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GLOBAL MIGRATION ANALYSIS OF REUSABLE FOOD CONTACT PACKAGING EXPOSED TO VARYING MICROWAVE POWER LEVELS AND DURATIONS

ANALIZA GLOBALNEJ MIGRACJI SUBSTANCJI Z OPAKOWAŃ WIELOKROTNEGO UŻYTKU DO ŻYWNOŚCI PODDANEJ RÓŻNYM POZIOMOM MOCY I CZASU DZIAŁANIA MIKROFAL

ABSTRACT: This paper focuses on the study of specific cases of substance migration from plastic packaging into food, aiming to better understand this phenomenon and assess its potential impact on food quality and safety. The samples consisted of 5 food containers obtained from publicly accessible retail chains. In the case of reusable packaging, in accordance with Commission Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food, and Commission Regulation (EU) 2020/1245 amending and correcting Regulation 10/2011, the overall migration test for reusable products and materials is performed three times on the same sample, each time using a different dose of a food simulant liquid. All containers were made of polypropylene (PP / 5) according to the markings on the bottom of the packaging, and were indicated by the manufacturers as suitable for microwave heating and freezing. Therefore, the tests also included trials with the use of microwaves. Consequently, tests were prepared for the first part of the study to account for the impact of microwave treatment on the overall migration of the examined containers into food simulant liquids, and for the second part of the study, in which the overall migration was conducted three times on the same packaging sample.
Key words: global migration, microwaves, food safety, polypropylene

STRESZCZENIE: Niniejsza praca koncentruje się na badaniu specyficznych przypadków migracji substancji z opakowań z tworzyw sztucznych do żywności, co ma na celu lepsze zrozumienie tego zjawiska oraz ocenę jego potencjalnego wpływu na jakość i bezpieczeństwo żywności. Próbki stanowiły 5 pojemników na żywność pozyskanych z ogólnodostępnych sieci handlowych.
W przypadku opakowań wielokrotnego użytku zgodnie z Rozporządzeniem Komisji (UE) nr 10/2011 w sprawie materiałów i wyrobów z tworzyw sztucznych przeznaczonych do kontaktu z żywnością oraz Rozporządzeniem Komisji (UE) 2020/1245 w sprawie zmiany i sprostowania Rozporządzenia 10/2011 badanie migracji globalnej wyrobów i materiałów wielokrotnego użytku przeprowadza się trzy razy na tej samej próbce, za każdym razem używając innej dawki płynu modelowego imitującego żywność. Wszystkie pojemnik zgodnie z oznaczeniami na dnie opakowania wykonane były polipropylenu (PP/5) oraz z sugerowaną przez producentów możliwością stosowania ich do podgrzewania mikrofalowego oraz mrożenia. Z tego względu w badaniach zdecydowano się również uwzględnić próby z wykorzystaniem mikrofal. W związku z tym zostały przygotowane próby na I część badań uwzględniając wpływ obróbki mikrofalowej na migrację globalną badanych opakowań do płynów imitujących żywność oraz na II część badań, w której przeprowadzono migrację globalną trzy razy na tej samej próbie opakowania.
Słowa kluczowe: opakowania, opakowania wielomateriałowe, odpady opakowaniowe

INTRODUCTION

Global production of plastics is constantly growing. During 50 years, production of plastics increased from 15 million tonnes in 1964 to 311 million tonnes in 2014 [4]. During the recent years the mentioned increase has remained rather slow; all over the world, production increased by 12 million tonnes in the years 2009-2014 and in Europe – from 55 million t in 2009 to 59 million tonnes in 2014[5]. Production of Finnish plastics constitutes a percent of the European production, that is, about 600 000 tonnes [6].

The need of feeling safe, being one of the fundamental human needs, should be satisfied also via packaging. According to the definition suggested by Lisińska-Kusnierz (2011 [11], safe packaging is "the packaging which under the typical or other, foreseeable conditions of utilization, does not create a risk for the consumer, or represents the minimum risk which may be conciliated with its standard utilization. The mentioned packaging considers a high level of requirements concerning protection of human health and life".

Food packaging is one of the most important processes in food industry, which helps in maintaining the quality of food products during their storage, transport and distribution [18]. It occurs so, first of all, with the aim to protect food products from the external factors such as biological and chemical damage and mechanical damages, to store food, and keep it in the packaged state via preventing the deterioration of the quality and attracting the consumers as well as supplying information on the product and its nutritive values. For the years, the ancient people consumed fresh food which they could gather from their natural environment without the storage of food products [22, 1].

