

1 *Modeling and MANOVA studies on toxicity and endocrine potential of packaging materials exposed to*  
2 *different extraction schemes*

3 Natalia Szczepańska<sup>1</sup>, Błażej Kudłak<sup>1\*</sup>, Stefan Tsakovski<sup>2</sup>, Galina Yotova<sup>2</sup>, Miroslava Nedyalkova<sup>3</sup>, Vasil  
4 Simeonov<sup>2</sup>, Anna Dołęga<sup>4</sup>, Jacek Namieśnik<sup>1</sup>

5  
6 <sup>1</sup> Department of Analytical Chemistry, Faculty of Chemistry, Gdańsk University of Technology, 11/12  
7 Narutowicza Str., Gdańsk 80-233, Poland

8  
9 <sup>2</sup> Department of Analytical Chemistry, Faculty of Chemistry and Pharmacy, University of Sofia, 1  
10 James Bourchier Blvd, Sofia 1164, Bulgaria

11  
12 <sup>3</sup> Chair of General and Inorganic Chemistry, Faculty of Chemistry and Pharmacy, University of Sofia  
13 "St. Kl. Okhridski", 1, J. Bourchier Blvd., 1164 Sofia, Bulgaria

14  
15 <sup>4</sup> Department of Inorganic Chemistry, Faculty of Chemistry, Gdańsk University of Technology, 11/12  
16 Narutowicza Str., Gdańsk 80-233, Poland

17  
18 *Corresponding Author:* blakudla@pg.edu.pl, ORCID: 0000-0002-2237-2927

19  
20 *Abstract:* The stability of the linings of packaging that is in contact with the goods stored has been of  
21 major concern during decades of the development of packaging materials. In this work, an attempt  
22 was undertaken to assess the applicability of using two bioassays (Microtox<sup>®</sup> and XenoScreen  
23 YES/YAS) in estimating the stability of packaging (cans, caps, multilayer material) and the impact of  
24 their degradation on the toxicity of some simulated media. The assessment of the impact of  
25 packaging storage conditions (temperature, disinfection, preservation, extracting and washing  
26 solvents) was planned and performed with i) regression modeling of the experimental effects on the  
27 ecotoxicity readings, ii) ANOVA and MANOVA estimation of the experimental conditions as  
28 significant factors affecting the toxicity results and iii) FTIR analysis of the packages. It is shown that  
29 the effects of temperature and extraction solvents could be quantitatively assessed by the  
30 agreement between all methods applied. It can be stated that temperature and acidity as well as the  
31 alcohol content in the sensitive media have the greatest impact on the toxicity of the extract and  
32 thus on the stability of the internal lining and the extractability of xenobiotics.

33  
34  
35 *Key words:* toxicity, endocrine potential, packaging materials, extraction, experimental design,  
36 modeling, MANOVA, FTIR

37  
38  
39  
40 *Highlights:*

- 41  
42 - Simultaneous assessment of the impact of treatment conditions on packages ecotoxicity.  
43 - Checking of the impact of temperature and extracting solvents on endocrine potential of packages.  
44 - Comparison of the package lining spectra before and after extraction.  
45 - Ecotoxicity parameters as a tool in packages lining stability assessment.

46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57 Post-print of: Szczepańska N., Kudłak B., Tsakovski S., Yotova G., Nedyalkova M., Simeonov,  
58 V., Dołęga A., Namieśnik J.: Modeling and MANOVA studies on toxicity and endocrine potential  
59 of packaging materials exposed to different extraction schemes. ENVIRONMENTAL RESEARCH. Vol.  
60 165, (2018), p. 294-305. DOI: 10.1016/j.envres.2018.05.004

## 36 1. Introduction

37 The introduction of packaging materials has revolutionized the sales of common products.  
38 The use of packaging has mainly contributed to the extension of the expiration date of food products  
39 and made their transport and storage easier. Currently, a vast majority of products are sold in such  
40 packaging as plastics, paper, glass, metal and composite materials. Despite the clear benefits of these  
41 materials, their long-term use has shown some negative aspects. Since the 1980s, we have known  
42 that they might be an additional source of exposing people to xenobiotics (Lau and Wong, 2000). The  
43 issue of food packaging safety is regulated by both the EU and domestic legislation. Nevertheless,  
44 numerous studies have proven that the small-molecule components of packaging may be eluted  
45 from the internal layer of a material due to the presence of the medium stored (Arvanitoyannis and  
46 Kotsanopoulos, 2014; Ossberger, 2015). These facts have caused the issues related to the migration  
47 of xenobiotics and factors that influence the intensification of the process to become one of the  
48 leading topics of interest for researchers. Actions are being taken mainly to identify and  
49 quantitatively determine the compounds released and eventually to assess the risk to humans  
50 (Canellas et al., 2015; Guart et al., 2011). As can be easily concluded, this task is particularly difficult.  
51 Due to a vast number of various types of substances used for the production of packaging materials,  
52 there are hundreds of compounds that can migrate from food contact materials to food or food  
53 simulated media additives starting from substances such as plasticizers, antioxidants, light and  
54 thermal stabilizers, slip compounds, antistatic agents, lubricants, and monomers to heavy metals and  
55 nanoparticles (García et al., 2006; Guart et al., 2011; Raptopoulou et al., 2014; Sanches-Silva et al.,  
56 2009). It is obvious that the exposure to pollutants always has an unfavorable impact on an  
57 organism. However, the threat is particularly severe in this case. A significant number of chemical  
58 substances from the abovementioned groups (e.g., bisphenol A, bisphenol A diglycidyl ether and its  
59 derivatives, phthalates, primary aromatic amines, perfluorinated compounds and some heavy  
60 metals) are classified as endocrine-disrupting compounds (EDC) (Moreira et al., 2013; Moreta and  
61 Tena, 2014; Pérez-Palacios et al., 2012; Pezo et al., 2012). The results of numerous studies indicate  
62 that EDCs may alter the activity of natural steroid hormones by modifying their regulatory pathways,  
63 interacting with steroid receptors and antagonizing endogenous hormones or simply mimicking  
64 steroid hormone-dependent effects (Kudlak et al., 2015).

65 Although first mentions about the activity of these compounds appeared many years ago,  
66 they are still the object of great interest for the researchers. More and more advanced techniques  
67 used in the research provide novel information about harmful activity of these compounds. The  
68 danger is much more significant than it was believed before. Therefore, it was necessary to  
69 implement numerous amendments to the regulations concerning acceptable safe doses specified as  
70 regards individual substances. The first regulatory standard for bisphenol A was established in 1988  
71 and the oral reference dose was assessed on 50 mg/kg/day. Then the value was reduced to 4 mg/kg  
72 of body mass (Ćwiek-Ludwicka, 2015). Regulations related to the acceptable limits of compounds  
73 migrating from the surface of a package have also been tightened up. SML value for bisphenol A was  
74 reduced in 2018 from 0.6 mg to 0.05 mg/kg of food or food simulant (Commission Regulation (EU)  
75 2018/213). Supposedly, these values will be reduced again in the nearest future.

76 Additional problem connected with the phenomena of releasing compounds from the  
77 surface of the package relies on the fact that apart from well-known starting substances, impurities  
78 known as Non-Intentionally Added Substances (NIAS) can be present in food as well as their  
79 transformation products. The difficulties related to the identification of all the released compounds  
80 and the lack of knowledge about the toxicity of those compounds have resulted in an increase in the  
81 importance of using bioanalytical techniques in such research areas (Maisanaba et al., 2014; Ozaki et  
82 al., 2004; Wagner and Oehlmann, 2011). The main advantage of *in vitro* bioassays is the possibility of

83 specifying the actual influence of the overall migration, considering most of the interactions  
1 84 occurring between pollutants released. This is particularly important in consideration of the fact that  
2 85 we currently know that compounds coexisting in the mixture may interact and cause an increase  
3 86 (synergism) or decrease (antagonism) in the final effect. There are many premises that such  
4 87 interactions occur between compounds released from the surface of packaging materials (Hu et al.,  
5 88 2014; Li et al., 2017; Wiczerzak et al., 2016). In our previous research, synergistic interactions were  
6 89 found in mixtures that contain such compounds as BADGE·H<sub>2</sub>O, BADGE·2H<sub>2</sub>O or BFDGE (Szczepańska  
7 90 et al., 2018).

11 91 Due to the properties of compounds released, researchers usually apply tests that enable  
12 92 specifying the hormonal activity of the packaging samples. The XenoScreen YES/YAS, ERa and AR  
13 93 CALUX served as analytical tools that enabled the confirmation that the compounds released from  
14 94 some carton and polypropylene packaging show estrogenic activity (YES EEQ = 59.6±29.3 ng/L) (Mertl  
15 95 et al., 2014). Another group of tests used in such studies includes those that provide information on  
16 96 mutagenicity, genotoxicity and cytotoxicity of the given samples (i.e., extracts of the packaging).  
17 97 Based on the results obtained with the use of the rec-assay and comet assay, it was possible to show  
18 98 that the compounds released from the surface of paper and paperboard packaging cause weak  
19 99 genotoxic and cytotoxic effect. In the literature, there is some additional information on the  
20 100 possibility of using bioassays in the research on paper and plastic packaging (Galotto and Ulloa,  
21 101 2010; Ozaki et al., 2005). To the best of our knowledge, there is no information on the toxicity and  
22 102 hormonal activity of compounds released from the internal surface of cans and multilayer composite  
23 103 packaging. Thus, it also seems that the current research will be a significant contribution to present  
24 104 knowledge and that it will be a perfect complement to the existing information on the influence of  
25 105 compounds released from common packaging materials on living organisms. The main objective of  
26 106 the research was the evaluation (with MANOVA data treatment) of the toxicity and endocrine  
27 107 potential of the compounds released from packaging using the XenoScreen YES/YAS and Microtox®  
28 108 biological tests.

## 33 109 2. Methodology

### 34 110 2.1. Experimental

35 111 Because one of the most commonly used types of food packaging is currently metallic and  
36 112 multi-material composite packaging, cans, multilayered composite packaging and cups were chosen  
37 113 for the study. The subjects of the study were 60 metal cans devoted to fish storage (total volume ca.  
38 114 0.15 dm<sup>3</sup>), 56 paper hot-drink cups (0.20 dm<sup>3</sup> volume) and 60 multilayered composite packaging units  
39 115 commonly used for milk or juice storage (1 dm<sup>3</sup> volume). None of the samples was in contact with  
40 116 food prior to testing, and care was taken to avoid any contamination of the samples during sampling,  
41 117 storage or transport. Two approaches were used in the study. The goal of the first approach was to  
42 118 estimate the toxicity and endocrine potential of compounds released into simulant liquids, whereas  
43 119 the second focused on determining whether and to what extent the exposure to the extraction  
44 120 agents/conditions results in the degradation of the polymer layer. Fig. 1 shows the schematic  
45 121 approach applied in studies. None of the samples were in contact with food prior to testing, and care  
46 122 was taken to avoid any contamination of the samples during sampling, storage or transport.

