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Abstract Beer phenols issued from malt and hop can contribute directly to several characteristics of beer, mainly flavor, astringency, haze, body, and fullness. Some phenolic structures can also impart very interesting health properties. Yet phenolic structures also evolve through storage. Low-molecular-weight phenols like 4-vinylsyringol can impart off-flavors in aged beer, while oxidized flavonoids strongly influence astringency, haze, and color. The instability of stilbenes, prenylchalcones, and derived flavanones could also modify their health potential.

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Keywords Aging - beer - brewing process - colloidal stability - flavor -  
(separated by “-”) polyphenols

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# 1 Polyphenols and Beer Quality

# 78

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## 22 Abstract

23 Beer phenols issued from malt and hop can contribute directly to several  
24 characteristics of beer, mainly flavor, astringency, haze, body, and fullness.  
25 Some phenolic structures can also impart very interesting health properties.  
26 Yet phenolic structures also evolve through storage. Low-molecular-weight  
27 phenols like 4-vinylsyringol can impart off-flavors in aged beer, while oxidized

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28 flavonoids strongly influence astringency, haze, and color. The instability of  
29 stilbenes, prenylchalcones, and derived flavanones could also modify their  
30 health potential.

---

### 31 **Keywords**

32 Aging • beer • brewing process • colloidal stability • flavor • polyphenols

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### 33 **Abbreviations**

34	AEDA	Aroma extract dilution analysis
35	APCI	Atmospheric-pressure chemical ionization
36	C	Catechin
37	E	Epicatechin
38	EGC and GC	Epigallocatechin and galocatechin
39	ESI	Electrospray ionization
40	FD	Dilution factor
41	HPLC or LC	High-performance liquid chromatography
42	MS	Mass spectroscopy
43	MS/MS	Tandem mass spectroscopy
44	NP	Normal phase
45	P1 to P10	Procyanidins from monomers to decamers
46	PVP	Polyvinylpyrrolidone
47	PVPP	Polyvinylpolypyrrolidone
48	RP	Reversed phase
49	UV	Ultraviolet

---

## 50 **1 Introduction**

51 Beer phenols issued from malt and hop can contribute directly to several charac-  
52 teristics of beer, mainly color, flavor, astringency, and haze. As antioxidants, they  
53 can also protect raw materials from oxidative degradation throughout the process,  
54 minimizing therefore off-flavors such as *trans*-2-nonenal.

55 In this chapter, all phenolic structures that have been found in beer will be  
56 described.

---

## 57 **2 Catechins and Proanthocyanidins**

58 Even compared to grapes, hop emerges as an exceptional source of catechins and  
59 proanthocyanidins. Therefore, although added in 100 times lesser quantity than  
60 malt, it can account for 30% of total beer polyphenols. Among hop cultivars, the  
61 lower the bitterness, the higher the flavonoid level (up to 1% “total flavanoids” in  
62 Saaz pellets, as expressed in terminal unit weight [1]). During mashing, malt

63 flavonoids are progressively dissolved in the wort (monomers dissolve much  
64 faster than oligomers). From mash filtration to boiling, a great proportion of  
65 them will be lost through oxidation, adsorption to spent grains, linkage to  
66 coagulated proteins, etc. According to the type of hop conditioning used  
67 (CO<sub>2</sub> extracts are much poorer in polyphenols than pellets and cones) and the  
68 stage of addition, more or less flavonoids will be brought into the wort in the  
69 boiling kettle [2].

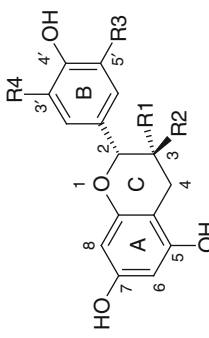
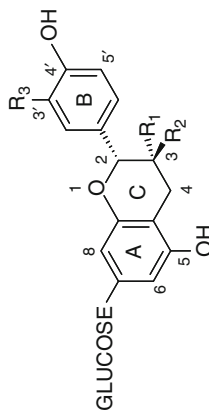
70 In hop dried cones or pellets, (+)-catechin and (–)-epicatechin monomers can  
71 reach up to 2,821 and 1,483 ppm, respectively [3–7]. Malt contains only  
72 10–100 ppm (+)-catechin (and no epicatechin at all) [3, 5, 8–10]. The main  
73 monomeric unit identified in beer is (+)-catechin (0.5 to 6.9 mg.L<sup>-1</sup>), but  
74 (–)-epicatechin (0.8–1.9 mg.L<sup>-1</sup>), (–)-catechin gallate, (–)-epicatechin gallate,  
75 and two glycosides have also been detected (Table 78.1) [8, 11–21].

76 Hop is also an excellent source of flavonoid oligomers (proanthocyanidins,  
77 known as anthocyanogens in the brewing field). For instance, B3 and B4  
78 procyanidin dimers have been detected at levels up to 0.1% [3, 5–7]. Malt  
79 contains two B3 dimers (prodelphinidin and procyanidin) at lower levels than in  
80 hop, but with higher amounts of gallo catechin units [3, 5, 10, 22]. Many trimers  
81 have also been detected in malt (catechin and gallo catechin units) and hop  
82 (catechin, epicatechin, and gallo catechin units, but always a catechin unit at the  
83 terminal position). Thiolysis hyphenated to RP-HPLC-ESI(–)-MS/MS was  
84 recently optimized by our group to investigate beer polyphenolic oligomers  
85 [17]. Thiolysis indicated that most beer dimers are procyanidins B3 (two catechin  
86 units), while most trimers are prodelphinidins (catechin in terminal units and  
87 gallo catechins or catechins in extension units). Despite the absence of chromato-  
88 graphic peaks corresponding to oligomers above trimers, an apparent degree of  
89 polymerization (mDP) close to 6 was calculated in a total LH20 extract. Detailed  
90 structures were determined by RP-HPLC-ESI(–)-MS/MS [16]. Four dimers were  
91 identified: three procyanidins (B1, B3, and B4) and one prodelphinidin (B3)  
92 (Table 78.1). Previously detected in hop or malt, three trimers (the procyanidin  
93 C-4 $\alpha$ -8-C-4 $\alpha$ -8-C and two prodelphinidins, GC-4 $\alpha$ -8-C-4 $\alpha$ -8-C and GC-4 $\alpha$ -  
94 8-GC-4 $\alpha$ -8-C), were distinguished for the first time in beer. As expected,  
95 according to previous thioacidolysis data, most beer proanthocyanidins carry  
96 a catechin as terminal unit.

