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Short communication

Enantiodifferentiation of whisky and cognac lactones using gas chromatography with different cyclodextrin chiral stationary phases

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ABSTRACT

The chiral lactone 5-butyl-4-methyloxolan-2-one or 5-butyl-4-methyldihydro-2(3*H*)-furanone, often named whisky lactone, is found in oak wood, then contributing to the appreciated flavor of beverages stored in such wooden barrels. Its next higher homologue is named cognac lactone (5-pentyl-4-methyloxolan-2-one or 5-pentyl-4-methyldihydro-2(3*H*)-furanone), however is much less known, probably due to its minor concentration level. In order to study the direct enantioseparation of both lactones by gas chromatography on chiral stationary phases, individual enantiomers, particularly for cognac lactone were made available. This was achieved by baker's yeast reduction of synthesized ethyl 3-methyl-4-oxononanoate or, after hydrolysis, of the corresponding 4-ketoacid, that gave access to individual enantiomers of cognac lactone. Good enantioseparation was achieved for both whisky and cognac lactone with high values for the chiral resolution with 6-*O*-*tert*. butyl dimethylsilyl-2,3-dialkylated or 6-*O*-*tert*. butyl dimethylsilyl-2,3-diacylated cyclodextrin derivatives as chiral selectors. The influence of the nature and position of derivatization of the cyclodextrin moiety revealed a strong impact on the chiral recognition mechanism, as the investigated alkylated derivatives heptakis-(2,6-di-*O*-*iso*-pentyl-3-*O*-allyl)-β-cyclodextrin and octakis-(2,3-di-*O*-pentyl-6-*O*-methyl)-γ-cyclodextrin did not provide any or only minor chiral selectivity for the two lactones.

1. Introduction

Lactones are highly valued aroma compounds in various fruits and foodstuffs. Due to their chirality, enantioselective analysis and evaluation of the enantiomeric ratio in authentic and commercial foodstuffs has a long tradition in food authenticity studies [1]. In the wine or spirit industry, a common vessel used for fermentation, storage or ageing is the wooden barrel that is often made of oak wood. A well-known aroma compound from oak wood is the so-called whisky lactone (WL; sometimes also named oak or Quercus lactone), chemically a 3-methyltoctan-4-olide (5-butyl-4-methyloxolan-2-one or 5-butyl-4-methyldihydro-2(3*H*)-furanone). In literature, different numbering systems can be found, eventually leading to some confusion. Here we will use the IUPAC-conform numbering starting at the ether oxygen (Fig. 1). Whisky lactone consists of two diastereomers and four enantiomers, which had been fully characterized by Günther and Mosandl [2]. It is found particularly in alcoholic beverages, such as spirits stored in wooden barrels, as e.g. in brandy or cognac [3]. A concise review by Maga summarizes the occurrence of WL [4]. Its next homologue, the 3-methylnonan-4-olide (5-pentyl-4-methyloxolan-2-one or 5-pentyl-4-methyldihydro-2(3*H*)-furanone, Fig. 1), is often called cognac lactone (CL) as it was identified as a trace-level compound in this beverage after working up more than 450 L of cognac [5].

Since whisky and cognac lactones are volatile compounds, analysis by gas chromatographic methods (GC) is usually the method of choice and often described in literature. In an early paper a (preliminary) assignment of the elution orders of the two diastereomers of