47 123  
48 124 **Fig. 1.**

### 49 125 50 126 2.1. Chemicals and reagents

51 127 Chemicals that were used for preparing simulant media were obtained from the following  
52 128 suppliers: sodium chloride (CAS no. 7440-23-5) (Sigma Aldrich, Germany), dipotassium phosphate  
53 129 (CAS no. 7758-11-4) (Ciech S.A., Poland), calcium chloride (CAS no. 7440-70-2) (Eurochem BGD,

130 Poland), magnesium chloride (CAS no. 7786-30-3), potassium chloride (CAS no. 7440-09-7),  
131 potassium carbonate (CAS no. 584-08-7), lactic acid (CAS no. 79-33-4), urea (CAS no. 57-13-6) (POCH  
132 S.A., Poland), ammonium hydroxide (25 % w/w) (CAS no. 1336-21-6), acetic acid (AcOH, 35-38% w/w,  
133 CAS no. 64-19-7) (Chempur, Poland), distilled water, EDC-Pak cartridge (Merck, Germany). Microtox<sup>®</sup>  
134 kit (2% NaCl, lyophilized *Vibrio fischeri* bacteria, Microtox Diluent, Microtox Acute Reagent, Osmotic  
135 Adjusting Solution (OAS), and Reconstitution Solution (RS) were purchased from ModernWater Ltd.  
136 (GB). Ethanol (EtOH, CAS no. 64-17-5), dimethyl sulfoxide (DMSO, CAS no. 67-68-5) and Parafilm<sup>®</sup>  
137 were purchased from Sigma-Aldrich (Germany). All reagents were of analytical grade or higher  
138 (reagents used for microbiological purposes). Reagents used for XenoScreen YES/YAS were  
139 purchased from Xenometrics G. A. (Switzerland). These were: vials containing hER $\alpha$  yeast cells (for  
140 YES assay) and hAR yeast cells (for YAS assay) on a filter paper, basal medium, vitamin, L-aspartic acid  
141 (CAS no. 56-84-8), L-threonine (CAS no. 72-19-85) and copper sulfate solutions (CAS no. 7758-98-7),  
142 CPRG (chlorophenol red- $\beta$ -D-galactopyranoside) (CAS no. 99792-79-9), vials with 17 $\beta$ -estradiol (CAS  
143 no. 50-28-2), 5 $\alpha$ -dihydrotestosterone (CAS no. 521-18-6), 4-hydroxytamoxifen (CAS no. 68392-35-8),  
144 flutamide (CAS no. 13311-84-7), DMSO (dimethyl sulfoxide) (CAS no. 67-68-5). 96-well plates, gas-  
145 permeable plate sealers, culture flasks with gas-permeable filter cap were purchased from GenoPlast  
146 Biochemicals (Poland). All reagents were of analytical grade purity or better in case of reagents for  
147 microbiological purposes. The instruments and equipment used during the study were: Microtox<sup>®</sup>  
148 500 from Modern Water Ltd. (GB), electronic multi- and single-channel pipettes from Eppendorf  
149 (Germany), NaOH (CAS no. 1310-73-2) and HCl (CAS no. 7647-01-0) (purchased from Avantor  
150 Performance Materials S.A. (Poland)), CP411 pH-meter from Metron (Poland), heater of Thermicon  
151 P<sup>®</sup> (type K1253S) Heraeus Instruments (Germany), microwave heating device (Samsung ME 733K  
152 (maximum power 1150 W) and shaker type water bath 357 from Elpan Laboratory Instruments  
153 (Poland).

## 2.2. Preparation of simulant liquids

154  
155  
156 All simulant solutions were prepared using reagents of analytical grade purity. Artificial saliva  
157 was prepared in accordance to the guidelines described in the DIN:53160-1:2010-10 standard (NaCl  
158 0.53 g/dm<sup>3</sup>, KCl 0.33 g/dm<sup>3</sup>, CaCl<sub>2</sub>·2H<sub>2</sub>O 0.15 g/dm<sup>3</sup>, K<sub>2</sub>HPO<sub>4</sub>·3H<sub>2</sub>O 0.76 g/dm<sup>3</sup>, MgCl<sub>2</sub>·6H<sub>2</sub>O 0.17  
159 g/dm<sup>3</sup>, K<sub>2</sub>CO<sub>3</sub> 0.53 g/dm<sup>3</sup>, and 1% HCl 0.75 g/dm<sup>3</sup>). The pH of the solution was adjusted using a 1%  
160 NH<sub>3</sub> solution to a value of 6.8. To minimize the problem of the background EDC pollution, the Milli-Q  
161 water was additionally purified by the use of an EDC-Pak cartridge (for removing  
162 endocrine-disrupting compounds) at the stage of the preparation of simulation liquids. Additionally,  
163 to reduce the risk of contamination of the glassware with organics, an additional step of heating  
164 utensils at 450°C for at least 4 hours was applied (Fierens et al., 2012). Simulation liquids were stored  
165 at +4 °C prior to performing the extraction process.

## 2.3. Sample collection

166  
167  
168 The migration tests were carried out in accordance with the test procedure indicated in the  
169 Commission Regulation (EU) No. 10/2011 and PN-EN 1186-1:2005 standard. Considering the fact that  
170 the tested packaging is intended for storing a very wide range of products (such as fruits and  
171 vegetables, meat products and various beverages), the simulation liquids most commonly used in the  
172 migration studies (distilled water, acetic acid solution and ethanol solution) were used in the study  
173 (standard procedures, e.g., the EU legislation recommends using 10% ethanol; however, due to the  
174 high alcohol content, an unintended elevated toxicity was observed and a lower ethanol content had  
175 to be utilized). Moreover, a 5% dimethyl sulfoxide (DMSO) solution and artificial saliva solution were  
176 used to check the extraction strength of other solvents (DMSO is considered as a factor reflecting the  
177 lipophilic properties of ingredients present in the product stored). The tests were performed using  
178 the filling method: the packages were filled with their respective simulation fluids up to 5 mm below

179 the upper edge. Since cans and multilayered composite packaging are intended for the long-term  
 180 storage of food, they were held at 60°C for 10 days (240h) after filling,. Additionally, in order to  
 181 determine the effect of temperature on the degree of release of xenobiotics, the different kinds of  
 182 packaging were also exposed to temperatures of 65°C and 121°C and the tests were also performed  
 183 for 336h (these results are presented in manuscript). A different procedure was used in the case of  
 184 research performed with cups. These were filled with boiled solvents up to 5 mm below the upper  
 185 edge. Additionally, in order to determine the effect of microwave heating on the migration of  
 186 chemical compounds from the cups, a microwave treatment was carried out. The treatment was  
 187 stopped when the temperature of the solvents reached 95–100°C. All objects were shaken with  
 188 orbital movement at 100 revolutions per minute (rpm) throughout the time period. Table 1 provides  
 189 more detailed information on the conditions and methods applied in the studies.

190 The extracts tested were stored at -20°C until the biological studies were performed. To learn  
 191 of possible changes in the surface-layer composition and structure of the materials studied, samples  
 192 of packaging material (taken before and after the extraction process) were cut into smaller pieces,  
 193 and surface analyses were performed on them.

Table 1. Information on methods applied in degradation and migration studies.

Type of packaging	Metal cans	Multilayer composite packaging	Cups
Simulant media	Distilled water, 5% ethanol, 3% acetic acid, 5% DMSO, artificial saliva solution		Distilled water, 5% ethanol, 3% acetic acid, 5% DMSO
Conditions	Room temperature	Room temperature	Room temperature
	100°C - 4 h + 60°C - 10 days	60°C - 10 days	filled with hot solvents (95°C -100°C )
	65°C - 30 min	65°C - 30 min	microwave radiation (10 min at 800 W)
121°C - 30 min	121°C - 30 min		
Sampling at:	12 h, 48 h, 240 h and 336 h		0.5 h, 1 h, 2 h, 6 h, 12 h

#### 2.4. Procedures of bioanalytical tests

Microtox<sup>®</sup> is an acute toxicity test, used here in order to determine the level of toxicity occurring after a short time period. The selection of this test was based on the fact that microorganisms represent the primary focus in the food chain, and therefore, any adverse changes occurring in them, directly or indirectly, can have an impact on organisms at higher trophic levels. The XenoScreen YES/YAS test used aimed to show whether the compounds released from the packaging exhibited hormonal activity. The use of genetically modified yeast with human receptors made it possible to estimate the effects of xenobiotics on the health of consumers. Although bioanalytical studies are precisely described elsewhere (Szczepanska et al., 2016; Wiczerzak et al., 2016) we present here complete methodologies to provide a full picture of the work performed.

##### 2.4.1. Microtox<sup>®</sup> methodology

Acute toxicity was assessed by determining the luminescence inhibition of the marine Gram (-) bacteria of *Vibrio fischeri*, after a 30 min exposure to respective samples. The degree of the

211 reduction of natural light output emitted by the bacteria is proportional to the degree of toxicity of a  
212 given sample. pH was adjusted to fall within the 6.5-7.5 range with NaOH and HCl. Acute toxicity was  
213 determined by standard protocol using the Microtox® Analyzer Model 500 and serial dilutions.  
214 Lyophilized reagent with *Vibrio fischeri* bacteria was hydrated with 1 mL of RS and maintained at  
215 5.5±1.0°C, subsequently 100 µL of 10-fold diluted reconstituted Microtox Reagent bacterial solution  
216 and 2 mL of samples were added into the vials. To produce a suitable osmotic pressure (above 2 %) OAS  
217 was added to the vial with the highest concentration and proper dilutions were prepared. For  
218 quality assurance of proper test run the following parameters according to producers guidelines  
219 were assumed: for Microtox® I<sub>0</sub> of bacterial suspension >70 U (chromium sulphate was used as a  
220 positive control of bacterial stock suspension test run).

#### 222 2.4.2. XenoScreen YES/YAS methodology

223 The test was performed on the basis of instructions delivered by the manufacturer, however,  
224 with certain modifications; generally it uses genetically modified yeast cells of *Saccharomyces*  
225 *cerevisiae* with human estrogen hERα or androgen hAR receptors stably integrated into the main  
226 chromosome of the yeast cells. Yeasts exposed to compounds that have endocrine potential produce  
227 β-galactosidase, which oxidizes the CPRG dye in growth medium. The interpretation occurs by  
228 measuring the density of the cell suspension and the color saturation of the oxidized dye.  
229 Furthermore, the cells also contain an expression plasmid carrying the lacZ reporter gene encoding  
230 the enzyme β-galactosidase and means responsive to estrogens (YES) or androgen (YAS). The yeast  
231 cells were cultured from the filter papers in growth medium (basic medium with a vitamin solution,  
232 solution of L-threonine, L-aspartic acid and copper (II) sulfate (VI)). 5 mL of growth medium was  
233 transferred to a labeled culture bottles with caps with a gas permeable filter, afterwards the yeast  
234 disks were sterilely transferred and placed on an orbital shaker set at 32 °C temperature and 100 rpm  
235 for 48 hours. 100 µL of DMSO was added to each control vial containing standards: E2 (control of YES  
236 agonist), DHT (control of YAS agonist), HT ( control of YES antagonist), FL (control of YAS antagonist).  
237 Test plates were prepared in such a way that the controls were in duplicate in eight serial dilutions.  
238 Final hormone concentration in positive controls ranged from 0.10 to 100 µM. 80 µL of 6 mM CRPG  
239 dye was added to each assay well. Next, 100 µL of YES and YAS suspension of yeast culture was  
240 added into agonist and antagonist YES and YAS plates, respectively. Assay plates were sealed with  
241 semi-permeable membranes and placed in the bag zipper moistened with watered gauze on an  
242 orbital shaker for 48 h at 32 °C 100 rpm. After 48 h of incubation, a cell density (by OD) was read at a  
243 wavelength of 690 nm and color intensity at a wavelength of 570 nm was determined. For the  
244 oestrogenic activity, the growth factor (G) and induction ratio (I<sub>R</sub>) according to the equations:

$$245$$
$$246 \quad G = \frac{A_{690,S}}{A_{690,N}} \quad (1)$$

$$247 \quad I_R = \frac{1}{G} \cdot \frac{(A_{570,S} - A_{690,S})}{(A_{570,N} - A_{690,S})} \quad (2)$$

248 where A<sub>690, S</sub> and A<sub>570, S</sub> is absorbance of samples respectively at 690 nm and 570 nm and A<sub>690, N</sub> and  
249 A<sub>570, N</sub> is absorbance of the solvent control respectively at 690 nm and 570 nm. The determinations  
250 were repeated three times.

251 For the data assessment, the criterion was adopted that the tested sample has agonistic  
252 YES/YAS properties if the value of the induction coefficient ≥1.5 (for control solutions) and shows  
253 antagonistic YES/YAS properties if the value of the induction factor ≤66.7 % of the value obtained for  
254 the control sample.

#### 256 2.5. FTIR studies



The FTIR spectra of crystalline products were recorded using Nicolet iS50 FT-IR spectrometer equipped with the Specac Quest single-reflection diamond attenuated total reflectance (ATR) accessory. Spectral analysis was controlled by the OMNIC software package. Polymers were identified by comparison with the reference spectra of the commercially available infrared library database implemented in OMNIC: HR Nicolet Sampler Library.

## 2.6. Chemometric studies

### 2.6.1. Experimental Design and Modeling

To assess the impact of various experimental conditions (resembling actual conditions to which different packaging materials are exposed), such as temperature, extraction time, and the concentration affecting the ecotoxicological response, an experimental design approach was used. A full factorial experimental design with two levels of variation of the input factor ( $2^n$  type) was chosen. The input factors were temperature ( $X_1$ ), extraction time ( $X_2$ ) and concentration ( $X_3$ ). The output function was the ecotoxicity assessment value determined by the two major ecotoxicity tests: Microtox and XenoScreen (with its four options: YES+, YES-, YAS+ and YAS-). Thus, for each experiment, five output values were recorded (Brereton, 2007). The scheme of the experimental design is presented below in Table 2.