In 2018, the European Commission adopted the European strategy for a closed economy, with the aim to support, strengthen and accelerate the application of the measures aiming at reduction of the amount of the plastic waste. One of the key elements of the mentioned plan is "the improvement of economics and quality of plastics recycling" [5]. Moreover, as being considered as important goal, it was mentioned that up to 2030 all plastic packaging introduced to the EU market must be reused or subjected to recycling in a profitable way [2]. When taking into consideration that recycling in a circular system is also covered with the discussed program, i.e. recycling of food packaging into new food packaging materials, the question arises: 1) what will be the impact of the EU strategies concerning the plastics in a circular economy on food safety and 2) whether it is possible to identify and quantify all risk connected with it for food safety [23]. Due to the discussed requiring EU policy, the packaging industry stays before the serious challenge i.e. recycling of packaging polymers. In fact, almost all big food or packaging enterprises and also, industrial associations, have published their targets in respect of collection and recycling in 2025 and the successive years [15, 21].

The plastic materials, being most frequently employed in packaging intended for contact with food include Polypropylene (PP), marked with number 5 or 05 on packaging. The mentioned plastic is denser, harder and more transparent as compared to polyethylene. It shows good chemical resistance and is an effective barrier to water vapour [12, 19]. Different forms of polypropylene have different hardness and melting temperature. Polypropylene has a high melting temperature (160oC) what makes it more suitable for the applications where thermal resistance is required, e.g. in hot filing. It is employed in containers for yoghurt and margarine [22].

Plastic containers intended for food have the greatest participation in the market due to their low cost, small weight and functional advantages such as the possibility of heating up in microwave oven, optical properties and the availability in different dimensions and shapes [9, 22]. In connection with this fact, the effect of storage and heating up the food products in reusable packages on the safety and health of the consumer is meaningful.

Many consumers are not aware of the other sources of food contamination which may have a more serious impact on human health. For example, food may be contaminated with chemical substances at a very low concentration as a result of chemical reactions and migration from food packaging, especially in the case of plastic packaging (PPM) [16, 17, 20]. Accumulation of low levels of chemical substances, long-lasting exposure to chemical contamination may lead to chronic intoxication [7, 14]. The impact on human health after the exposure to chemical contaminations (e.g. cancers, infertility) may last for decades; therefore, the frequency of incidence is unforeseeable and may be higher than in the case of biological contamination [10]. From among chemical contaminations, originating in food packaging, the compounds which interfere hormonal system (EDC) cause the greatest concern as the unfavourable consequences of some of them are irreversible [13, 8]. In fact, according to the World Health Organisation, the consequences of certain EDC are maintained for the generations [3].

THE RESEARCH MATERIAL

The test material included reusable plastic packaging (Polypropylene/05) intended to come into contact with food; they were obtained from commercial shops at the territory of Lublin. Five packaging types coming from different producers were chosen for the tests. They were numbered from 001 to 005. All packaging had printed marks of PP and/or 05 what indicated the type of the material used for their production, i.e. polypropylene and mark of the destination of a given packaging indicating the possibility of heating up in microwave oven.

THE RESEARCH METHODS

The tests of the global migration from the examined samples of food packaging to water model (simulant) liquids were carried out by complete immersion with the use of laboratory incubator, in accordance with PN-EN 1186 by the immersion method. The conditions of testing the migration and the simulant liquids were so selected as to satisfy the requirements of real utilization of the tested packaging in contact with the specified food products. Global migration was determined in conformity with the Commission Regulation (EU) 2020/1245 three times with each sample, using each time a new portion of food-imitating simulant liquid. The table given below shows the conditions of testing the migration.

DETERMINATION OF GLOBAL MIGRATION

After employment of the time of the test, i.e. 30 minutes, and 10 days of the contact of the selected packaging with the simulant liquids, the liquids were transferred to evaporating dishes, being earlier dried up to a constant weight, they were evaporated to dryness and dry residues, after drying to the constant weight were weighed with the accuracy to 0.001 mg. The global migration from the tested materials was determined for each type of the samples, prepared in three repetitions. The weight of the dry residues was determined also for the control samples after evaporation of simulant liquid. Additionally, the tests with the earlier application of microwaves of frequency equal to 2.45 Hz and power of 800 and 1000 W were carried out. To this end, before testing the migration, the samples of plastic packaging were subjected to the effect of the mentioned above waves for 2, 3, 5 and 10 minutes in direct contact with the simulant liquids; then the test of the global migration were conducted according to the description as given above.