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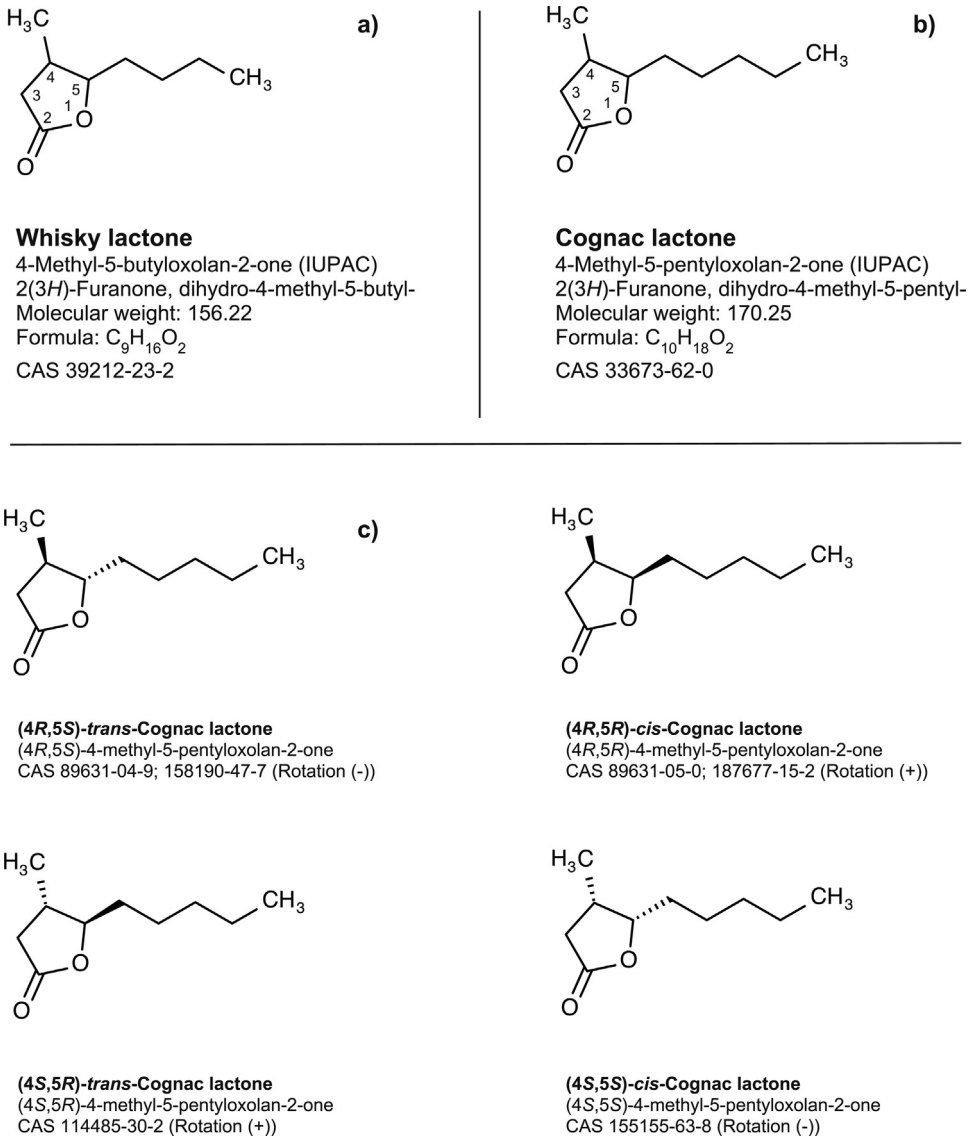

Fig. 1. Structures of whisky lactone (a), cognac lactone (b), and individual enantiomers of cognac lactone (c).

whisky (Quercus) lactones was done by Masuda and Nishimura [6] in such a way that the isomer eluting first in gas liquid partitioning chromatography (GLC) on an achiral UCON HB 2000 stationary phase was assigned to the *cis* diastereomer. Kepner and co-workers supported this assignment after GLC on polyethylene glycol type stationary phases (Carbowax 20 M and FFAP) and preliminary NMR experiments [7]. In 1981, Masuda and Nishimura then determined the absolute configurations of naturally occurring *trans*- and *cis*-whisky lactones to be (3*S*,4*R*) and (3*S*,4*S*), with carbon number assignments made according to the non-IUPAC numbering system [8]. Triggered by the opposing results from ter Heide et al. [5] they also reinvestigated their earlier assignment of the *cis* and *trans* isomers eluting from UCON HB 2000, now with NMR experiments using a paramagnetic chelate ($Eu(fod)_3$). This experiment finally confirmed the assignment of ter Heide et al. [5]. Other authors later also confirmed this elution order and extended the knowledge about elution orders for various stationary phases, such as e.g. methyl polysiloxanes DB1 [9], methyl phenyl polysiloxanes (SE54, PS255) and Carbowax [2,10]. In all these cases, the *trans* diastereomer elutes before the *cis* diastereomer. However, even in recent publications, an erroneous assignment may still occur in literature, as found e.g. in the work of King et al. [11]. Thus, care has to be taken and this overview on the historical development might be helpful for future researchers.

An early (indirect) enantioselective analysis of WL was achieved by Günther and Mosandl applying a reductive cleavage with $LiAlH_4$, producing the stereoisomers of 3-methyloctan-1,4-diol, which were then differentiated as their diastereomeric di-esters with (*R*)-Mosher acid (α-methoxy-α-trifluoromethylphenylacetic acid) and (*S*)-*O*-acetyllactic acid, respectively [12]. A direct enantioseparation was later achieved by the same group [13] with hexakis(3-*O*-acetyl-2,6-di-*O*-pentyl)-α-cyclodextrin as stationary phase in GC, revealing optically pure (3*S*,4*R*)-*trans* and (3*S*,4*S*)-*cis* diastereomers as constituents in oak wood. From other studies it is known that different oak species, e.g. French (*Quercus robur* and *Quercus petrea*) and American (*Quercus alba*) oaks vary in their diastereomeric ratios. The latter is important, since the two isomers also vary in their sensory properties. Günther and Mosandl described the odors of the WL isomers as being reminiscent of coconut; the *cis*-isomers were woody and earthy, while the *trans*-isomers resembled celery [2]. Furthermore, odor thresholds also vary amongst the individual diastereomers and even the enantiomers, as determined e.g. by GC-sniff (olfactometric detection) [14], in alcoholic solution [15], or in wine [16]. Interestingly, apart from many publica-