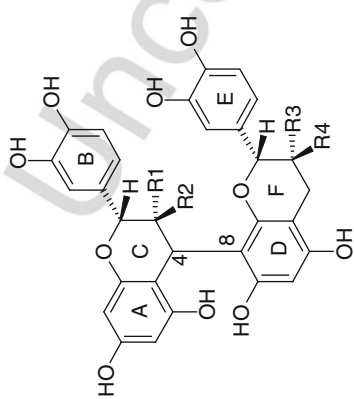
## 97 2.1 Colloidal Instability

98 Colloidal instability due to interactions between polyphenols and proteins limits the  
99 shelf life of beer. A lag phase is usually observed in lager beers before chill-haze  
100 development [23–25]. The time needed to form critical amounts of tanning  
101 polyphenols leading to visible chill-haze particles corresponds to the lag  
102 phase. As described by Leemans et al. [25] for different batches, the longer the  
103 lag phase, the better the colloidal stability. Chill haze (or reversible haze), defined

**Table 78.1** Flavan-3-ol monomers, polymers, and range of concentrations in beer [8, 11, 13, 14, 16, 19–21, 31, 62, 70, 124–126]

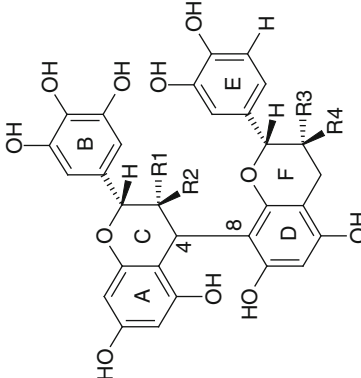
	Structures	Compounds	R1	R2	R3	R4	Concentrations in beer (mg.L <sup>-1</sup> )
t1.1							
t1.2							
t1.3	<b>Monomers</b>						
t1.4		(+)-Catechin	H	OH	H	OH	0.28–6.9
t1.5		(-)-Epicatechin	OH	H	H	OH	<0.10–1.9
t1.6		(-)-Catechin gallate	H	Gallate	H	OH	5–20
t1.7		(-)-Epicatechin gallate	Gallate	H	H	OH	5–20
		3-O-methylcatechin	H	OCH <sub>3</sub>	H	OH	Detected
t1.8		Catechin-7-O-β-D-glucopyranoside	H	OH	OH	OH	Detected
		Catechin-7-O-β-(6'-O-nicotinoyl)-β-D-glucopyranoside	H	OH	OH	OH	Detected

Dimers		Procyanidins B						
t1.9								
t1.10								
t1.11								
t1.12								



(continued)

t1.13 **Table 78.1** (continued)

Structures	Compounds	R1	R2	R3	R4	Concentrations in beer (mg.L <sup>-1</sup> )
t1.14 t1.15 <i>Prodelphinidins B</i>		H	OH	H	OH	Traces-3.3
t1.16	<b>B3</b> (-)-Gallocatechin-(4 $\alpha$ -8)-(+)-catechin	OH	H	H	OH	Detected
	<b>B9</b> (-)-Gallopeicatechin-(4 $\beta$ -8)-(+)-catechin	OH	H	H	OH	Detected



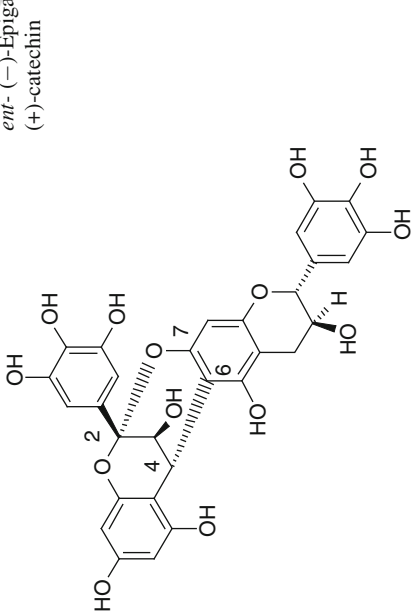
11.17 **Prodelphinidins A**



Detected

(continued)

**Table 78.1** (continued)

t1.18	Structures	Compounds	R1	R2	R3	R4	Concentrations in beer (mg.L <sup>-1</sup> )
t1.19		<i>ent</i> - (-)-Epigallocatechin-(4 <i>x</i> -6, 2 <i>x</i> -O-7)-(+)-catechin					Detected

11.20 **Trimers**

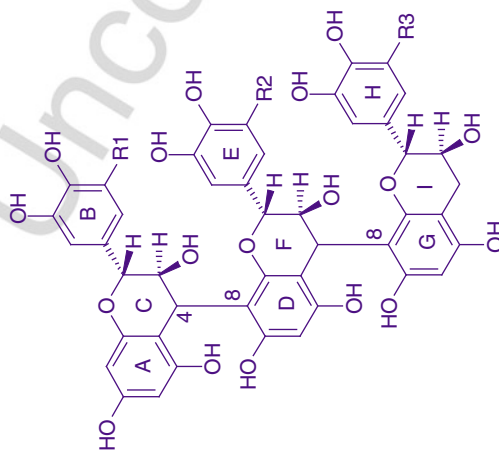
11.21 **Procyanidins C**

	H	OH	and R5 = H	and R6 = OH	Detected
<b>C2</b> (+)-Catechin-(4 <i>α</i> -8)-(+)-catechin - (4 <i>α</i> -8)-(+)-catechin					
					

(continued)

**Table 78.1** (continued)

Structures	Compounds	R1	R2	R3	R4	Concentrations in beer (mg.L <sup>-1</sup> )
<i>Prodelphinidins C</i>						
t1.22	(-)-Gallocatechin-(4 <i>x</i> -8)-(-)-gallocatechin-(4 <i>x</i> -8)-(+)-catechin	OH	OH	H	/	Detected
t1.23	(-)-Gallocatechin-(4 <i>x</i> -8)-(+)-catechin	OH	H	H	/	Detected
t1.24	(-)-Gallocatechin-(4 <i>x</i> -8)-(+)-catechin	OH	H	H	/	Detected



Uncorrected Proof

104 by non-covalent bonds between polyphenols and active proteins, can eventually  
105 turn into permanent haze that no longer dissolves as the beer warms.