274

Table 2. Experimental design  $2^3$

Exp. No.	$X_0$	$X_1$	$X_2$	$X_3$	$X_{12}$	$X_{13}$	$X_{23}$	$X_{123}$	$\Psi_{15}$
1	+1	+1	+1	+1	+1	+1	+1	+1	
2	+1	-1	+1	+1	-1	-1	+1	-1	276
3	+1	+1	-1	+1	-1	+1	-1	-1	
4	+1	-1	-1	+1	+1	-1	-1	+1	277
5	+1	+1	+1	+1	+1	-1	-1	-1	
6	+1	-1	+1	-1	-1	+1	-1	+1	278
7	+1	+1	-1	-1	-1	-1	+1	+1	
8	+1	-1	-1	-1	+1	+1	+1	-1	279

For each of the input factors, two levels of variation were chosen, coded as +1 (high level) and -1 (low level). For the temperature, these levels were 121°C and room temperature; for time, they were 336 and 48 hours; and for concentration, they were the highest and lowest concentrations studied from the experimental scheme. Some minor variations were necessary for cups as the subject (no saliva as extraction media; only two factors were varied for DMSO) of the design, but the general principle was maintained. The experimental design was applied to each type of packaging material (cans, multilayered composite packaging and cups) and for each of the extraction media (water, ethanol, acetic acid, DMSO and saliva).

The experimental design allows for the creation of a polynomial model of the system studied of the form  $Y = a_0 + \sum a_i X_i + \sum a_{ij} X_i X_j + a_{ijk} X_i X_j X_k$ . The model reveals the impact of each input factor on the values of the output function and, additionally, the options for mixed interaction between the inputs leading to changes in the output. The sign and the values of each regression coefficient are measures of the weight and the direction of effect of the input factors. Using the experimental design above, eight regression coefficients were calculated:

295  $a_0$ : intercept; assessment of the “conditional average” value of the output for the experimental  
1 296 conditions;  
2 297  $a_1$ – $a_3$ : coefficients assessing the individual (single) impact of each of the factors studied on the output  
3 298 function;  
4 299  $a_{12}$ ,  $a_{13}$ , and  $a_{23}$ : coefficients assessing the mixed (by couples) impact of the combination of each pair  
5 300 of factors studied on the output function; and  
6 301  $a_{123}$ : coefficient coefficients assessing the mixed (triple) impact of the combination of all three factors  
7 302 studied on the output function.  
8 303 The model is tested for homogeneity of variance, significance of the regression coefficients and  
9 304 validity.

14 305 Additionally, hierarchical cluster analysis (HCA) and principal component analysis (PCA) were  
15 306 applied for data interpretation. For each type of packaging material, a data set was organized having  
16 307 dimensions of [25x8] for cans and multilayered composite packaging and [15x8] for cups. As objects,  
17 308 the packaging material in different extraction media were included, and the features (variables)  
18 309 describing the objects were the regression coefficients calculated by the experimental design  
19 310 procedure (from  $a_0$  to  $a_{123}$ ). It must be mentioned that the cup packaging material set has a lower  
20 311 dimension since only three solvents were included as extraction media (water, ethanol and acetic  
21 312 acid). The major goal of the chemometric data mining was to reveal specific patterns of similarity  
22 313 between the objects and between the variables. This could explain in a proper way any hidden  
23 314 relationships between the effects of the experimental conditions affecting the toxicity records for  
24 315 different packaging materials. Both multivariate statistical methods are well documented and do not  
25 316 need a detailed description (Masserat and Kaufman, 1987). The hierarchical cluster analysis was  
26 317 performed on standardized input data (z-standardization) using Ward’s method of linkage and the  
27 318 squared Euclidean distances as measures of similarity. The cluster significance was determined by  
28 319 the criterion of Sneath. Additionally, PCA was performed (Varimax rotation mode) to confirm the  
29 320 results of clustering.

#### 321 322 2.6.2. MANOVA studies

323 Multivariate analysis of variance (MANOVA) was used to evaluate the effects of the three  
324 main factors of solvent, temperature (temperature regime for the cups), and contact time in addition  
325 to solvent interactions with the other factors on the respective dependent variable (acute toxicity or  
326 endocrine-disruption potential). For the can and multilayer composite packaging experiments, three  
327 different food simulants (distilled water, ethanol, and acetic acid) were used since in the cup  
328 experimental design DMSO and saliva were also included. The three-way MANOVA procedure  
329 compares the acute toxicity and endocrine-disruption potential results obtained under different  
330 experimental conditions using different food simulants. For each type of packaging, three  
331 independent variables (factors) were considered in the factorial design: simulant, temperature  
332 (temperature regime for cup) and contact time. For can and multilayer composite packaging lining  
333 extracts, each of the factors of temperature and contact time takes three levels. This leads to 9  
334 experiments for each food simulant, as conditions for each experiment are obtained by combinations  
335 of temperature and contact time levels (refer to Supplementary Table 1.). For cup extracts, the  
336 contact time takes five levels, which were performed at three temperature regimes: at 25°C, after a



337 microwave oven heating procedure and after using hot solvent (the data are presented in  
1 338 Supplementary Table 1) for each food simulant. Each experiment from both experimental designs  
2 339 was run in triplicate for acute toxicity and in duplicate for the determination of endocrine-disruption  
3 340 potential.  
4 341

### 7 342 3. Results and discussion

9 343 In Supplementary Table 2., the coefficients of all model parameters calculated for all types of  
10 344 packaging and extraction media are given. For convenience, the coded names of the objects are  
11 345 given as follows—the first two letters are for the type of packaging, the next letters indicate the  
12 346 solvent medium, and the last two indicate the ecotoxicity test applied (e.g., Can-Water\_MT means  
13 347 cans in water medium tested by Microtox).  
14 348

#### 17 348 3.1. Discussion on experimental design results

##### 19 349 3.1.1. Extraction medium and package type assessment with respect to toxicity tests

###### 21 350 a) Microtox test results

23 351 It can be noticed (refer to Supplementary Table 2.) that the ethanol solution shows similar  
24 352 behavior when tested in the cases of all the packaging; the same holds true for acetic acid, where the  
25 353 highest toxicity values are recorded. Both cases for saliva are also identical for the can and  
26 354 multilayered composite packaging experiments. Surprisingly, MT toxicity records in water medium  
27 355 are very high for cans in contrast to the very low levels for multilayered composite packaging and cup  
28 356 extracts. DMSO medium is also highly toxic for cans and much lower for multilayered composite  
29 357 packaging.  
30 358

###### 33 358 b) XenoScreen test results

35 359 The same assessment was done for all four XenoScreen tests (see Supplementary Table 3.),  
36 360 YES+, YES-, YAS+ and YAS-, for all tested media and types of packaging. Again,  $a_0$  values were used for  
37 361 the comments and conclusions. As shown in Supplementary Table 3., YES+ and YAS+ tests are very  
38 362 similar in that they indicate low activity for all media and all types of packaging. The records for YES-  
39 363 are highest for all cases with a maximum for cans. YAS- records resemble those for YES- with non-  
40 364 significant differences for the different extraction media.  
41 365

##### 44 365 3.1.2. Experimental conditions impact

46 366 The assessment is based on the values of the regression coefficients  $a_1$ – $a_3$ , which indicate the  
47 367 weights of temperature, time of extraction and concentration on the output function records  
48 368 (toxicity). The temperature impact for Microtox testing (Supplementary Table 4.) is dominantly  
49 369 positive (a temperature increase leads to an increase in toxicity) for cans (DMSO and saliva media),  
50 370 for multilayered composite packaging and for cups in ethanol medium. A significant negative  
51 371 temperature impact is observed for multilayered composite packaging and cups in water medium. All  
372 other temperature effects are negligible. The time impact for Microtox testing (Supplementary Table  
373 4.) is dominantly negative (a decrease in time corresponds to an increase in toxicity) except for two  
374 cases: multilayered composite packaging and cup packages in ethanol solution. The concentration  
375 impact for Microtox testing (Supplementary Table 4.) is dominantly positive with a few non-  
376 significant exceptions (the concentration increase causes toxicity levels to increase). In general, the

377 regression coefficients indicating the impact of the mixed interactions in the system  
 1 378 (temperature/time, temperature/concentration, time/concentration and  
 2 379 temperature/time/concentration) are statistically non-significant and do not contribute to the  
 3 380 interpretation of the model. The impacts of the experimental factors on the toxicity records by all the  
 4 381 XenoScreen tests are much lower and insignificant compared with those indicated by Microtox. In  
 5 382 Table 3, a short summary is given of the impact shown by  $a_1$ ,  $a_2$  and  $a_3$  in all cases tested by  
 6 383 XenoScreen.  
 7  
 8  
 9

10 Table 3. Summary of the experimental factors impact on toxicity indicated by XenoScreen tests (only  
 11 significant effects are presented)  
 12

	$a_1$	$a_2$	$a_3$
YES +	Non-significant impact	Non-significant impact	Non-significant impact
YES-	<b>Cans – acetic acid</b> <b>Cans – saliva (positive impact)</b>	<b>Cups – acetic acid (negative impact)</b> <b>multilayer composite packaging - DMSO (positive impact)</b>	<b>Cans – water</b> <b>Cans – ethanol</b> <b>Cans – acetic acid</b> <b>Cans – DMSO (positive impact)</b>
YAS+	Non-significant impact	Non-significant impact	Non-significant impact
YAS-	Non-significant impact	<b>multilayer composite packaging - saliva (negative impact)</b>	Non-significant impact

### 3.2. MANOVA results and discussion

#### 3.2.1. Microtox

##### a) Cans

384  
 385  
 386  
 387  
 388  
 389 The MANOVA model for the evaluation of the acute toxicity data for the can lining extracts  
 390 exhibits a significant influence by all the main effects (solvent, temperature, and contact time) and  
 391 their interactions on acute toxicity (Supplementary Fig. 1. and Fig. 2.). The most toxic are the acetic  
 392 acid extracts with a mean predicted bioinhibition value of 93.82%, followed by water, ethanol and  
 393 DMSO extracts with bioinhibition values in the range 65-72% (Supplementary Fig. 1a). The extracts of  
 394 the last solvent, saliva, are not toxic, since they are accompanied by an absence of bioluminescence  
 395 inhibition. Generally, for the other two factors of temperature and contact time, acute toxicity  
 396 significantly increases with an increase in each independent variable (Supplementary Figs. 1b and 1c).  
 397 Such an increase is more pronounced for temperature, while for contact time, the maximum  
 398 bioinhibition is at 48 hours.  
 399

400 The solvent interaction effect plots with contact time and temperature for can lining extracts  
 401 are presented in Fig. 2. The solvent-contact time interaction plot (Fig. 2a) exhibits two groups of  
 402 solvents. The first group of solvents consisting of water, ethanol, acetic acid and DMSO has minimum  
 403 extract acute-toxicity levels at 12 h and maximum levels at 48 h following contact time, effecting the  
 404 shape presented in Fig. 2b. The toxicity of saliva extracts decreases with an increase in contact time,  
 405 and the negative bioinhibition value at 336 h (increase in bioluminescence) is an indication that  
 406 hormesis occurs under the conditions of the longest contact times. The solvent-temperature  
 407 interaction shows a quite different behavior for the solvents used for can-lining extracts (Fig. 2b).  
 408 Water, acetic acid and saliva extracts have the lowest acute toxicity levels at 25°C, and their toxicity  
 409 increases with increasing temperature as the effect is more pronounced for the water and saliva  
 solvents. The acute toxicity of ethanol and DMSO extracts does not possess a clear relationship with

410 temperature, and it is worth mentioning that the highest bioinhibition values of DMSO extracts were  
411 obtained at 25°C.

412

413 **Fig. 2.**

414  
415 b) Multilayer composite packaging

416 The MANOVA model of the acute toxicity data for the multilayer composite packaging lining  
417 extracts shows the significance of all main effects and their interactions on the acute toxicity of the  
418 extracts. Again, the most toxic are the acetic acid extracts with bioinhibition values for all obtained  
419 extracts of 100% (Supplementary Fig. 2a). Similarly, in the can-lining extract experiment, acetic acid is  
420 followed by less toxic water, ethanol and DMSO extracts. The toxicity of the multilayer composite  
421 packaging extracts of these solvents (bioinhibition values between 20 and 45%) is significantly lower  
422 than that of the can-lining extracts. Following this trend, the multilayer composite packaging saliva  
423 extracts are characterized by an increase in bioluminescence with a mean predicted bioinhibition  
424 value of -28.76%. The temperature and contact time do not strongly affect the solvent extract acute  
425 toxicity (Supplementary Fig. 2b and 2c), which is an indication that migration of toxic compounds  
426 occurs dominantly at the lowest levels of both factors, namely, 12 h and 25°C.