CALCULATION OF THE RESULTS

The results were expressed in mg/dm^2 of surface of the packaging intended to come into contact with food, as the mean from three repetitions.

TAB.1. CONDITIONS OF TESTING THE GLOBAL MIGRATION IN THE SELECTED PACKAGING

Type of packaging	Simulant liquid	Time and temperature of test
- 001 PP (Polypropylene) colourless	3- % acetic acid	30 min - 100°C
- 002 PP (Polypropylene) colourless	Distilled water	10 days - 40°C
- 003 PP (Polypropylene) colourless	20 – % acetic acid	
- 004 PP (Polypropylene) colourless	3 – % acetic acid	
- 005 PP (Polypropylene) colourless	50 – % ethanol/water	

The level of migration was calculated according to the following formula:

$$M = \frac{m_a - m_b \cdot 1000}{S}$$

where:

M – global migration to simulant liquid, in mg/dm^2 of the surface of sample, intended to come into contact with food [mg/dm^2]

m_a – weight of the residues obtained after evaporation of simulant liquid where the tested samples were immersed [g]

m_b – weight of the residues, obtained after evaporation of the simulant liquid (control sample) [g]

S – area of the surface of the tested sample which remained in the contact with the liquid [dm^2]

THE RESULTS OF THE TESTS

The results of the global migration from the analysed reusable plastic packaging intended to come into contact with food have been given in Tables 2-10.

The examined global migration from the selected packaging to distilled water (Tab.2) amounted, from the lowest one equal to 3.05 mg/dm^2 for sample 005 to the highest one equal to 5.30 mg/dm^2 for sample 001. Somewhat different results were obtained for the global migration with the earlier application of microwaves (Tab.3); in such case, the lowest results of migration were recorded for the sample marked as 002 and 003 in the range 3.15-3.40 mg/dm^2, (sample 002) and from 3.12 to 3.42 mg/dm^2 (sample 003), respectively. In the discussed test, any statistically significant differences between the employed time periods of the samples' exposure to microwave effect were not found; it may be, however, observed that the longer time of the microwave application affected the increase of global migration from the tested packaging to a small extent. On the other hand, we should mention that all the examined samples of reusable packaging were found in the standard for global migrations which is equal to 10 mg/dm^2. Utilization of distilled water as the simulant liquid facilitates obtaining information on the possibilities of storing food at pH >4.5 in the tested material.

Somewhat different relationship was recorded for the samples with the application of acetic acid as the simulant liquid

TAB.2. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO A DISTILLED WATER

Tested samples	Global migration (mg/dm^2)
	Conditions of test: 10 days, 40°C
Sample 001	5.30
Sample 002	3.20
Sample 003	3.10
Sample 004	4.15
Sample 005	3.05

TAB.3. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO DISTILLED WATER WITH THE APPLICATION OF MICROWAVES

Tested samples	Global migration (mg/dm^2) / Conditions of test - 10 days, 40°C							
	Time of microwave effect; 800 W				Time of microwave effect; 1000 W			
	2 min	3 min	5 min	10 min	2 min	3 min	5 min	10 min
Sample 001	5,35 ^{a}	5,35 ^{a}	5,40 ^{ab}	5,45 ^{b}	5,34 ^{a}	5,41 ^{ab}	5,44 ^{b}	5,47 ^{c}
Sample 002	3,15 ^{a}	3,22 ^{a}	3,18 ^{a}	3,40 ^{c}	3,14 ^{a}	3,26 ^{b}	3,31 ^{b}	3,39 ^{c}
Sample 003	3,12 ^{a}	3,21 ^{b}	3,30 ^{b}	3,42 ^{c}	3,12 ^{a}	3,25 ^{b}	3,29 ^{b}	3,44 ^{c}
Sample 004	4,20 ^{ab}	4,15 ^{a}	4,32 ^{c}	4,36 ^{d}	4,19 ^{ab}	4,21 ^{b}	4,38 ^{d}	4,43 ^{e}
Sample 005	3,33a	3,40 ^{ab}	3,45 ^{b}	3,45 ^{b}	3,42 ^{ab}	3,46 ^{b}	3,45 ^{b}	3,52 ^{c}

** a, b, c... means marked with the same letters do not differ statistically significantly at 5% error (Tukey test)

TAB.4. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO 3-% ACETIC ACID

Tested samples	Global migration (mg/dm^2)	
	Conditions of test:	
	10 days, 40°C	30 min 100°C
Sample 001	6.10	5.87
Sample 002	4.18	5.15
Sample 003	5.22	6.11
Sample 004	4.25	4.72
Sample 005	3.25	3.89