106 Catechin does not rapidly induce strong haze. Upon storage, however, it does.  
107 Likewise, colloidal instability caused by dimers and trimers is enhanced after  
108 oxidation (not true for tetramers and pentamers) [26–28]. Free radicals are known  
109 to enhance haze [29]. Tannoids have been defined by Chapon [30] as intermediates  
110 in the oxidation of simple flavanoids to tannins, forming complexes with proteins.  
111 On the other hand, according to O'Rourke et al. [28], oxidized flavanols cause  
112 chill haze, but only subsequent polymerization leads to tannoids and permanent  
113 haze [28, 31].

114 Leemans et al. [25] have proposed a model in which aldehydes and oxygen play  
115 key roles in tanning polyphenol formation [25, 31]. Not only dissolved oxygen but  
116 also shaking, higher temperature, polyphenol-rich raw materials, light, and heavy  
117 metals will significantly increase colloidal instability [25, 31].

118 Beer contains less haze-active polyphenols than haze-active proteins. Derived  
119 from barley hordeins, haze-active proteins (10–30 kDa) are acidic hydrophilic  
120 polypeptides, rich in both proline and glutamic acid [26] and glycosylated [32].  
121 Much more haze is produced near pH 4.0 than at pH 3.0 or above pH 4.2. At the  
122 beer pH, ethanol at low concentration causes a modest decline of haze, while strong  
123 haze is observed at higher concentrations [33].

124 To preserve beer colloidal stability, brewers usually remove haze-active materi-  
125 als [34]. To get rid of haze-active proteins, precipitation with tannic acid,  
126 hydrolysis with papain and adsorption to bentonite [35] or silica gel [36, 37] are  
127 very effective, but unfortunately in some cases, such procedures also remove  
128 foam proteins. To remove haze-active polyphenols, the most usual way is adsorp-  
129 tion to polyvinylpyrrolidone-PVPP. Because of the structural analogy  
130 between these compounds and proline [38], pyrrolidone rings bind polymerized  
131 flavanoids through hydrogen and ionic bonds.

132 New combined absorbents are now proposed to brewers, such as PVPP mixed  
133 with silica xerogel, PVP bound onto silica, and tannin linked to silica [23, 39].  
134 Another innovative way is the use of flavan-3-ol and proanthocyanidin-free malt  
135 which allows affording an excellent colloidal stability [40].

## 136 2.2 Astringency

137 In beer, flavanoids could be also responsible for astringency [41, 42]. Catechin and  
138 epicatechin thresholds lie between 1 and 20 ppm [41, 42], with higher values for the  
139 beer matrix (20 ppm). Astringency is intensified at low pH, especially near 4.0–4.2  
140 [43], but a higher astringency has been measured by François et al. [44] in beers  
141 with a pH close to 5. In this case, it was suspected that the pH of the samples fell in  
142 the mouth before polyphenol/protein interactions occurred. Sensory analyses  
143 applied to top-fermented beers have shown that storage (20°C or 40°C with air in  
144 the headspace) decreases bitterness and post-bitterness but intensifies astringency  
145 [45]. On the other hand, no significant astringency-related deterioration was

146 measured in lager beers aged for 5 days at 40°C (with or without oxygen) [44]. In  
147 both cases, an increase in DP (global assay) and a decrease in total flavanoids were  
148 mentioned, especially at higher temperature or pH, in the presence of air [44, 45].

### 149 **2.3 Color**

150 Beer color increases through storage, especially in the presence of oxygen and at  
151 higher temperature. At pH 3, colorless catechin-derived products are formed after  
152 enzymatic oxidation, whereas at pH 6 after chemical degradation, yellow products  
153 including dehydrodiccatechin A dimers differing by their interflavan linkages can be  
154 detected in model media (Fig. 78.1) [46, 47]. Recently, Callemien and Collin [15]  
155 detected dehydrodiccatechin A in a beer spiked with catechin after storage.