427 The solvent-contact time and solvent-temperature interaction plots confirm the small  
428 influence of extraction time and temperature on the acute toxicity of particular solvent extracts (Figs.  
429 3a and 3b). An exception could be noted (Fig. 3a) in the solvent-contact-time plot that showed more  
430 pronounced hormesis of saliva extracts at 336 h. The solvent-temperature interaction plot (Fig. 3b)  
431 shows the similar behavior of DMSO and saliva with the can and multilayer composite packaging  
432 extracts, with maximum bioinhibition values for DMSO and saliva extracts at 25°C and 121°C  
433 respectively. In contrast to the can-lining experiment, the maximal acute toxicity of acetic acid  
434 multilayer composite packaging extracts is at 121°C, which is an indication for additional migration of  
435 toxic compounds at the highest temperature level.

436  
437 **Fig. 3.**

438  
439 c) Cups

440 The factors studied (and their interactions) have a significant effect on the acute toxicity of  
441 the extracts of the internal surfaces of cups. The solvent extract toxicity increases in the order of  
442 water, ethanol, and acetic acid with bioinhibition values similar to those of multilayer composite  
443 packaging lining extracts (Supplementary Fig. 3a). The increase in contact time is accompanied first  
444 by a decrease in toxicity and achieving the maximum bioinhibition values at prolonged extraction  
445 times (Supplementary Fig. 3b). Such dependence could be explained by transformations of more  
446 toxic substances to less toxic products during the extractions with durations of 1 to 2 hours, followed  
447 by migration of toxic compounds during prolonged extractions. Different temperature regimes do

448 not strongly affect the acute toxicity of solvent extracts, as the most toxic are extracts obtained after  
1 449 hot solvent treatment (Supplementary Fig. 3c.). It should be mentioned that during microwave-  
2 450 assisted extraction, the heat and mass gradients work in one and the same direction, contrary to the  
3  
4 451 other temperature regimes.  
5

6 452 The solvent-contact time interaction plot (Fig. 4.) shows the different behaviors of the  
7 453 solvent extracts. The acute toxicity of the ethanol extracts increases with increasing extraction time,  
8 454 since the toxicity of the aqueous extracts decreases. The acetic acid extracts follow the pattern  
9 455 presented in the plot of the contact-time effect (Fig. 4a). The solvent-temperature regime interaction  
10 456 plot (Fig. 4b) confirms the small effect of temperature regimes on the acute toxicity of extracts, as  
11 457 the only exception is the low bioinhibition value of ethanol extracts obtained after microwave  
12 458 treatment.  
13  
14  
15

16 459  
17  
18  
19 460 **Fig. 4.**  
20

### 21 461 22 23 462 3.2.2. XenoScreen YES/YAS

#### 24 25 26 463 a) Cans

27  
28 464 The MANOVA implementation to determine the endocrine-disruption potential of the can-  
29 465 lining extracts exhibits a clear difference between their estrogenic and androgenic disruption  
30 466 potential. The extracts of all solvents possess higher androgenic disruption potential than estrogenic  
31 467 disruption potential (Fig. 5.). Significant androgenic agonistic potential (ratio higher than 1 with  
32 468 respect to control values) has acetic acid extracts followed by DMSO and ethanol extracts, since  
33 469 water extracts possess significant androgenic antagonistic potential. The time-effect plot presented  
34 470 in Fig. 6. confirms the difference between their estrogenic and androgenic disruption potential.  
35 471 Similar to the acute-toxicity study of can-lining extracts, the time-effect plot notes the maximum  
36 472 androgenic disruption potential values at 48 h.  
37  
38  
39

40 473  
41  
42 474  
43 475  
44 476 **Fig. 5.**  
45 477  
46  
47

48 478 **Fig. 6.**  
49

50 479  
51  
52 480 The temperature does not strongly affect the solvent extract endocrine-disruption potential  
53 481 (Fig. 7.), as this effect is not significant for estrogenic and androgenic antagonistic potentials. It seems  
54 482 that for both can studies related to acute toxicity and endocrine-disruption potential, the migration  
55 483 of toxic compounds occurs predominantly at 25°C.  
56  
57

58 484

485

**Fig. 7.**

1 486

2 487

3 488

4 489

5 490

6 491

7 492

8 493

9 494

10 495

11 496

12 497

13 498

14 499

15 500

16 501

17 502

18 503

19 504

20 505

21 506

22 507

23 508

24 509

25 510

26 511

27 512

28 513

29 514

30 515

31 516

32 517

33 518

34 519

35 520

36 521

37 522

38 523

39 524

40 525

41 526

42 527

43 528

44 529

45 530

The solvent-contact time interaction plot (Fig. 8.) shows that the highest androgenic disruption potential possessed by the can-lining extracts is obtained at 48 h. It should be mentioned that increasing contact time leads to an increase in androgenic disruption potential of the water extracts, which could be caused by the additional migration of toxic compounds during longer extraction procedures.

**Fig. 8.**

In general, the solvent-temperature interaction plot (Fig. 9.) confirms the small effect of temperature on the endocrine-disruption potential of the extracts. As exceptions, the increase in the androgenic disruption potential of water extracts and the decrease in androgenic antagonistic activity of ethanol extracts could be mentioned. The water extracts exhibit the same behavior as at prolonged extractions, which proves that migration of compounds with higher androgenic disruption potential occurs at higher temperatures and contact times. The decrease in the androgenic antagonistic activity of ethanol extracts with increasing temperature could be explained by the transformation of migrating substances to products with lower androgenic disruption potential.

**Fig. 9.**

b) Multilayer composite packaging (Supplement)

The MANOVA model for the endocrine-disruption potential of multilayer composite packaging lining extracts shows that temperature has no significant influence on the estrogenic disruption potential of extracts, and the same holds true for contact time regarding their androgenic agonistic activity. The solvent effect plot (Supplementary Fig. 4.) for multilayer composite packaging lining extracts shows the difference between their agonistic and antagonistic disruption potentials. Extracts of all solvents possess significantly higher estrogenic and androgenic antagonistic activity than agonistic ones. The acetic acid (YAS-), DMSO (YES-) and saliva (YES-) extracts show significant endocrine-disruption potential.

The time-effect plot does not reveal any large influence of contact time on the endocrine-disruption potential of the extracts model studied (Supplementary Fig. 5.). Only the increasing of androgenic antagonistic activity with an increase in contact time could be excluded from this tendency.

521 Taking into account the MANOVA results, the influence of temperature on the endocrine-  
1 522 disruption potentials of extracts could be discussed only for their androgenic disruption potential.  
2 523 The impact of temperature on androgenic agonistic activity of extracts is not well outlined, but  
3 524 extracts obtained at 65°C show a well-pronounced androgenic antagonistic maximum  
4 525 (Supplementary Fig. 6.). It could be concluded that migration of compounds with high androgenic  
5 526 antagonistic activity occur at 65°C and 336 h contact time.  
6  
7

8  
9 527 The solvent-time interaction plot (Supplementary Fig. 7.) confirms significant endocrine-  
10 528 disruption potential of acetic acid (YAS-), DMSO (YES-) and saliva (YES-, YAS-) extracts. The highest  
11 529 androgenic antagonistic activity of acetic acid extracts obtained after 336 h supports the previously  
12 530 mentioned increase with time. The solvent-temperature interaction plot shows that the maximum  
13 531 values of antagonistic disruption potential for the acetic acid, DMSO and saliva extracts are obtained  
14 532 at 65°C (Supplementary Fig. 8.). It should be mentioned that both interaction plots show significant  
15 533 estrogen and androgen antagonistic potential in the saliva extracts.  
16  
17  
18

### 19 534

### 20

### 21 535 3.3. Multivariate statistics

22 536 In the figures below (Supplementary Figs. 9-11), the graphical output of the cluster and  
23 537 principal components analysis is shown. It must be kept in mind that the chemometric analysis aims  
24 538 to assess the effect of the experimental conditions on the toxicity record of three different types of  
25 539 packaging material. This assessment is based on the results of the polynomial model obtained by the  
26 540 experimental design procedure. The important features are therefore the regression coefficient  
27 541 showing the effects of various experimental conditions in different extraction media and for different  
28 542 packaging materials.  
29  
30  
31

#### 32 543

#### 33

#### 34 544 a) Cans

35 545 In Supplementary Fig. 9a-c, the results from the hierarchical clustering of the variables  
36 546 (regression weights) and of the various toxicity tests applied to the packaging materials for cans in  
37 547 different extraction media are shown. Additionally, the biplot of PCA for the relationship between  
38 548 the factor loadings for two identified latent factors is presented. The same scheme is used for the  
39 549 other two packaging materials – multilayered composite packaging and cups.  
40  
41

42 550 Based on data presented in Supplementary Fig. 9a, it is evident that a close relationship  
43 551 exists between the features assessing the “average” toxicity ( $a_0$ ), the temperature effect ( $a_1$ ) and the  
44 552 concentration effect ( $a_3$ ) for can packaging. The effect of the time of extraction ( $a_2$ ) is not directly  
45 553 related to the other impacts and influences of mixed effects with time involvement. It could be  
46 554 concluded that the toxicity of the can extracts is subject to two major impacts—one related to  
47 555 concentration and temperature, and the other, to the time of extraction. This pattern separation has  
48 556 to be considered in relationship with the results shown in Supplementary Fig. 9b. All XenoScreen  
49 557 toxicity tests show a high level of similarity and form a very homogeneous cluster. This might mean  
50 558 that the effect of the extraction media is negligible. On the other hand, the Microtox test indicates  
51 559 variability with respect to the extraction media: Saliva and ethanol are outliers showing some  
52 560 resemblance to the XenoScreen tests, and water and DMSO are relatively similar to each other but  
53 561 very different from the XenoScreen tests. In Supplementary Fig. 9c, the relationship previously  
54 562 mentioned for the linkage between the regression coefficients as indicators for experimental factors  
55 563 impact is proven:  $a_0$ ,  $a_1$  and  $a_3$  belong to one latent factor, and  $a_2$  belongs to another.

564

1 565 b) Multilayer composite packaging

2  
3 566 As seen in Supplementary Fig. 10a, the clustering of the regression coefficients for multilayer  
4 567 composite packaging is slightly different from that of the cans. Here, the “average” toxicity weight  $a_0$   
5 568 is related to  $a_2$  and  $a_3$  (the time of extraction and concentration), and  $a_1$  (temperature impact) differs  
6 569 from the rest. This might mean that for multilayer composite packaging, the temperature impact is  
7 570 more specific, as the time of extraction impact was for can packaging. This is entirely confirmed by  
8 571 the biplot of factor loadings (Supplementary Fig. 10c) from PCA. The linkage between the different  
9 572 objects of multilayer composite packaging tested for toxicity (Microtox and XenoScreen) in different  
10 573 extraction media is the same as in the case of can packaging: non-specific and homogeneous (with  
11 574 respect to extraction media) results with XenoScreen and more specific with Microtox. Again, testing  
12 575 the toxicity using Microtox indicates significant differences for water, ethanol and saliva media and a  
13 576 slight resemblance between acetic acid and DMSO media with XenoScreen testing.

14 577

15 578 c) Cups

16 579 The results for the cup packaging material are obtained from the results of fewer  
17 580 experiments as already indicated. In Supplementary Fig. 11a, the clustering of  $a_0$  and  $a_3$  is obvious,  
18 581 since  $a_1$  and  $a_2$  are joined together. This means that the concentration factor is significant for the  
19 582 general toxicity, and the time and temperature factors form the other pattern of impact. The  
20 583 principal component analysis (biplot diagram in Supplementary Fig. 11c) confirms this conclusion. In  
21 584 Supplementary Fig. 11b, the non-specificity of the XenoScreen tests is indicated again. The Microtox  
22 585 test is seriously affected by the ethanol media (an outlier), and the other two media tested (water  
23 586 and acetic acid) are similar to each other but different from XenoScreen.

24 587

25 588 3.4. Results of FTIR studies

26 589 The spectra are presented in the electronic supplementary materials to this paper  
27 590 (Supplementary Figs. 16-18, respectively, for the spectra of can linings, multilayer composite  
28 591 packaging and cups). Each spectrum of the lining after extraction with a given solvent (for given time  
29 592 and temperature regime) was compared in reference to the spectrum of the “original” lining, i.e.,  
30 593 before the extraction. The bands missing after the extraction are indicated with the blue arrows. The  
31 594 new bands that emerged or were definitely enlarged (as a result of the extraction) are denoted with  
32 595 the red arrows.

