



# Evaluation of electronic cigarette liquids and vapour for the presence of selected inhalation toxins.

Farsalinos KE, Kistler KA, Gillman G, Stefopoulos C, Spyrou A, Voudris V

Department of Cardiology, Onassis Cardiac Surgery Center, Athens, Greece

Department of Chemistry, The Pennsylvania State University, Media, Pennsylvania, USA

Enthalpy Analytical Inc., Durham, North Carolina, USA

## Background

Electronic cigarette liquids are available in a variety of flavorings. In most cases, food-grade chemicals are used, which have not been assessed for safety when inhaled. Additionally, there are chemicals which are known to be hazardous when inhaled, despite being safe for ingestion. Two such examples are diacetyl (DA) and acetyl propionyl (AP) (Figure 1). They are used for their buttery taste in a variety of food preparations; they are also present naturally in dairy products and alcoholic drinks. Exposure to these substances through inhalation causes a decline in respiratory function and the development of a rare clinical syndrome called obliterative bronchiolitis.

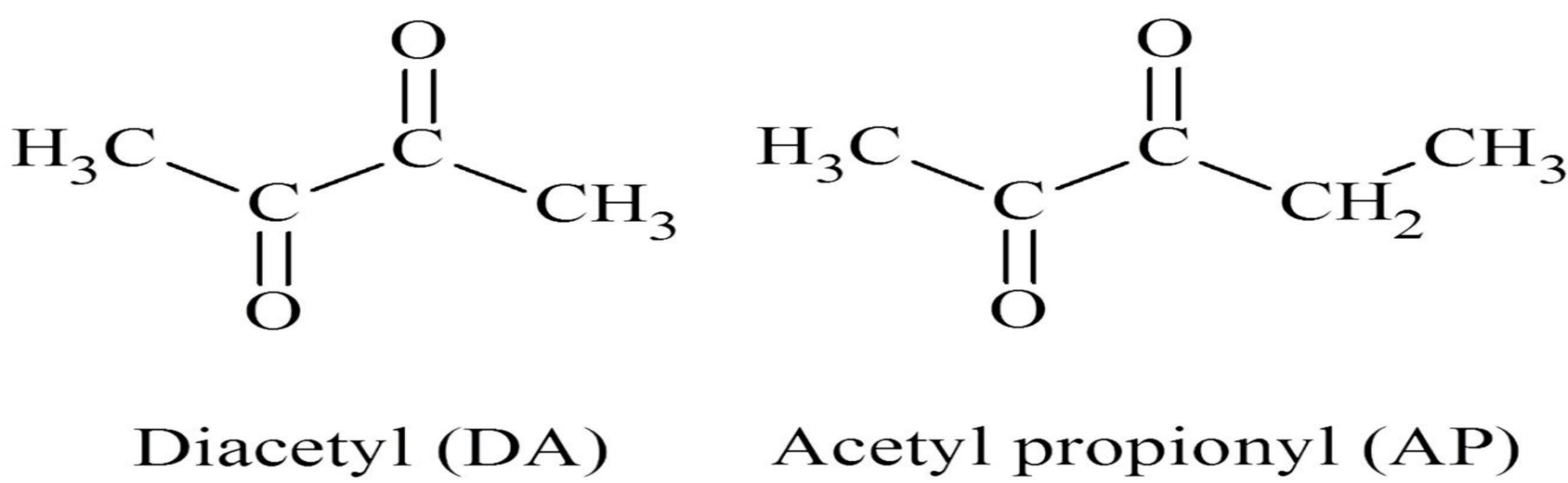
## Purpose

The purpose of this study was to evaluate sweet-flavored EC liquids for the presence of DA and AP.