### 156 **2.4 Health Properties**

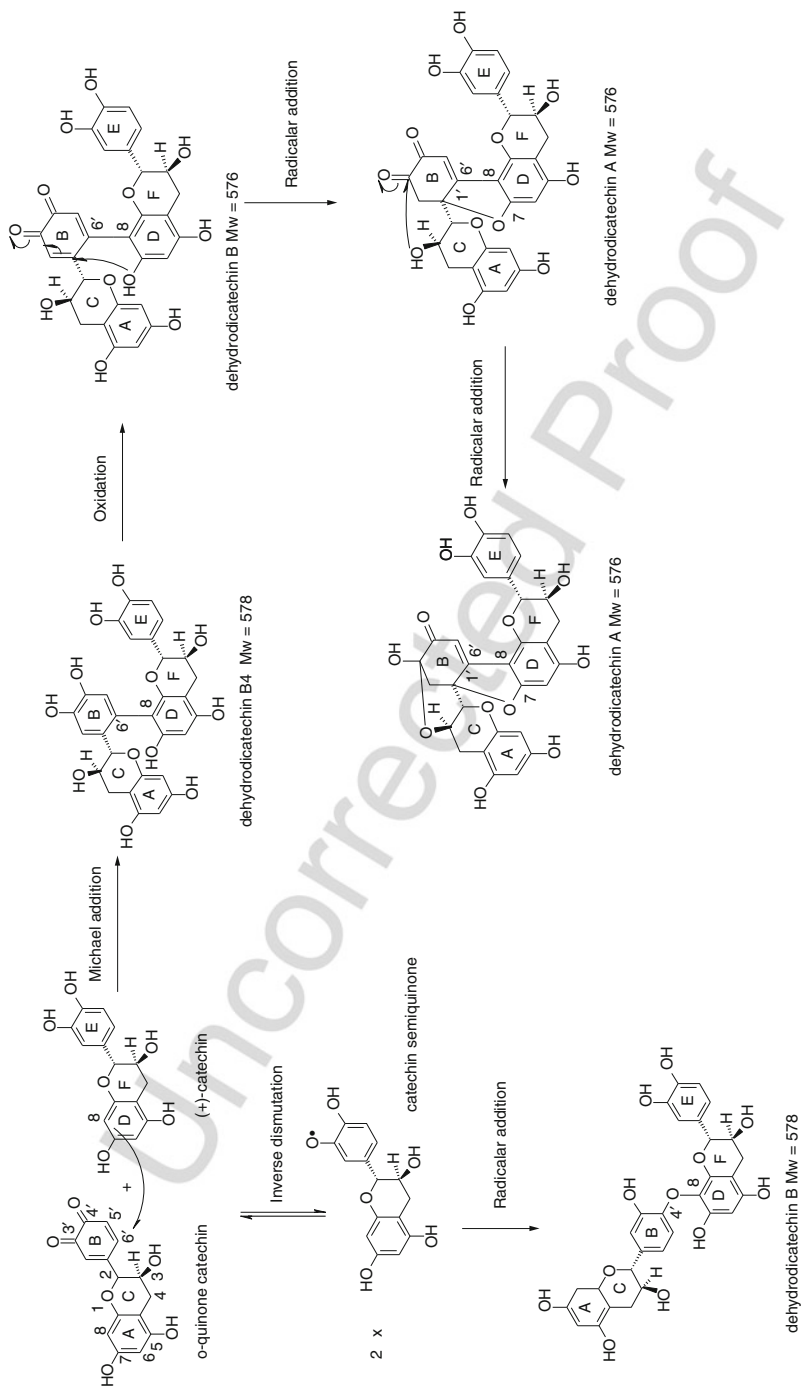
157 Flavan-3-ols induce cardioprotective effects, including antioxidant effects (protec-  
158 tion against LDL oxidation) and inhibition of platelet activity and vasodilatation  
159 [48, 49]. Flavonoids might reduce the risk of cancer, although some  
160 procarcinogenic activities have also been reported [48, 50]. Flavonoids alter the  
161 synthesis of eicosanoids (mediators of inflammation). They decrease the leukotri-  
162 ene/prostacyclin ratio by modifying lipoxygenase activity [51, 52]. Immune regu-  
163 lation has also been observed [53]. Hop proanthocyanidins can help prevent nitric  
164 oxide-related disorders such as Alzheimer's and Parkinson's diseases [7].

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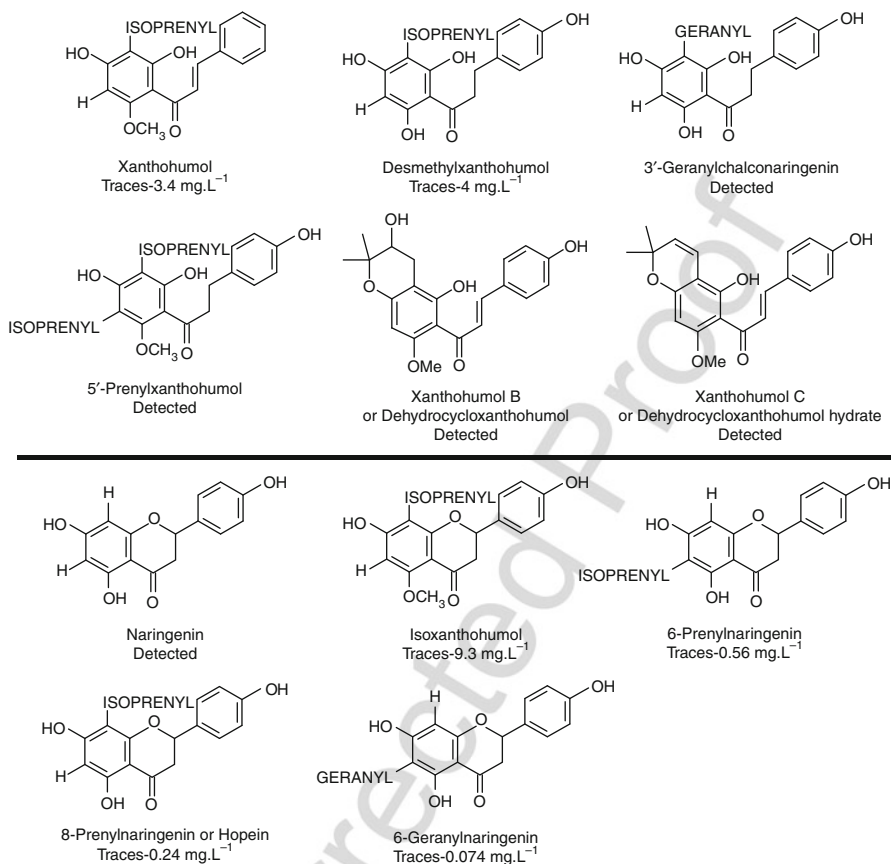
## 165 **3 Prenylchalcones and Derived Flavanones**

166 More than twenty prenylchalcones and derived flavanones, studied mainly for their  
167 biological effects, have been identified in hop [54]. Concentrations higher than  
168 0.6%, with a predominance of xanthohumol and desmethylxanthohumol, are usu-  
169 ally found (Fig. 78.2) [55]. Levels of 80 and 90 ppm have been reported for the  
170 corresponding flavanones, isoxanthohumol and hopein. The higher the  $\alpha$ -acid  
171 content (bitter acids in hop), the higher the xanthohumol level [56].

172 Since hop is the only source of these compounds in beer, a relation can be  
173 established between their concentration and the rate of hopping. Xanthohumol  
174 isomerizes easily during the brewing process into isoxanthohumol [57]. Only  
175 15–50% hop xanthohumol remains in the final beer [58, 59], leading to concentra-  
176 tions often below 1 mg.L<sup>-1</sup> [18, 55, 60, 61]. Stout- and Porter-style beers are  
177 characterized by slightly higher levels because dark malts contain compounds  
178 inhibiting xanthohumol isomerization [57]. The use of xanthohumol-enriched hop  
179 products (obtained by ethanol-CO<sub>2</sub> extraction) combined with late hopping makes  
180 it possible to increase significantly the xanthohumol and isoxanthohumol potential  
181 of beer (close to 10 mg.L<sup>-1</sup>).