33 596 FT-IR ATR spectra of the can lining confirm the chemical character of the polymer as an epoxy  
34 597 resin mixture (Supplementary Fig. 12). They also exhibit a very high degree of resemblance to the FT-  
35 598 IR spectra of the diglycidyl ether of the bisphenol A mixture (Supplementary Fig. 13). The correlation  
36 599 coefficients between the measured and library spectra are 67.41% for the epoxy resin and 67.37% for  
37 600 the spectrum of the diglycidyl ether of the bisphenol A mixture. The spectral similarity was also  
38 601 inspected visually. The major differences, i.e., additional bands that are found in the 2700-2100  $\text{cm}^{-1}$   
39 602 region, are most likely caused by the contamination of the resin during the manufacturing process.  
40 603 This additional absorption may be produced by the remnants of a catalyst (most probably  
41 604 thiocyanate) in the polymer. Instrumental studies aiming for its identification are being continued. As  
42 605 observed in all extraction experiments, the impurities responsible for the appearance of the

606 additional bands were repeatedly eluted with every solution applied to the extraction  
607 (Supplementary Figs. 16a-y). This means they are not incorporated into the polymer chain but are  
608 only weakly interacting with it. Moreover, it is very likely that these impurities are water-soluble.  
609 Such conclusions are confirmed by the fact that the correlation percentage between the spectrum of  
610 the epoxy resin and the studied can lining increased to nearly 71% after the extractions  
611 (Supplementary Fig. 16).

612 The multilayer composite packaging lining is a pure polyethylene (93.99% resemblance,  
613 Supplementary Fig. 14), which is basically not affected by the treatment with various solutions up to  
614 65°C. At higher temperatures, the polyethylene is probably oxidized and/or absorbs the organic  
615 molecules of the solvent, which results in the appearance of additional bands that are ascribed to the  
616 absorption by carbonyl groups (please refer to Supplementary Fig. 17 for details). Similar to  
617 multilayer composite packaging the cup lining is polyethylene (93.91% match, Fig. 15). The  
618 correlations between the spectra of samples of cups treated with the studied liquids and the  
619 spectrum of polyethylene remain within a very narrow range of 93.64-94.18%. The results indicate  
620 that the interior of the cup is practically unaffected by treatments with the test solutions (please  
621 refer to Supplementary Fig. 18 for details).

#### 622 4. Conclusions

623  
624 The massive production and extensive usage of various packaging materials such as cups,  
625 cans, and composites (e.g., TetraPak) require a careful assessment of the impact of different storage  
626 and packaging conditions (temperature, disinfection, preserving, extracting and washing solvents) on  
627 the pollution and toxic effects of the packaging that becomes waste. Since the variety of  
628 temperature, type of solvent and concentration influences is quite broad, it seems reasonable to  
629 interpret the experimental results by chemometric means, including carefully designed experiments.  
630 An additional problem is the involvement of different ecotoxicity tests to assess the possible  
631 hazardous impact of the packaging wastes after usage or in the case of prolonged food-package  
632 contact under unfavorable conditions. Finally, an objective comparison of the chemical composition  
633 of the package lining before and after extraction procedures seems important in order to correctly  
634 assess the toxicity hazards.

635 FT-IR ATR spectroscopy is a useful, routine technique that allows to monitor the chemical  
636 changes of a polymer coating without any special pretreatment of the samples, provided they adhere  
637 to the refracting crystal (Tiefenhaller et al., 2017, Nikafshar et al., 2017, Yao et al., 2017). As studied  
638 by Tiefenhaller et al. (2017) the thermal stability of diglycidyl ether of the bisphenol A varies greatly  
639 with thermal regime applied and FTIR studies are indispensable to study processes occurring there  
640 and versatile transformation products are generated in the process and released to surrounding  
641 environment. Manguia-Lopez and Soto-Valez (2001) studied degradation and migration processes on  
642 tuna fish and pepper cans with chromatographic and FTIR methods. Enhanced migration of BPA and  
643 BADGE derivatives was stated in case of thermal treatment of objects (impact of time was not so  
644 significant). FCM and food itself processing certainly has also impact the package material  
645 degradation but also on degradation of (on the other hand favorable and desired) antioxidants; such  
646 non-intentional impact of treatment and processing was studied e.g. by Alin and Hakkarainen (2011)  
647 with gas chromatography methods or Gulmine et al. (2003) with FTIR spectroscopy. The microwave  
648 heating (in comparison to conventional heating) caused significantly higher specific migration of  
649 antioxidants studied. In other works, Atek and Belhaneche-Bensemra (2005) studied (with FTIR



650 methods) impact of simulation media and time/temperature regime on stability of poly (vinyl  
1 651 chloride) as well as specific migration; the applicability of spectroscopic methods was also confirmed  
2 652 in field of mass transfer studies. For these, among other, reasons Nikafshar et al. (2017) started  
3 653 searching for renewable bio-based epoxy resin that could possibly be used as can lining material  
4 654 however with reduced toxicity. The vanillin-based product was confirmed to possess similar  
5 655 mechanical behavior like currently used analogs of diglycidyl ether of the bisphenol A.

6 656 Utilizing biological methods in FCM degradation and SM studies is less common than  
7 657 application of instrumental techniques known since mid XIX century. Most of these biological studies  
8 658 involved acute toxicity, endocrine potential, genotoxicity, cytotoxicity and mutagenicity  
9 659 determination. In the work of Mertl et al. (2014) migration of xenobiotics from carton and  
10 660 polypropylene packaging into food simulants was studied with CALUX assay; antagonistic effects  
11 661 were noted for foil and carton for milk product extract while no androgenic actions could be noted.  
12 662 Endocrine potential of recycled and virgin paper kitchen rolls was also studied by Vinggaard et al.,  
13 663 (2000). In this case estrogenic response was observed mainly for ethanol extracts of recycled paper.  
14 664 Test with HELN, HG5LN cell lines was used by Chevolleau et al. (2016) to assess toxicity/endocrine  
15 665 potential of water stored in PET and glass bottles under different treatment processes, although the  
16 666 approach suggested did not allow to obtain any distinctive measures of endocrine potential. Such  
17 667 potential was found by Wagner and Oehlmann (2011) that performed similar studies however  
18 668 utilizing E-SCREEN assay; significant estrogenic effects in a human cancer cell line from 19.8 to 50.2%  
19 669 compared to 17-estradiol was confirmed. Galotto and Ulloa (2010) studied estrogenic activity of  
20 670 simulated liquids extracts of plastic packaging. Fatty simulation products appeared to have the  
21 671 highest estrogen activity for paper/aluminum/PE composites. Acute toxicity with bioluminescent  
22 672 bacteria of extracts of metal cans with polymeric linings was studied by Szczepańska et al. (2017) and  
23 673 acetic acid extracts appeared to be the most toxic to bioindicating organisms.

24 674 Certainly more studies are being performed in this area however their description falls out of  
25 675 scope of this paper. Still, it should be stressed that none of approaches utilized all three  
26 676 (instrumental, biological and chemometric) methods to study degradation phenomena of FCM. In the  
27 677 present studies, all of these aspects mentioned above were taken into account by the application of  
28 678 a full factorial experimental design followed by i) regression modeling of the experimental effects on  
29 679 the ecotoxicity readings, ii) ANOVA and MANOVA estimation of the experimental conditions as  
30 680 significant factors affecting the toxicity results and iii) IRFT analysis of the packaging. It is shown that  
31 681 the effects of temperature and extraction solvents could be quantitatively assessed with good  
32 682 correlation between different statistical estimates. Comparison of the results of instrumental and  
33 683 biological studies confirm the assumptions that bioassays can serve as a valuable and validated tool  
34 684 in assessing the stability and impact of packages on goods stored both for short and long periods of  
35 685 time. In some cases, the bioassays were proven to be more sensitive and reliable than IR studies,  
36 686 especially when studies deal with assessing the impact of acidic or alcohol-containing stimulants. In  
37 687 this study, it was confirmed that instrumental screening studies are not precise enough to assess the  
38 688 change in composition of FCM after some basic treatment processes, reflecting those processes that  
39 689 naturally occur during packaging and storage. On the other hand, bioassays may deliver suitable  
40 690 information when the results of extract screening of materials are referred to validated results for  
41 691 their respective lining material and chemometric tools are utilized to assess these relationships.  
42 692 Certainly, the method described, although proven to be reliable tool in FCM studies, has its  
43 693 limitations; just to mention: i) necessity to use non-toxic simulation agents not always reflecting

694 already standardized instrumental methodologies, ii) need of performing studies with certifies  
1 695 organisms from different trophic levels, iii) lack of sufficient number of correlation studies to explain  
2 696 observed toxicological responses under different extraction conditions, iv) involving time-tested and  
3 697 sometimes highly qualified personnel to perform instrumental, biological and chemometric studies.  
4 698

6 698 In any case, the performance of future work is indispensable to i) identify the chemicals  
7 699 responsible for observable toxicological levels (currently being performed in many scientific centers  
8 700 and laboratories including those of the authors), ii) assess the applicability of other bioassays as  
9 701 presented in the methodology of this research, iii) construct a battery of bioassays enabling exposure  
10 702 and degradation assessment for different types of packages and FCM, being at the same time  
11 703 complementary and universal for various treatment regimes, iv) propose international standards on  
12 704 the application of certified bioassays as recognized tools in the assessment of exposure to pollutants  
13 705 migrating from and created within FCMs, and v) comprehensively estimate (with classical and  
14 706 biological tools) the impact of packaging material wastes reaching different environmental niches  
15 707 after being used by households and industry, as they pose a serious source of small molecules and  
16 708 microplastics.  
17 709

#### 23 710 Acknowledgments:

25 711 The work has been co-financed by the National Science Center, Poland, grant no.  
26 712 2015/17/N/ST4/03835. The support of H2020 program of the European Union (project Materials  
27 713 Networking) is gratefully acknowledged by prof. V. Simeonov, prof. S. Tsakovski, Dr. M. Nedyalkova  
28 714 and Dr. G. Yotova.  
29 715

#### 33 716 References:

- 35 717 Alin, J., Hakkarainen, M., 2011. Microwave Heating Causes Rapid Degradation of Antioxidants in  
36 718 Polypropylene Packaging, Leading to Greatly Increased Specific Migration to Food Simulants As  
37 719 Shown by ESI-MS and GC-MS. *J. Agric. Food Chem.* 59, 5418-5427  
38 720 10:36
- 40 721 Arvanitoyannis, I.S., Kotsanopoulos, K. V., 2014. Migration Phenomenon in Food Packaging. *Food-*  
41 722 *Package Interactions, Mechanisms, Types of Migrants, Testing and Relative Legislation-A Review.*  
42 723 *Food Bioprocess Technol.* 7, 21–36.
- 44 724 Atek, D., Belhaneche-Bensemra, N., 2005. FTIR investigation of the specific migration of additives  
45 725 from rigid poly(vinyl chloride), *Eur. Polym. J.* 41, 707-714  
46 726 10:35
- 48 727 Brereton, R.G., 2007. *Applied chemometrics for scientists.* John Wiley & Sons.
- 49 728 Canellas, E., Vera, P., Nerín, C., 2015. Risk assessment derived from migrants identified in several  
50 729 adhesives commonly used in food contact materials. *Food Chem. Toxicol.* 75, 79–87.
- 51 730 Chevolleau, S., Debrauwer, L., Stroheker, T., Viglino, L., Mourahib, I., Meireles, M.H., Grimaldi, M.,  
731 Balaguer, P., di Gioia, L., 2016. A consolidated method for screening the endocrine activity of drinking  
732 water. *Food Chem.* 213, 274–283.
- 733 Comission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended  
734 to come into contact with food. *Official Journal of the European Union* 2011; 54: 1–89,  
735 [https://doi.org/10.3000/17252555.L\\_2011.012.eng](https://doi.org/10.3000/17252555.L_2011.012.eng)

