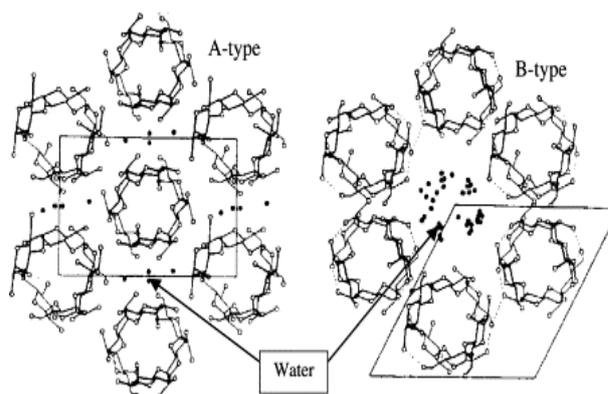

Figure 4. Crystalline packing of double helices in A-type and B-type of amylose (Source: Walter, 1998)

interactions is useful to improve food flavouring and to develop new carriers for flavour encapsulation.

Starch is widely used in food matrices for its textural properties. The ability of amylose to interact with certain ligands, particularly aroma compounds, has been known for a long time. The different types of diffraction patterns of starch are labelled in terms of A, B and C. A and B patterns can be obtained from cereal and tuber starches, respectively. C-pattern is though to be a mixture of A and B patterns and found in tuber and legume seed starches. The packing of double helices within the A-type polymorphic (crystalline) structure is relatively compact with low water content, whilst the B-type polymorph has a more open structure containing a hydrated helical core. In the A-type structure, the double helices are packed in a monoclinic unit cell with eight water molecule per unit. In the B-type structure, double helices are packed in a hexagonal unit cell with 36 water molecule per unit cell (Biliaderis, 1998) (Figure 4). Therefore, A- type starch can bind water or ligand less than B-type starch. Type of starch also influenced flavour retention and release as reported by Jouquand *et al.* (2006) who studied the retention of C6-aroma compounds with corn and potato starches dispersions. Four aroma compounds including to hexanol, 2-hexanone, trans-2-hexenal and hexanal were used in this studied. Flavour retention seemed to be slightly lower for corn starch dispersions. This phenomenon may due to different of starch types. Corn starch and potato starch is A and B type starch, respectively. During processing, flavour compound can entrap in B type starch much more than A type starch as indicated by the retention of flavour compound in potato starch higher than corn starch. Arvisenet *et al.* (2002) studied the retention of flavour compounds in different starches including corn starch, waxy corn starch, amylose rich corn starch and cross-linked corn starch. Ethyl hexanoate, linalool and isoamy acetate were used as aroma compounds.

Aroma retention is about 20 to 30% less in waxy corn starch matrices than in amylose-containing matrices. Indeed, the external branches of amylopectin have the same structure as amylose, and they could be able to interact in the same way with small ligands. This would be all the more possible if linalool and ethyl hexanoate interact at helices surface. Some evidence suggests that small molecules such as lipids and flavours can interact with amylopectin as well as amylose. Huang and White (1993) suggested that the interaction between lipid and amylopectin depends on the conditions for preparing the complexes and the sources of amylopectin used. Studies on the interaction between lipid-amylopectin and flavour-amylopectin have been also reported. Several researches have shown some evidence to support the presence of lipid-amylopectin and flavour-amylopectin complexes. Lagendijk and Penning (1970) reported the complex formation between potato amylopectin and various monoglyceride and also stated that the amount of complexation increased linearly with increasing monoglyceride chain length. Similar results were obtained by Huang and White (1993) who found that the amylopectin from waxy corn starch was complexed with monoglycerides (such as monolaurin, monomyristin, monoplamitin and monosterin). Moreover, for all aroma compounds, the retention is significantly higher in modified waxy corn starch matrices (cross-linked starch) than in unmodified waxy starch matrices. This could be caused by an interaction between aroma compounds and the chains added by chemical modifications, or to the effect of the modifications on the texture. This can be particularly interesting, because chemical modifications are generally used to modify textural properties of starch-based products. They could also be used to influence the retention of aroma compounds.

Concentration of carbohydrates

The texture or consistency of industrially liquid foods is often controlled by the used of carbohydrate thickeners. The concentration of carbohydrates affect on viscosity of system and effect on retention and release of flavour compound. Several solute parameters affect the viscosity: molecular weight, molecular weight distribution, degree of hydration, extent of intramolecular interaction and intermolecular interaction. Diffusion of flavour molecules is reduced as solution viscosity increases. The volatility of a flavour molecule may also be affected by the formation of barriers occurring in high-viscosity matrices and by specific binding interactions with the thickener.