**Fig. 78.1** Proposed degradation schemes of (+)-catechin to form colorless compounds with M<sub>w</sub> = 578 and yellow compounds with M<sub>w</sub> = 576 [15, 46]



**Fig. 78.2** Prenylchalcones, derived flavanones, and range of concentrations in beer (Adapted from [31])

### 182 3.1 Health Properties

183 Xanthohumol is a “broad-spectrum” cancer chemopreventive agent acting on all  
 184 three stages of carcinogenesis. Xanthohumol and isoxanthohumol are both active  
 185 ROS scavengers, while only the former is active in superoxide scavenging assays.  
 186 Isoxanthohumol, 8-prenylnaringenin, and xanthogalenol may also exert chemopre-  
 187 ventive effects [18, 61–64].

188 Prenylflavonones have mainly been studied for their estrogenic activity.  
 189 Hopein is a very potent phytoestrogen. The authors recommend its application  
 190 in prevention or treatment of (post)menopausal symptoms and osteoporosis  
 191 [61, 63, 65]. Weak estrogenic activity has been observed for close analogs like  
 192 6-prenylnaringenin, 8-geranyl naringenin, 6,8-diprenylnaringenin, and  
 193 isoxanthohumol. Prenylchalcones like xanthohumol and xanthogalenol also show  
 194 low activity [66].



## 195 **4 Flavonols**

196 Sixteen flavonol glycosides (mainly mono-, di-, and triglycosides of quercetin and  
197 kaempferol) have been detected in hop [31]. Although boiling can extract 91% of  
198 the kaempferol and 88% of the quercetin glycosides, only a few ppms of flavonols  
199 are found in the final beer (Fig. 78.3) [8, 11, 13, 67, 68].

### 200 **4.1 Bitterness**

201 In beer, flavonols could be responsible for bitterness but do not participate in beer  
202 haze formation [31].

### 203 **4.2 Health Properties**

204 Flavonols induce cardioprotective effects, including antioxidant effects (protection  
205 against LDL oxidation) and inhibition of platelet activity and vasodilatation  
206 [48, 69], while very little information is available on their potential anticancer  
207 effects.

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## 208 **5 Hydroxybenzoic Acids, Hydroxycinnamic Acids, and 209 Derived Compounds**

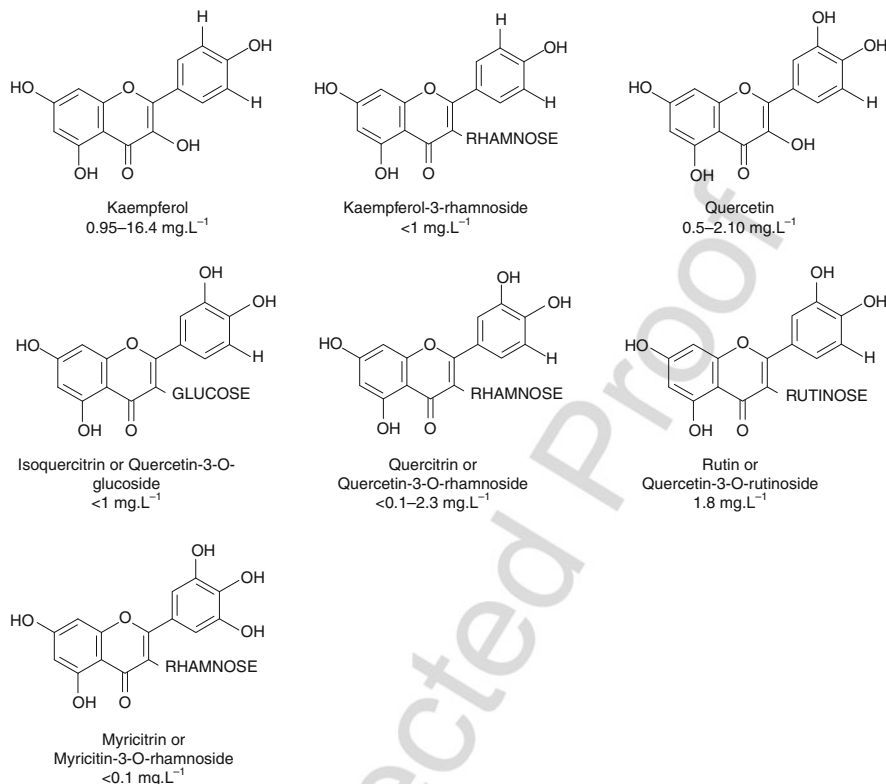
210 Malt and hop contain various hydroxybenzoic acids, which are retained at least  
211 partially up to the final beer (Fig. 78.4). Total hydroxybenzoic acids – mainly  
212 *p*-hydroxybenzoic, vanillic, and gallic acids – usually reach a few ppms in beer.  
213 They have also been found as glycosides or other bound forms [8, 11–14, 70–74].

214 Hydroxycinnamic acids are partially recovered in beer (Fig. 78.4). Most of them  
215 are in combined forms in the raw materials, either with quinic acid, glucose, or cell-  
216 wall constituents [8, 11–14, 70–78]. In malt, *p*-coumaric and ferulic acids are  
217 esterified with arabinoxylans [79]. They can be both water extracted and enzymati-  
218 cally solubilized by cinnamoyl esterases [80]. After mashing, an additional release of  
219 ferulic acid may occur during fermentation due to yeast cinnamoyl esterases [81].

220 Three coumarins issued from orthohydroxycinnamic acid cyclization have also  
221 been found in beer (Fig. 78.5) [8, 73].