- 736 Commission Regulation (EU) 2018/213 of 12 February 2018 on the use of bisphenol A in varnishes  
1 737 and coatings intended to come into contact with food and amending Regulation (EU) No 10/2011 as  
2 738 regards the use of that substance in plastic food contact materials. *Off. J. Eur. Union.* 41, 6-12.
- 3  
4 739 Fierens, T., Servaes, K., Van Holderbeke, M., Geerts, L., De Henauw, S., Sioen, I., Vanermen, G., 2012.  
5 740 Analysis of phthalates in food products and packaging materials sold on the Belgian market. *Food*  
6 741 *Chem. Toxicol.* 50, 2575–2583.
- 7  
8 742 Galotto, M., Ulloa, P., 2010. Detection and Identification of Oestrogen-Active Substances in Plastic  
9 743 Food Packaging Migrates. *Packag. Technol. Sci.* 23, 253–266.
- 10  
11 744 García, R.S., Silva, A.S., Cooper, I., Franz, R., Losada, P.P., 2006. Revision of analytical strategies to  
12 745 evaluate different migrants from food packaging materials. *Trends Food Sci. Technol.* 17, 354–366.
- 13  
14 746 Guart, a, Bono-Blay, F., Borrell, A., Lacorte, S., 2011. Migration of plasticizersphthalates, bisphenol A  
15 747 and alkylphenols from plastic containers and evaluation of risk. *Food Addit. Contam. Part A* 28, 676–  
16 748 685.
- 17  
18 749 Gulmine J., V., Janissek, P., R., Heise, H., M., Akcelrud, L., 2003. Degradation profile of polyethylene  
19 750 after artificial accelerated weathering. *Polym. Degrad. Stab.* 79, 385-397.
- 20  
21 751 Hu, Y., Wang, R., Xiang, Z., Qian, W., Han, X., Li, D., 2014. Mixture effects of nonylphenol and di-n-  
22 752 butyl phthalate (monobutyl phthalate) on the tight junctions between Sertoli cells in male rats in  
23 753 vitro and in vivo. *Exp. Toxicol. Pathol.* 66, 445–454.
- 24  
25 754 Kudlak, B., Szczepańska, N., Owczarek, K., Mazerska, Z., Namieśnik, J., 2015. Revision of Biological  
26 755 Methods for Determination of EDC Presence and Their Endocrine Potential. *Crit. Rev. Anal. Chem.* 45,  
27 756 191–200.
- 28  
29 757 Lau, O.-W., Wong, S.-K., 2000. Contamination in food from packaging material. *J. Chromatogr. A* 882,  
30 758 255–270.
- 31  
32 759 Li, X., Yin, P., Zhao, L., 2017. Effects of individual and combined toxicity of bisphenol A, dibutyl  
33 760 phthalate and cadmium on oxidative stress and genotoxicity in HepG 2 cells. *Food Chem. Toxicol.*  
34 761 105, 73–81.
- 35  
36 762 Maisanaba, S., Pichardo, S., Jordá-Beneyto, M., Aucejo, S., Cameán, A.M., Jos, Á., 2014. Cytotoxicity  
37 763 and mutagenicity studies on migration extracts from nanocomposites with potential use in food  
38 764 packaging. *Food Chem. Toxicol.* 66, 366–372.
- 39  
40 765 Massart D. L, Kaufman L. Interpretation of analytical data by the use of Cluster Analysis, Elsevier,  
41 766 Amsterdam, 1987
- 42  
43 767 Mertl, J., Kirchnawy, C., Osorio, V., Grininger, A., Richter, A., Bergmair, J., Pyerin, M., Washüttl, M.,  
44 768 Tacker, M., 2014. Characterization of estrogen and androgen activity of food contact materials by  
45 769 different in vitro bioassays (YES, YAS, ER $\alpha$  and AR CALUX) and chromatographic analysis (GC-MS,  
46 770 HPLC-MS). *PLoS One* 9.
- 47  
48 771 Moreira, M.A., André, L.C., Cardeal, Z.L., 2013. Analysis of phthalate migration to food simulants in  
49 772 plastic containers during microwave operations. *Int. J. Environ. Res. Public Health* 11, 507–26.
- 50  
51 773 Moreta, C., Tena, M.T., 2014. Determination of perfluorinated alkyl acids in corn, popcorn and  
774 popcorn bags before and after cooking by focused ultrasound solid-liquid extraction, liquid  
775 chromatography and quadrupole-time of flight mass spectrometry. *J. Chromatogr. A* 1355, 211–218.
- 776 Manguia-Lopez, E., M., Soto-Valez, H., 2001. Effect of Heat Processing and Storage Time on Migration  
777 of Bisphenol A (BPA) and Bisphenol A-Diglycidyl Ether (BADGE) to Aqueous Food Simulant from  
778 Mexican Can Coatings. *J. Agric. Food Chem.* 49, 3666-3671  
779 10:38

- 780 Nikafshar S., Zabihi O., Hamidi S., Moradi Y., Barzegar S., Ahmadi M., Naebe M., 2017, A renewable  
1 781 bio-based epoxy resin with improved mechanical performance that can compete with DGEBA. RSC  
2 782 Adv., 7, 8694–8701.
- 3  
4  
5 783 Ossberger, M., 2015. Food migration testing for food contact materials, Global Legislation for Food  
6 784 Contact Materials. Elsevier Ltd.
- 7  
8 785 Ozaki, A., Yamaguchi, Y., Fujita, T., Kuroda, K., Endo, G., 2005. Safety assessment of paper and board  
9 786 food packaging: chemical analysis and genotoxicity of possible contaminants in packaging. Food  
10 787 Addit. Contam. 22, 1053–60.
- 11  
12 788 Ozaki, A., Yamaguchi, Y., Fujita, T., Kuroda, K., Endo, G., 2004. Chemical analysis and  
13 789 genotoxicological safety assessment of paper and paperboard used for food packaging. Food Chem.  
14 790 Toxicol. 42, 1323–1337.
- 15  
16 791 Pérez-Palacios, D., Fernández-Recio, M.Á., Moreta, C., Tena, M.T., 2012. Determination of bisphenol-  
17 792 type endocrine disrupting compounds in food-contact recycled-paper materials by focused ultrasonic  
18 793 solid-liquid extraction and ultra performance liquid chromatography-high resolution mass  
19 794 spectrometry. Talanta 99, 167–174.
- 20  
21 795 Pezo, D., Fedeli, M., Bosetti, O., Nerín, C., 2012. Aromatic amines from polyurethane adhesives in  
22 796 food packaging: The challenge of identification and pattern recognition using Quadrupole-Time of  
23 797 Flight-Mass Spectrometry. Anal. Chim. Acta 756, 49–59.
- 24  
25 798 PN-EN 1186-1:2005 Material and goods for contact with food products - Plastics - Part 1: Guide to  
26 799 select conditions and methods to study global migration, [in Polish: Materiały i wyroby przeznaczone  
27 800 do kontaktu z produktami spożywczymi -- Tworzywa sztuczne -- Część 1: Przewodnik dotyczący  
28 801 wyboru warunków i metod badań migracji globalnej]
- 29  
30 802 Raptopoulou, K.G., Pasias, I.N., Thomaidis, N.S., Proestos, C., 2014. Study of the migration  
31 803 phenomena of specific metals in canned tomato paste before and after opening. Validation of a new  
32 804 quality indicator for opened cans. Food Chem. Toxicol. 69, 25–31.
- 33  
34 805 Sanches-Silva, A., Andre, C., Castanheira, I., Cruz, J.M., Pastorelli, S., Simoneau, C., Paseiro-Losada, P.,  
35 806 2009. Study of the migration of photoinitiators used in printed food-packaging materials into food  
36 807 simulants. J. Agric. Food Chem. 57, 9516–9523.
- 37  
38 808 Szczepańska, N., Namieśnik, J., Kudlak, B., 2016. Assessment of toxic and endocrine potential of  
39 809 substances migrating from selected toys and baby products. Environ. Sci. Pollut. Res. 23, 24890–  
40 810 24900.
- 41  
42 811 Szczepańska, N., Kudlak, B., Yotova, G., Tsakovski, S., Namieśnik, J., 2017. Assessing Acute Toxicity of  
43 812 Selected Packages Internal Layers Extracts using Microtox<sup>®</sup>. Packag. Technol. Sci. 30, 347–357.
- 44  
45 813 Szczepańska, N., Kudlak, B., Namieśnik, J., 2018. Assessing ecotoxicity and the endocrine potential of  
46 814 selected phthalates, BADGE and BFDGE derivatives in relation to environmentally detectable levels.  
47 815 Sci. Total Environ. 610–611, 854–866.
- 48  
49 816 Tiefenhaller R., Fluch R., Strauss B., Hild S., 2017. Thermal stability and lifetime prediction of an  
50 817 epoxide adhesive system. In Deformation and fracture behaviour of polymer materials, eds. W.  
51 818 Grellmann, B. Langer Springer International Publishing, 297-309.
- 819 Vinggaard, A.M., Körner, W., Lund, K.H., Bolz, U., Petersen, J.H., 2000. Identification and  
820 quantification of estrogenic compounds in recycled and virgin paper for household use as  
821 determined by an in vitro yeast estrogen screen and chemical analysis. Chem. Res. Toxicol. 13, 1214–  
822 1222.

823 Wagner, M., Oehlmann, J., 2011. Endocrine disruptors in bottled mineral water: Estrogenic activity in  
1 824 the E-Screen. *J. Steroid Biochem. Mol. Biol.* 127, 128–135.  
2  
3 825 Wiczerzak, M., Kudlak, B., Yotova, G., Nedyalkova, M., Tsakovski, S., Simeonov, V., Namieśnik, J.,  
4 826 2016. Modeling of pharmaceuticals mixtures toxicity with deviation ratio and best-fit functions  
5 827 models. *Sci. Total Environ.* 571, 259–268.  
6  
7 828 Yao S.-F., Chen X.-T., Ye H.-M., 2017, Investigation of structure and crystallization behavior of  
8 829 poly(butylene succinate) by Fourier Transform Infrared Spectroscopy. *J. Phys. Chem. B* 121, 9476-  
9 830 9485.  
10  
11 831

832 **Figures captions:**

1  
2 833 Fig. 1. Schematic presentation of research performed in the study

3  
4 834 Fig. 2. Solvent interaction effect plots for acute toxicity determination of can lining extracts with: (a)  
5 835 contact time [h] and (b) temperature [°C]

6  
7 836 Fig. 3. Solvent interaction effect plots for acute toxicity determination of multilayer composite  
8 837 packaging lining extracts with: (a) contact time [h] and (b) temperature [°C]

9  
10  
11 838 Fig. 4. Solvent interaction effect plots for acute toxicity determination of cup internal surface extracts  
12 839 with: (a) contact time [h] and (b) temperature regime

13  
14  
15 840 Fig. 5. Solvent effect plot for endocrine disruption potential determination of can lining extracts

16  
17 841 Fig. 6. Time effect plot for endocrine disruption potential determination of can lining extracts

18  
19 842 Fig. 7. Temperature effect plot for endocrine disruption potential determination of can lining extracts

20  
21 843 Fig. 8. Solvent-time interaction plot for endocrine disruption potential determination of can lining  
22 844 extracts

23  
24 845 Fig. 9. Solvent-temperature interaction plot for endocrine disruption potential determination of can  
25 846 lining extracts