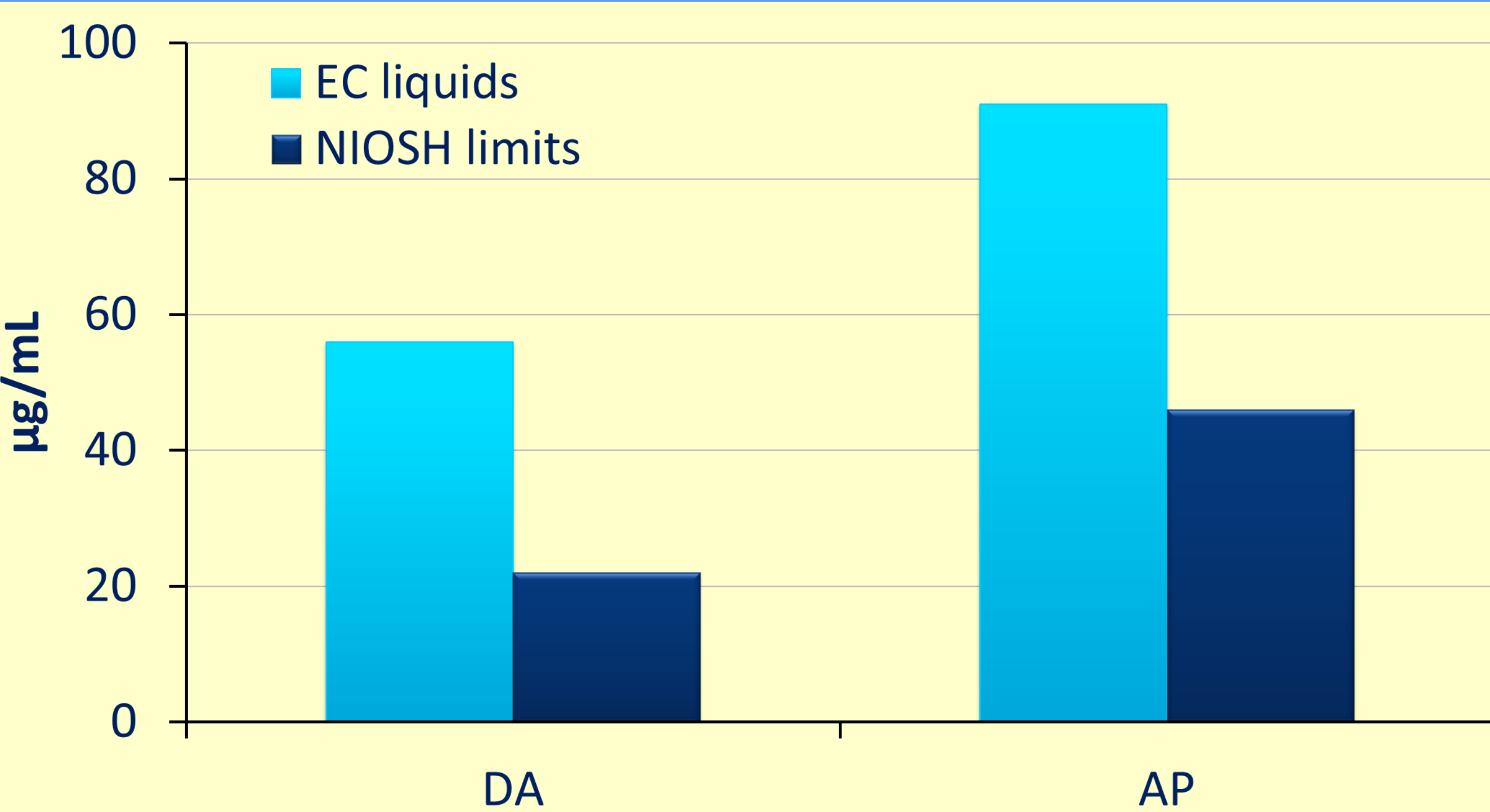
## Methods

- In total, 159 samples (refill liquids and concentrated flavors) were purchased from 36 manufacturers and retailers from 6 European countries and the US; they were tested for the presence of DA and AP by HPLC.
- To examine whether these chemicals are delivered to the vapor, three liquids were prepared by dissolving a concentrated flavor sample of known DA and AP levels at 5%, 10% and 20% concentration in a mixture of propylene glycol and glycerol. Vapor produced by an electronic cigarette was analyzed to determine the concentration of DA and AP.