### 222 **5.1 Flavor**

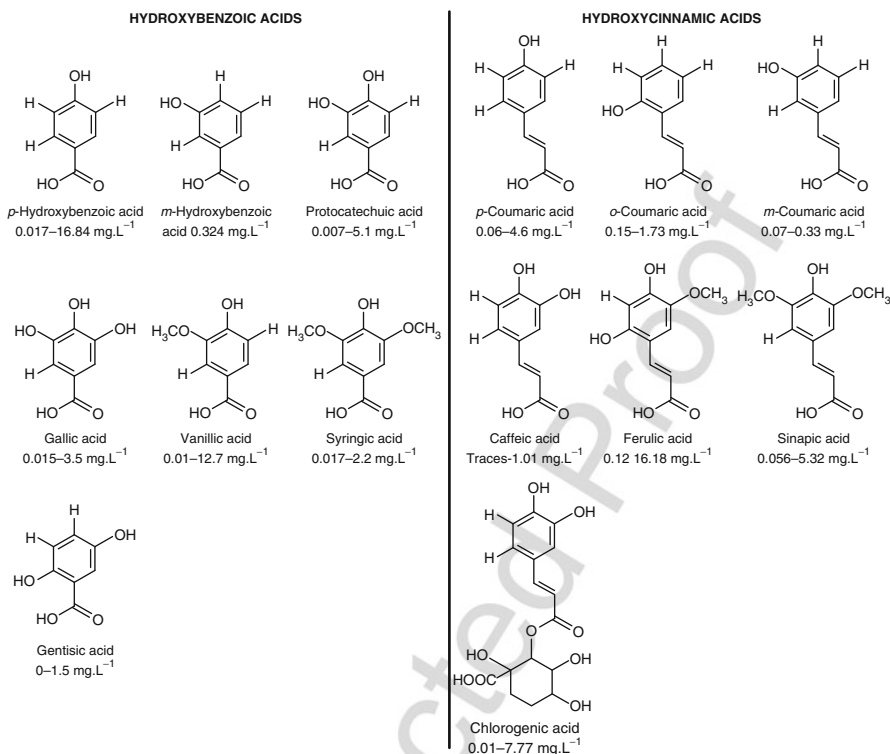
223 Hydroxybenzoic and hydroxycinnamic acids are characterized by relatively high  
224 flavor thresholds (> ppm, mainly bitter taste and astringency) [82]. On the other  
225 hand, their decarboxylated derivatives (Fig. 78.5) can impart very strong phenolic/  
226 clove/smoked flavors to beer because of their low threshold values (ppb order).



**Fig. 78.3** Flavonols and range of concentrations in beer (Adapted from [31])

227 Decarboxylation can occur either by thermal degradation [83] during malt  
 228 kilning and in the boiling kettle [77, 84], or during fermentation. In this last case,  
 229 decarboxylation is catalyzed by the phenylacrylic acid decarboxylase found in  
 230 *Saccharomyces cerevisiae* strains displaying the Pof<sup>+</sup> phenotype (phenolic off-  
 231 flavor) [85, 86] and in some contaminating microorganisms like *Brettanomyces*/  
 232 *Dekkera* spp. [87] or *Enterobacteriaceae* [88]. In this way, 4-vinylguaiacol is  
 233 issued from ferulic acid, while 4-vinylphenol derives from *p*-coumaric acid.  
 234 4-Vinylguaiacol has been also found in hop [89].

235 In Belgian white beer production, enzymatic decarboxylation of ferulic acid  
 236 occurs linearly through fermentation at a rate close to 140 ppb/day (Fig. 78.6).  
 237 The rate decreases strongly during secondary fermentation, down to 20 ppb/day.  
 238 Compared to *p*-coumaric acid, ferulic acid is preferentially degraded by yeast  
 239 (*p*-coumaric acid remains unmodified until the ferulic acid concentration reaches  
 240 2 ppm) [31]. Concentrations up to 6.2 ppm in 4-vinylguaiacol and up to 3.2 ppm in  
 241 4-vinylphenol have been reported in wheat beers [8, 77–79, 81, 90–97].  
 242 For instance, 4-vinylguaiacol contributes to the specificity of Belgian white beers