Figure 1

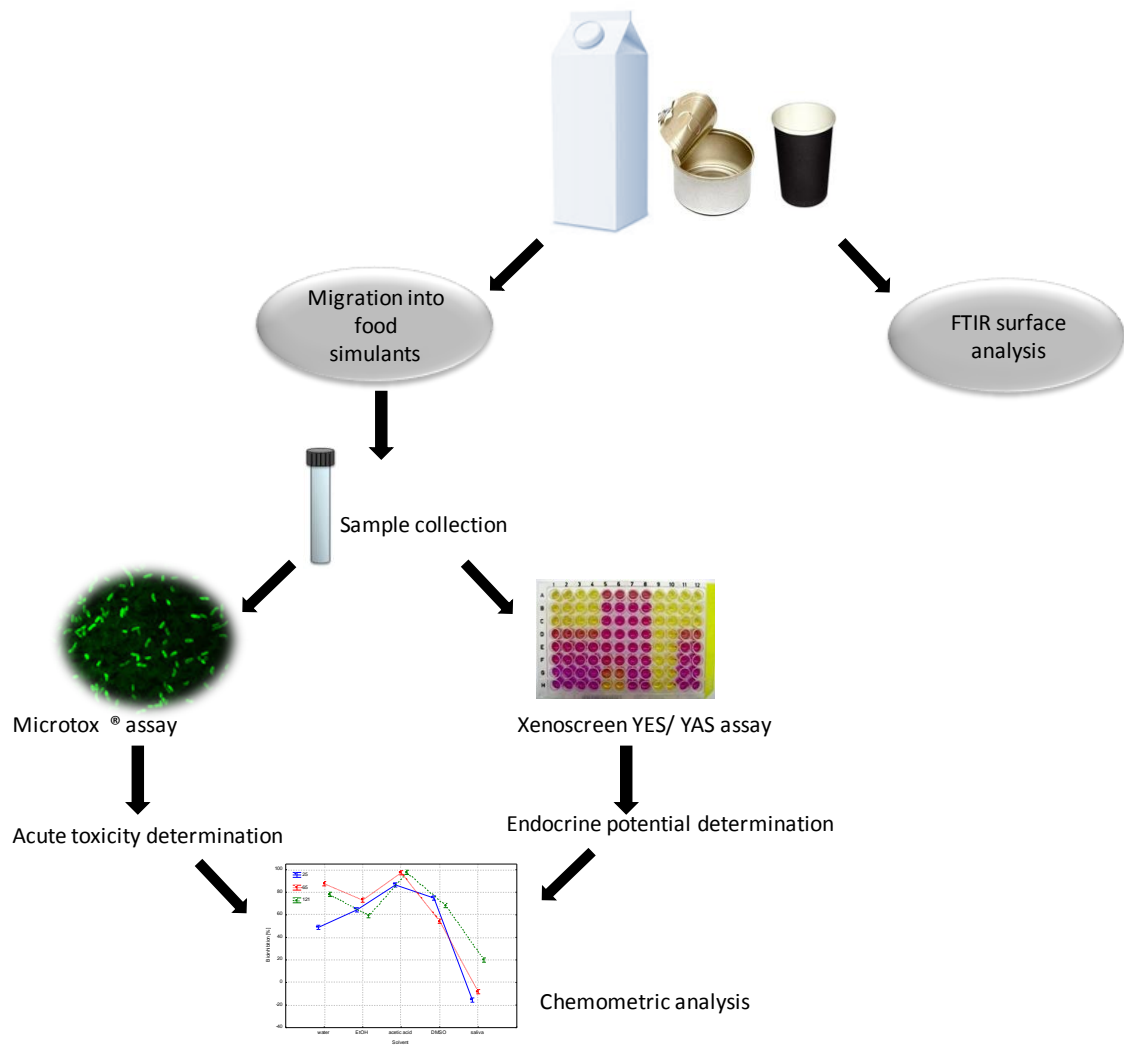


Fig. 1. Schematic presentation of research performed in the study

Figure 2

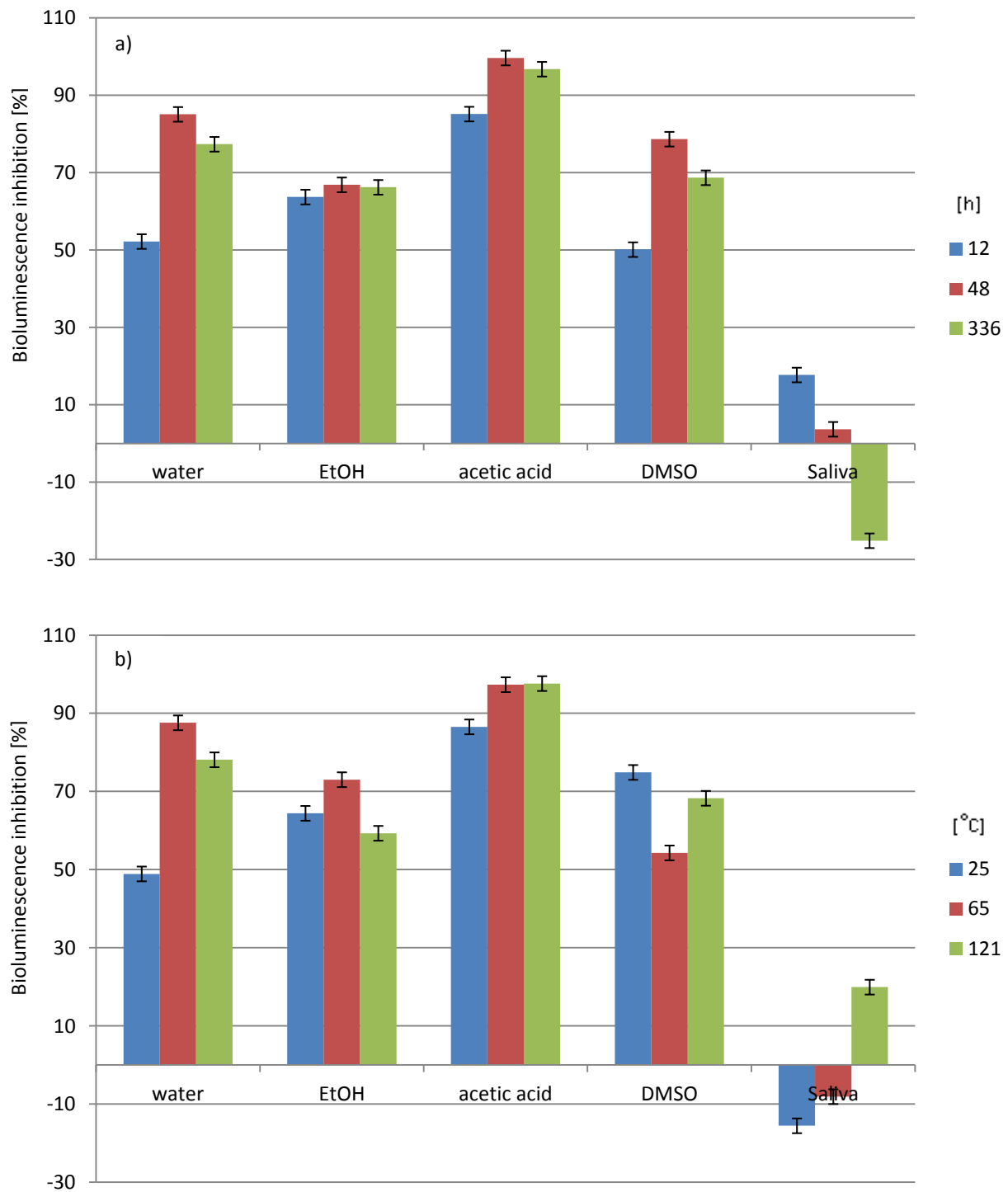


Fig. 2. Solvent interaction effect plots for acute toxicity determination of can lining extracts with: (a) contact time [h] and (b) temperature



Figure 3

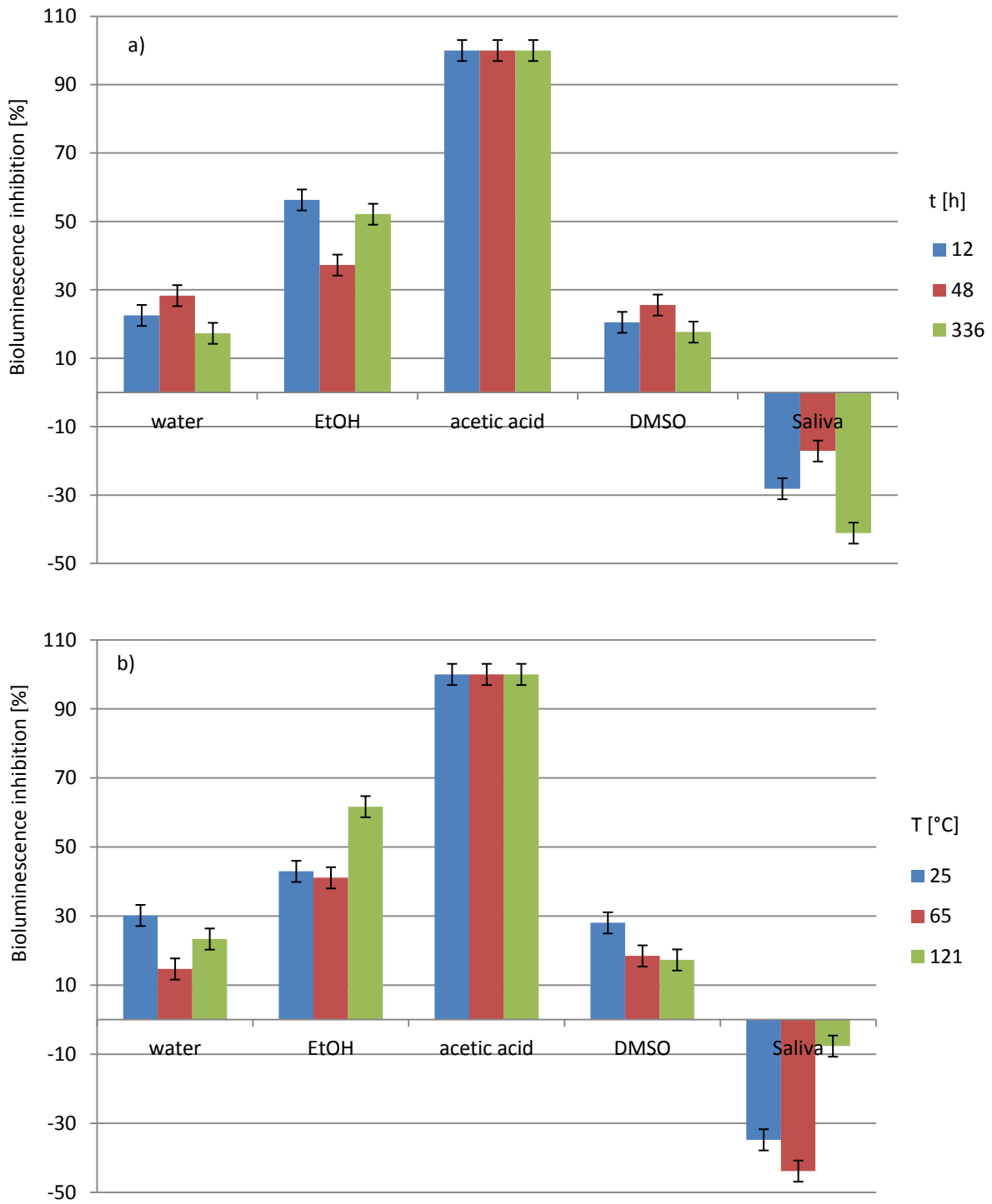


Fig. 3. Solvent interaction effect plots for acute toxicity determination of multilayer composite packaging lining extracts with: (a) contact time [h] and (b) temperature [°C]

Figure 4

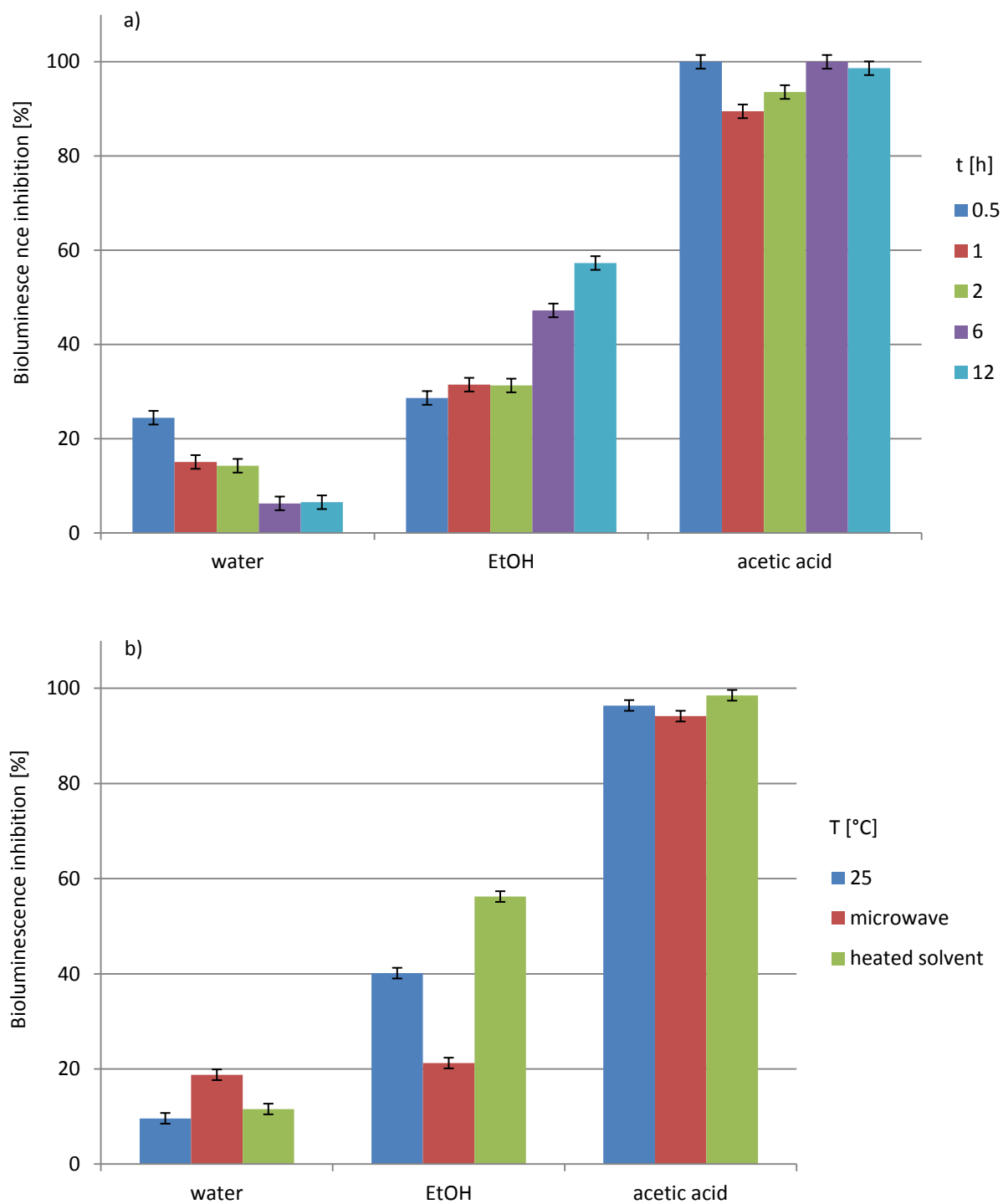


Fig. 4. Solvent interaction effect plots for acute toxicity determination of cup internal surface extracts with: (a) contact time [h] and (b) temperature regime