**Figure 1.** Chemical structures of diacetyl (DA) and acetyl propionyl (AP).



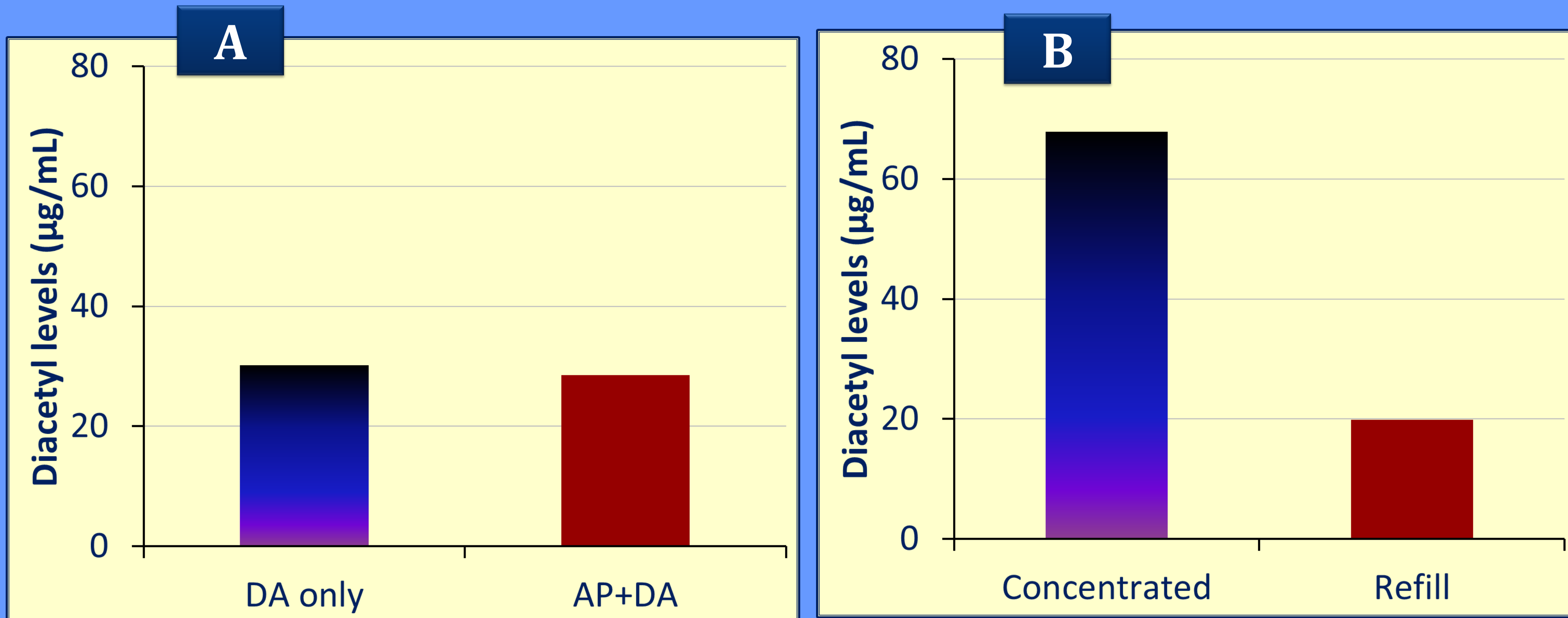
**Figure 4.** Average estimated daily exposure to diacetyl (DA) and acetyl propionyl (AP), compared with the respective NIOSH-defined safety limits. An average daily EC liquid consumption of 3ml was assumed.