Binding interactions with carbohydrate-based thickeners are often due to adsorption, entrapment in microregions, complexation, encapsulation, and hydrogen bonding (Kinsella, 1989). Hansson *et al.* (2001) studied the effect of sugars on flavour release from soft drink-related model system. The effect of concentration of sugars were investigated by adding different concentrations of sucrose (5, 10, 20, 40 and 60% w/w) and glucose syrup (DE 40, glucose 15% w/w, maltose 12.3% w/w, maltotriose 9.2% w/w, higher sugars 48% w/w) (5, 10, 20, 40 and 60% w/w) to the soft drink model system. An increase in the concentration of sucrose (from 20 to 60% w/w) was shown to signifcantly increase the release of isopenthyl acetate, ethyl hexanoate, *cis*-3-hexenyl acetate, linalool and L-menthone to the gas phase above the soft drink. This was probably due to a ``salting-out'' effect of sucrose (Voilley *et al.,* 1977) whereby sucrose interacts with water, increasing the concentration of flavour compounds in the remaining ``free'' water. There was, however, no signifcant change in the release of limonene in response to the increased sucrose concentration. The release of limonene was high, irrespective of the sucrose concentration, because of the strongly non-polar nature of this compound. To define the hydrophobicity of a flavour compound, log P-values can be used, with negative values indicating hydrophilic compounds. Glucose syrup at a concentration of 60% w/w was shown to significantly increase the release of ethyl hexanoate, L-menthone and *cis*-3-hexenyl acetate. Likewise, linalool had a tendency to be released at raised levels if 60% glucose syrup was added; however, neither isopenthyl acetate nor limonene was affected by the addition of glucose syrup. Glucose syrup is formed by hydrolysis of starch and contains larger molecules than does sucrose. Therefore, it has fewer binding sites for water when used at the same concentration as sucrose. More free water is thus available, decreasing the concentration of the flavour molecules in the water, reducing the release to the gas phase. Secouard *et al.* (2003) studied the release of limonene and menthol from different xanthan concentration solutions (0-0.5%). It indicates that limonene release largely depends on the xanthan concentration regime (Cuvelier and Launay, 1986). Initially, xanthan concentration remains lower than the critical overlapping concentration (0-0.03%), there was no significant difference between limonene release from xanthan-containing matrices and that of pure water. The explanation may be that, in the dilute regime, wherein macromolecules were isolated from each other, limonene behaviour remained constant when interactions between the polymer species remained

negligible. In addition, at higher polysaccharide concentrations (0.03-0.1%), corresponding to the semi-dilute regime wherein the polymer chains begin to overlap, limonene release significantly decreased, thus indicating that limonene was mainly retained by the xanthan solution through steric phenomena. When the concentrated regime approximately 0.1% was reached, the release decreased less and less and tended to a constant value with a limit corresponding to the maximum level of limonene retention in the media (about 50% of relative release in the present case). Xanthan has a more distinctive hydrophobic character compared to other hydrocolloids, and this may influence flavor release. Xanthan consists of a cellulose backbone with ionized trisaccharide branches on every second. In the ordered conformation, the side chains fold back around the main chain to give a structure analogous to a double helix. In this conformation the ordered molecule is stabilized through hydrogen bonds by non-covalent side chain-main chain interactions involving hydrogen bonding. In this way, the configuration of xanthan may create a hydrophobic interior in the carbohydrate molecule, which can ''include'' flavor compounds. Hansson *et al.* (2003) studied flavour release in pectin gel. Each gel was produced by different concentration of pectin (1.5-2% pectin) and white syrup (34% sucrose, 24% glucose, 22% fructose, and 20% water). As concentration of pectin increased, the gel strength increased. According to the results most of the aroma compounds showed significantly higher air/gel partition coefficients from weaker gel compared to that from a stronger gel. The air/gel partition of the aroma compounds was probably influenced by two mechanisms; one by addition of sucrose "salting out" or retention depending on the polarity of the aroma compound and one from the pectin that retained the molecules in the network either by sterical hindrance or by formation of nonpolar micelles.

Conclusion

The used of carbohydrate in food industry has increased significantly. These compounds are highly recommended for application in food processing and as food additive. However, the use of carbohydrates may induce a significant decrease in flavour perception and/or release as reported in previous studies. Moreover, even when used at low concentrations, carbohydrates not only can change the structure and texture of product, but also lead to modification of flavour profile and/or perception. To optimize product quality, it is important to understand factor affecting retention and release of flavour compound on carbohydrates. Some factors affecting on the retention and release of volatile flavour compounds by carbohydrates are depending on physicochemical properties of flavour compounds, type of carbohydrates and their concentrations. Firstly, high molecular weight flavour compounds tend to retain in carbohydrate than low molecular weight flavour compounds. Additionally, long linear chain length molecules will be retained in polysaccharide matrix higher than short chain molecules or aromatic one. Among the volatile flavour compounds such as alcohol, aldehyde, ester and ketone, alcohol are usually the best retained in carbohydrates. The retention of polar (hydrophilic) volatiles flavour compounds is expected to be very low in carbohydrates complex which indicate in terms of log P. The second factor is depending on type of carbohydrates. Each type of carbohydrate presents different structure that influence on the interaction between flavour compounds and its structure and also the retention and release. Thirdly, the concentration of carbohydrates generally shows that an increase in the concentration of sugar is proportional of the release of flavour compounds due to the salting out effect. On the other hand, an increase in polysaccharide concentration leads to a decrease the release of flavour compounds due to complexation and viscosity effect of that polysaccharide themselves. Therefore, this knowledge can be used to optimize product quality in term of flavour retention during preparation or processing and its release during eating.

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