Figure 5

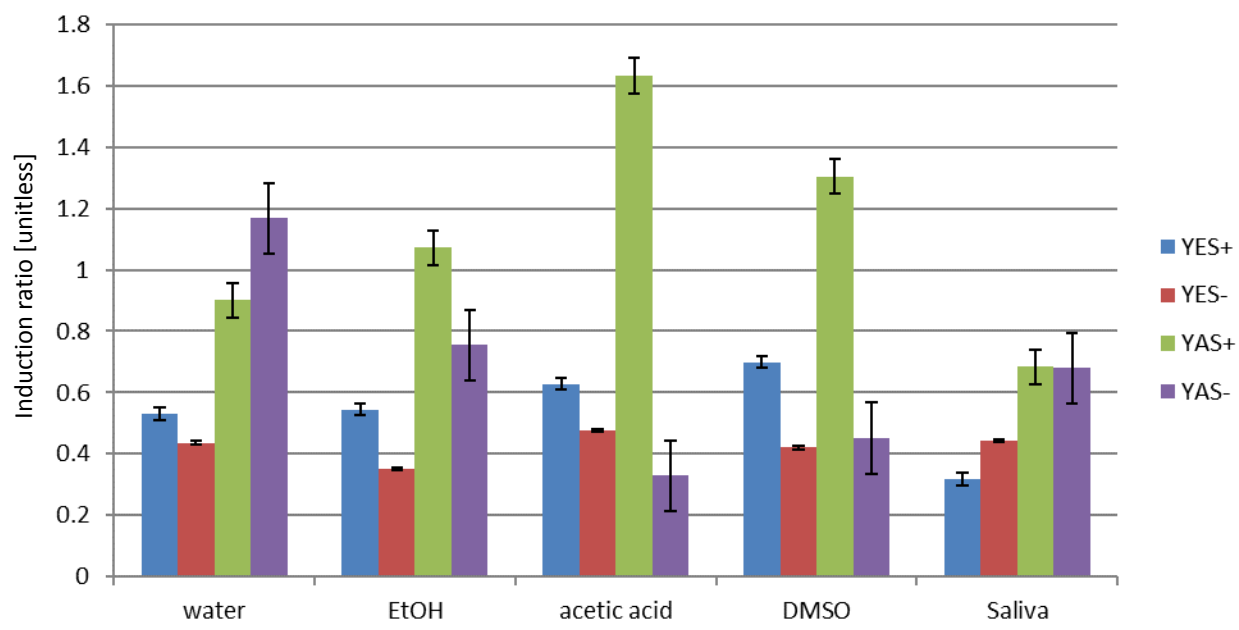


Fig. 5. Solvent effect plot for endocrine disruption potential determination of can lining extracts

Figure 6

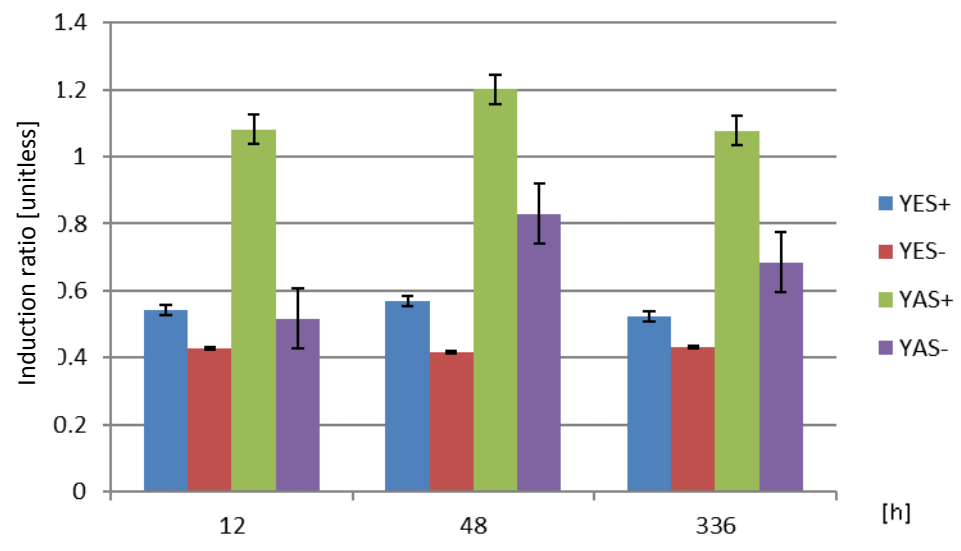


Fig. 6. Time effect plot for endocrine disruption potential determination of can lining extracts

Figure 7

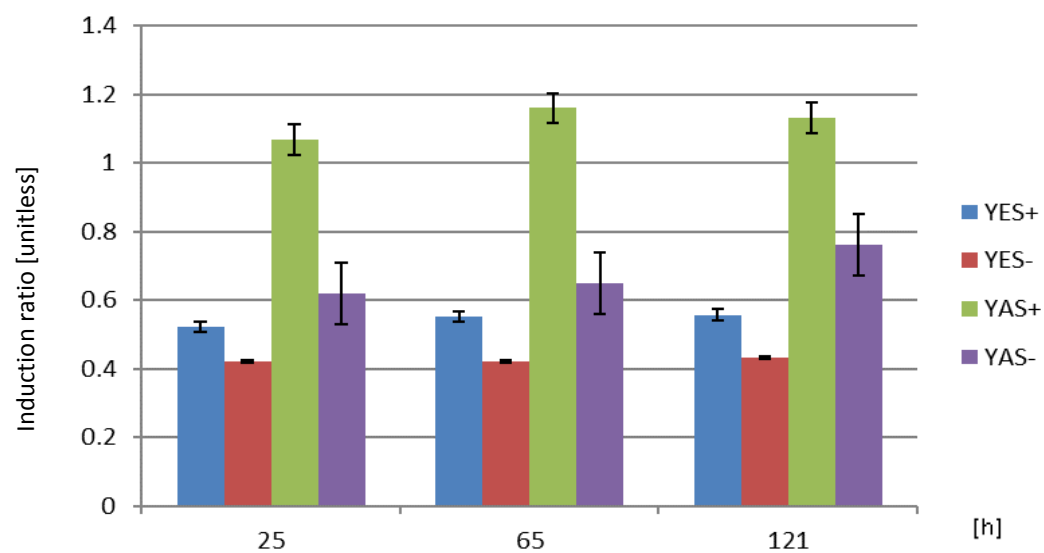


Fig. 7. Temperature effect plot for endocrine disruption potential determination of can lining extracts

Figure 8

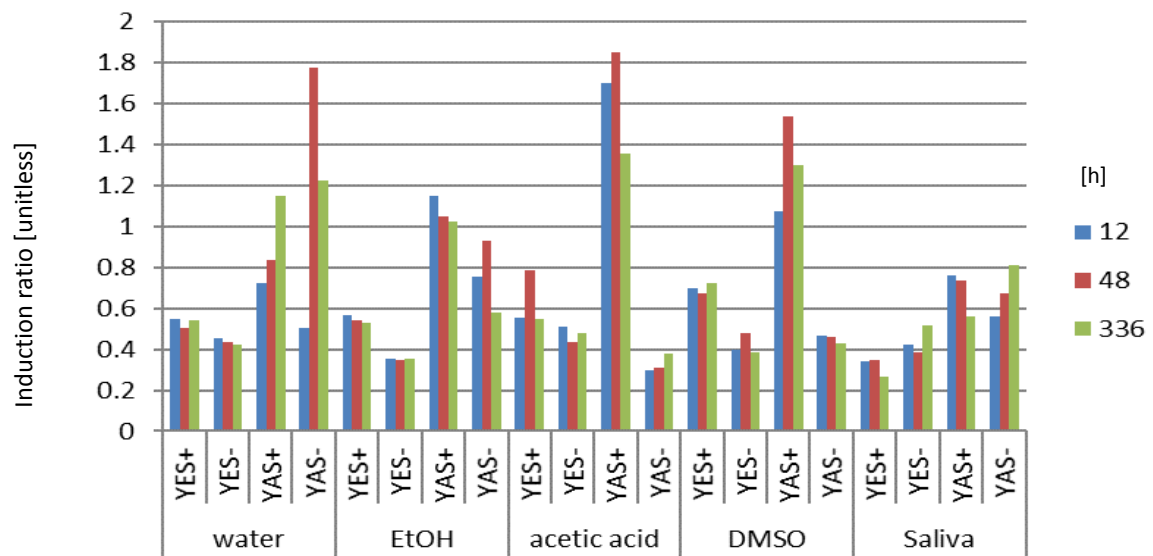


Fig. 8. Solvent-time interaction plot for endocrine disruption potential determination of can lining extracts

Figure 9

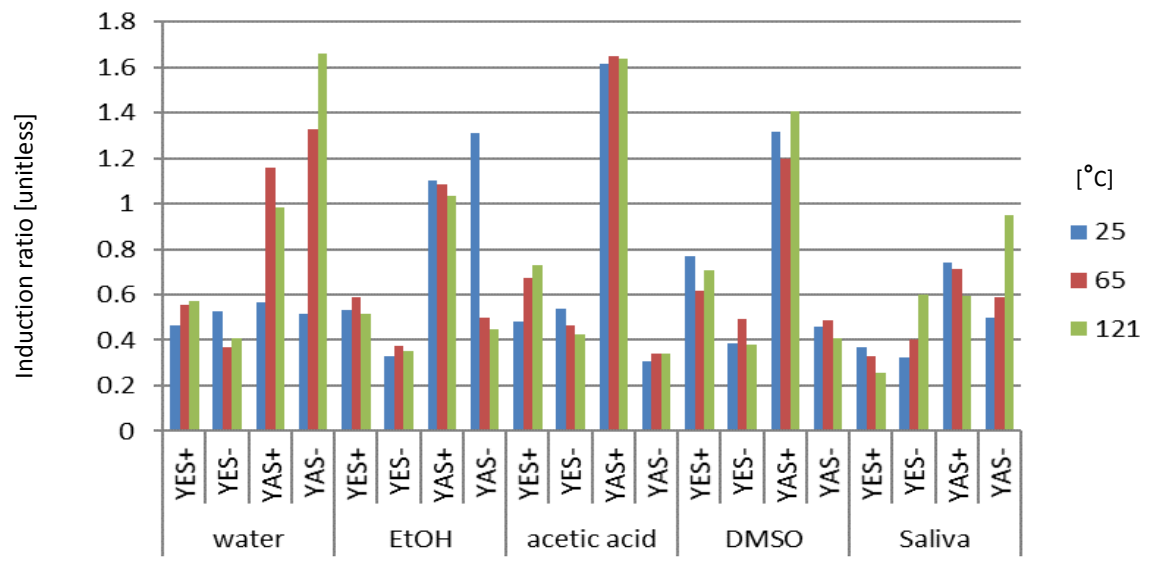


Fig. 9. Solvent-temperature interaction plot for endocrine disruption potential determination of can lining extracts