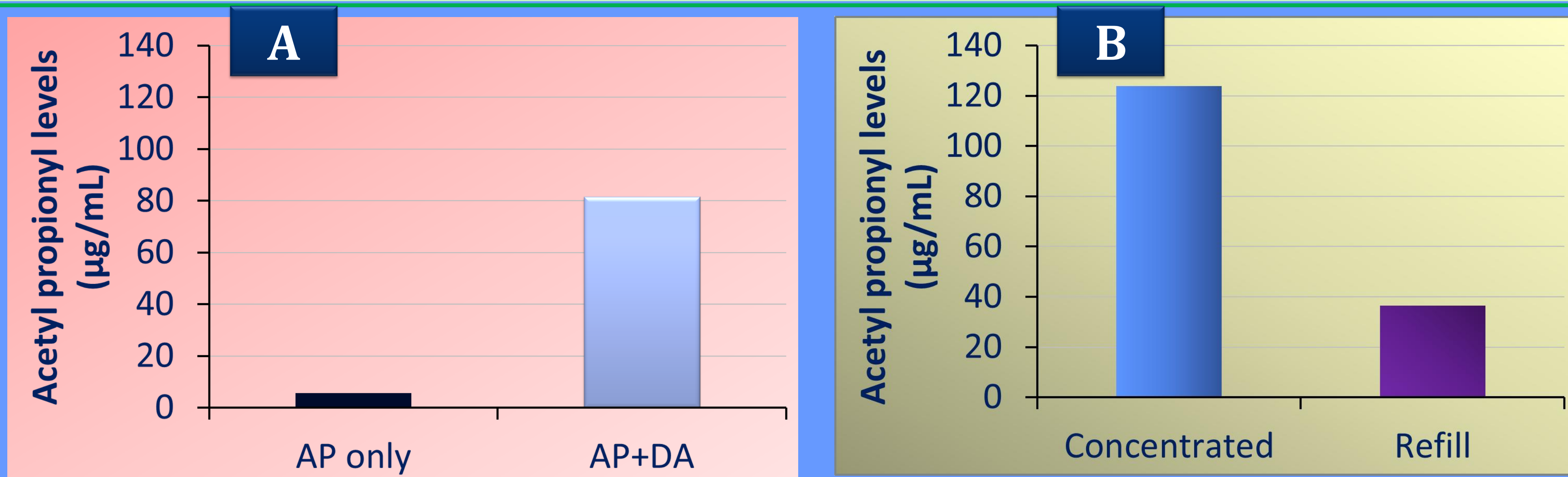
## Results.

DA and AP were found in 74.2% of the samples, with more samples containing DA. The levels found are presented in **Figures 2 and 3**. The calculated median daily exposure levels were 56µg/mL (IQR: 26-278µg/mL) for DA and 91µg/mL (IQR: 20-432µg/mL) for AP. They were 2-times higher than the strict NIOSH-defined safety limits (**Figure 4**) but 100 and 10 times lower compared to smoking respectively. Similar concentrations were found in liquid and vapor for both chemicals (**Figure 5**), with a very strong correlation between the concentration in liquid and in vapor for both substances.