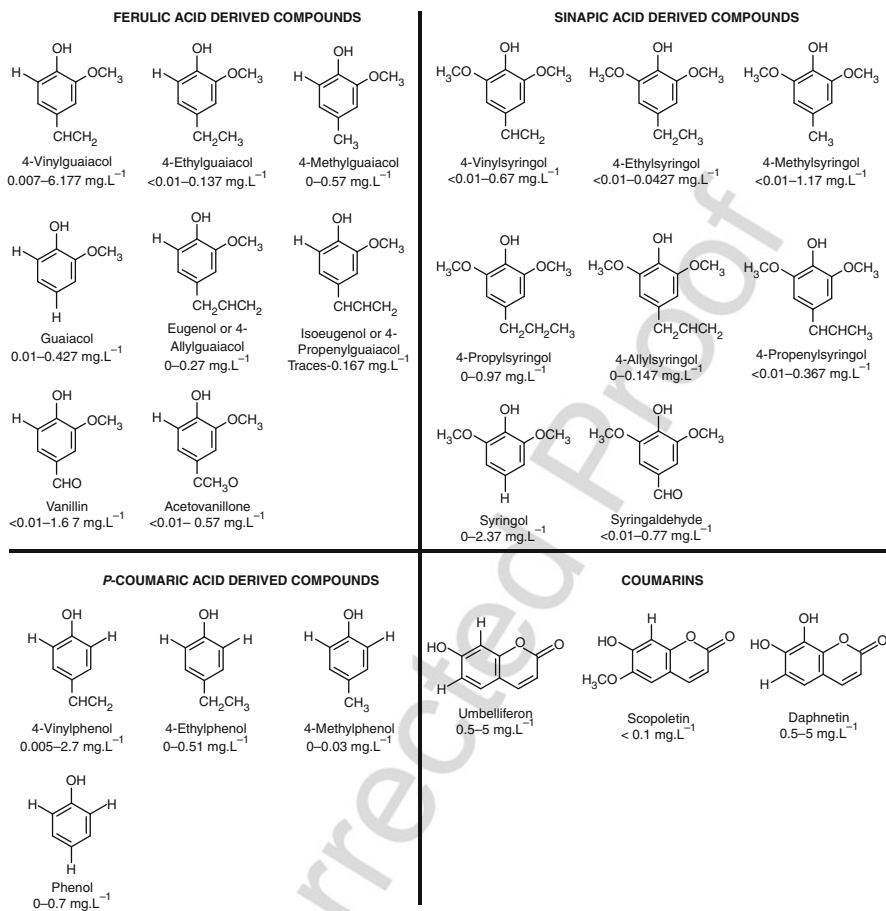


**Fig. 78.4** Hydroxybenzoic acids and hydroxycinnamic acids and range of concentrations in beer (Adapted from [31])

243 (made with unmalted wheat) and German rauch and weizen beers (made with  
 244 malted wheat) [92, 94, 97, 98]. According to its concentration, 4-vinylguaiacol  
 245 can lead either to strong pharmaceutical off-flavor defects [91] or to pleasant  
 246 clove flavors [79], while 4-vinylphenol is always considered to be an off-flavor  
 247 [79]. These vinyl compounds can be further oxidized or reduced into smaller  
 248 molecules like vanillin, 4-ethylguaiacol, guaiacol, and 4-ethylphenol through  
 249 chemical reactions [99] or through the activity of wild yeasts like *Brettanomyces*/  
 250 *Dekkera* spp. [87].

251 Degradation of 4-vinylguaiacol through natural aging (25% after 20 days)  
 252 or at 40°C (50% after 20 days) has been reported [77, 94, 100]. This compound  
 253 could be partially transformed to 4-ethylguaiacol, vanillin, and guaiacol [79, 101].

254 By using the AEDA methodology on aged lager beers, 4-vinylsyringol was  
 255 identified as a strong old-beer-like phenolic odorant (FD value as high as that of  
 256 *trans*-2-nonenal, responsible of the cardboard off-flavor in aged beer) [102, 103]. Its  
 257 release through aging should be due to acidic hydrolysis of a glycoside, since  
 258 sinapic acid decarboxylation occurs much earlier in the process, either in the boiling  
 259 kettle or during fermentation.



Au2

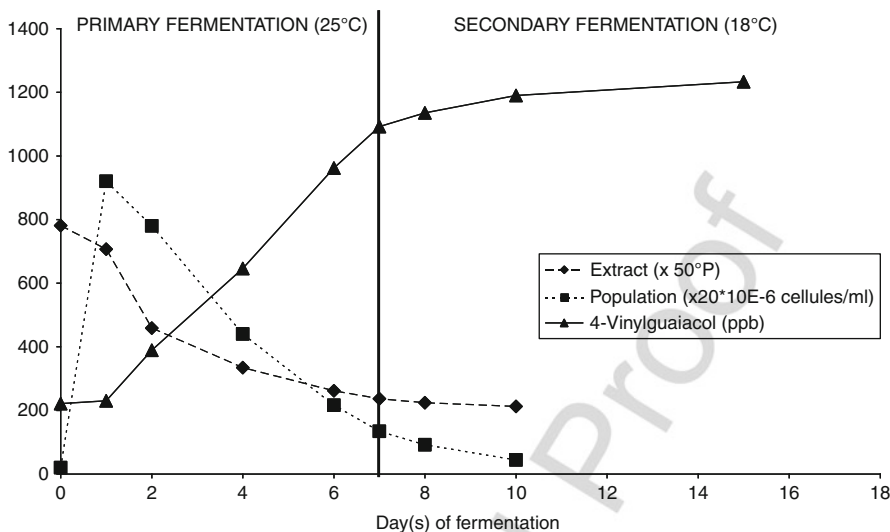
**Fig. 78.5** Hydroxybenzoic- and hydroxycinnamic acid-derived compounds and range of concentrations in beer (Adapted from [31])

260 **5.2 Color**

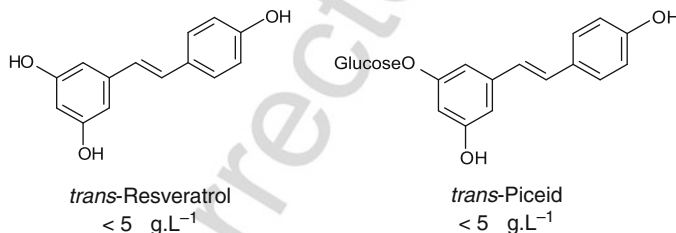
261 Phenolic acids do not participate in beer haze formation [27, 104], but vinylphenol  
 262 and cinnamic acid have been described as potential pigments [105–108].

263 **6 Stilbenes**

264 Our group recently discovered three stilbenes in hop: *trans*-resveratrol, *trans*-  
 265 piceid, and *cis*-piceid [4, 109]. Concentrations ranging from 0.7 to 11 ppm *trans*-  
 266 piceid and from 0.03 to 2.3 ppm *trans*-resveratrol have been reported in hop cones  
 267 [110]. A strong influence of geographic origin and harvest year has been shown