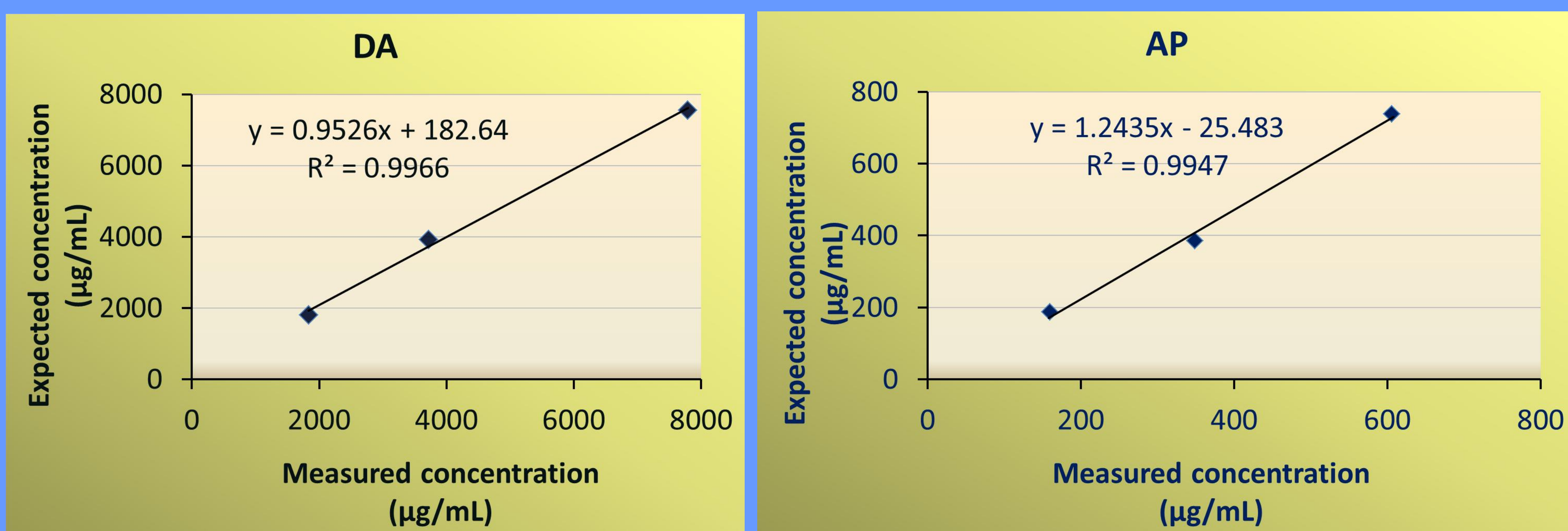
**Figure 2.** Levels of diacetyl (DA) found in the samples tested. A. Similar levels of DA were found in the samples containing DA only (n=65, 30.2µg/ml [IQR: 10.2-638.0µg/ml]) and in those containing both acetyl propionyl (AP) and DA (n=45, 28.5µg/ml [IQR: 10.3-53.2µg/ml]); Mann-Whitney test P=0.469. B. Higher levels of DA were found in concentrated flavorings samples (n=32, 67.9µg/ml [IQR: 23.2-950.8µg/ml]) compared to refill samples (n=78, 19.9µg/ml [IQR: 9.6-58.1µg/ml]); Mann Whitney test P=0.001.



**Figure 3.** Levels of acetyl propionyl (AP) found in the samples tested. A. Higher levels of AP were found in the samples containing both diacetyl (DA) and AP (n=45, 81.7ug/ml [IQR: 11.8-283.5] compared to those containing AP only (n=8, 5.6ug/ml [IQR: 4.5-38.8]); Mann-Whitney test P=0.002. This is probably because the samples containing AP-only were all refill samples. B. Higher levels of AP were found in concentrated flavorings samples (n=10, 123.9 [IQR: 17.5-582.5]) compared to refill samples (n=43, 36.5 [IQR: 6.7-158]), but the difference was not statistically significant; Mann Whitney test P=0.114.



**Figure 5.** Correlation between the expected and the measured concentrations of diacetyl (DA) and acetyl propionyl (AP) in vapour.



**Conclusions.** DA and AP were found in a large proportion of sweet-flavored EC liquids, at levels that were higher than the strictest safety limits but significantly lower compared to smoking. The presence of these chemicals in EC liquids represents an avoidable risk. Proper measures should be taken by EC liquid manufacturers and flavoring suppliers to eliminate these hazards from the products, without necessarily limiting the availability of sweet flavors.