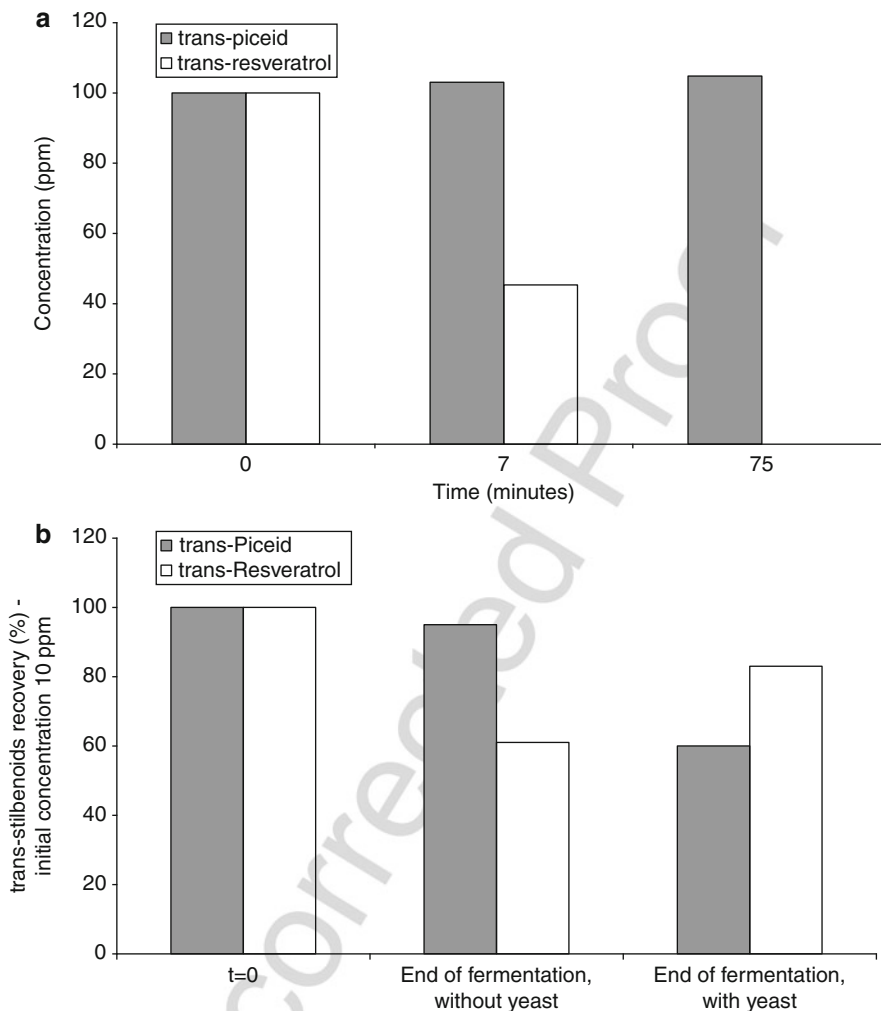
**Fig. 78.6** Evolution of extract, cell population, and 4-vinylguaiacol concentration through fermentation of a Belgian white beer



**Fig. 78.7** Stilbenes and range of concentration in beer [114]

268 [110], but American aromatic cultivars like Willamette and Cascade emerge in  
 269 all cases as the best sources of stilbenes. Resveratrol is very sensitive to heat and  
 270 light [110]. Even during hop storage, a significant loss occurs, especially in highly  
 271 oxygen-sensitive varieties, leading to new analogs like *cis*-resveratrol and dimers  
 272 [111]. Likewise, hop pelletization induces strong degradation [111, 112]. *trans*-  
 273 Resveratrol and glycosides are absent from malt [113], so one should not  
 274 be surprised to find only traces of stilbenes in beer (Fig. 78.7). Up to  $5 \mu\text{g.L}^{-1}$   
 275 *trans*-resveratrol was detected by our group in Belgian commercial beers [114].

276 Taking into account a concentration of 1–10 ppm stilbenes in hop and hopping  
 277 close to  $200 \text{ g.hL}^{-1}$  in wort, a maximum of  $2\text{--}20 \mu\text{g.L}^{-1}$  stilbenes could be  
 278 expected in beer. Moreover, massive degradation of *trans*-resveratrol is known to  
 279 occur in the boiling kettle (60% degradation after 7 min of boiling – Fig. 78.8a).  
 280 *trans*-Piceid is much more stable during heat treatment, and it can be converted to



**Fig. 78.8** Follow-up of the degradation of *trans*-resveratrol and *trans*-piceid (a) in an aqueous model medium previously flushed by nitrogen-mimicking wort ebullition (b) through wort fermentation [112, 114]

281 free resveratrol through wort fermentation (only 60% recovered from a beer prepared  
 282 by spiking an industrial wort at 10 mg.L<sup>-1</sup> before fermentation – Fig. 78.8b). When  
 283 the wort was not pitched, *trans*-piceid remained stable, suggesting that yeast enzymes  
 284 catalyze this hydrolysis to free resveratrol, as previously described for wine [114].  
 285 On the other hand, the *trans*-resveratrol concentration decreased even in the absence  
 286 of yeast (40% degradation), most likely because of reactions with wort components  
 287 (apparent degradation of 17% in the presence of yeast due to the equilibrium with  
 288 piceid).

289 In order to increase the stilbene level, stilbene-enriched hop products and  
290 brewery process modifications are needed (e.g., adding a stilbene-enriched  
291 ethanolic hop extract after fermentation significantly increases the beer stilbene  
292 potential).

## 293 **6.1 Health Properties**

294 *trans*-Resveratrol shows an impact on platelet aggregation and vasodilatation, and  
295 through its effect on the antioxidant status, regulates gene expression and decreases  
296 the total lipid concentration (cholesterol and triglycerides) [115]. Although less  
297 potent, *cis*-resveratrol, *trans*-, and *cis*-piceid also improve the antioxidant activity  
298 [116, 117].

299 Piceid absorption is enhanced by the presence of its sugar [118].

300 *trans*-Resveratrol inhibits the initiation and growth of tumors. It inhibits cyclo-  
301 oxygenase, ornithine decarboxylase, and angiogenesis [119, 120]. *trans*-Piceid is  
302 a weaker inhibitor of ROS production [121]. As flavonoids, *trans*-resveratrol alters  
303 the synthesis of eicosanoids (mediators of inflammation) and decreases the leuko-  
304 triene/prostacyclin ratio by modifying lipoxigenase activity [120–122]. Estrogenic  
305 activity has recently been reported for some stilbenes, especially *trans*-resveratrol.  
306 *cis*-Resveratrol appears less potent [120, 123].

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## 307 **7 Conclusion**

308 The aim of the present chapter was to review all phenolic structures that have  
309 been found in beer. Each family was discussed according to its properties and  
310 stability through storage. However, at the end of this chapter, it is very difficult  
311 to advice brewers as to which phenols should be kept in the final beer and at  
312 what levels.

313 Beer phenols issued from malt and hop can contribute directly to several  
314 characteristics of beer, mainly flavor, astringency, haze, body, and fullness. Some  
315 phenolic structures also impart very interesting health properties. However,  
316 degradation of such compounds will inevitably lead to alteration of fresh beer.  
317 On the other hand, as antioxidants, these compounds can considerably protect raw  
318 materials from oxidative degradation throughout the process.

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