(Tab.4-5). In such case, the lowest migration of plastic packaging was obtained for sample 005 i.e. 3.25 (conditions of migration: 3% acetic acid, time – 10 days, temperature 40°C) and 3.89 mg/dm^2 (conditions of migration: 3% acetic acid, time – 30 minutes, temperature 100°C); the highest one was found for sample 001 – 5.87 (conditions of migration: 3% acetic acid, time – 10 days, temperature 40°C) and 6.10 mg/dm^2 (conditions of migration: 3% acetic acid, time – 30 minutes, temperature 100°C). On the other hand, during the tests with the application of microwaves (Tab.5) there was recorded the lowest migration for sample 005 which increased together with the prolongation of the time of microwave exposure from 3.42 to 4.32 mg/dm^2. The sample marked as 001 revealed the highest global migration similarly as in the case of the test with the application of distilled water. During the test conducted in the conditions with the application of the higher temperature (30 minutes, 100°C), values of migration were higher as compared to the standard conditions what may indicate the lower stability of the packaging in higher temperatures.

The application of 3% acetic acid as the simulant liquid is universally employed with the purpose to assess the possibilities of storing food with acidic pH ≤4.5. From the analysis of the tests it is resulted that all the examined materials ensure the appropriate conditions for a long storage of this type of the food products.

The application of the exposure of the tested packaging materials to microwaves revealed that together with the prolongation of the time and power of the employed microwaves, global migration in the samples marked as 001 and 005 was increased. The employment of the higher power, i.e. 1000 W has also contributed to higher migrations. The discussed results suggest that it is safer to heat up the foods in glass containers than in those made from plastics. All results obtained in the mentioned study were, of course, found within the standard, although – as it was mentioned at the beginning of the present paper – the effects of the long-lasting exposure of human organism to the compounds derived from plastics may have the consequences in the future. Moreover, the obtained results indicate that in spite of the employment of the same plastics, we may observe considerable differences between the global migrations of the tested materials what may be evidence of a different quality of the produced packaging.

TAB.5. GLOBAL MIGRATION FROM TESTED PACKAGING TO 3% ACETIC ACID, WITH THE APPLICATION OF MICROWAVES

Tested samples	Global migration (mg/dm^2) / Test conditions – 10 days 40°C							
	Time of microwave effect; 800 W				Time of microwave effect; 1000 W			
	2 min	3 min	5 min	10 min	2 min	3 min	5 min	10 min
Sample 001	6,16 ^{a}	6,15 ^{a}	6,35 ^{c}	6,44 ^{d}	6,21 ^{a}	6,34 ^{c}	6,52e	6,60 ^{f}
Sample 002	4,42 ^{a}	4,55 ^{sb}	4,62 ^{b}	5,01 ^{c}	4,69 ^{b}	5,12 ^{c}	5,60 ^{d}	5,74 ^{e}
Sample 003	5,36 ^{a}	5,31 ^{a}	5,48 ^{c}	5,98 ^{e}	5,41 ^{b}	5,57 ^{d}	5,77 ^{e}	6,23 ^{f}
Sample 004	4,44 ^{a}	5,03 ^{b}	5,12 ^{bc}	5,48 ^{d}	4,89 ^{ab}	5,21 ^{c}	5,65 ^{e}	6,02 ^{f}
Sample 005	3,42 ^{a}	3,65 ^{ab}	3,98 ^{b}	4,32 ^{c}	4,02 ^{b}	4,14 ^{bc}	4,44 ^{d}	4,65 ^{e}

* a, b, c... – means marked with the same letters do not differ statistically significantly at 5% error (Tukey test)

TAB.6. GLOBAL MIGRATION

Tested samples	Global migration (mg/dm²) / Test conditions – 10 days 40°C							
	Time of microwave effect; 800 W				Time of microwave effect; 1000 W			
	2 min	3 min	5 min	10 min	2 min	3 min	5 min	10 min
Sample 001	5,87 a	5,93 a	6,11 b	6,42 d	5,96 ab	6,32 c	6,69 e	7,11 f
Sample 002	5,15 a	5,21 ab	5,54 d	5,55 d	5,25 b	5,43 c	5,61 e	5,63 e
Sample 003	6,11 a	6,05 a	6,23 b	6,33 c	6,18 b	6,25 b	6,22 b	6,46 d
Sample 004	4,72 a	5,01 b	5,16 c	5,21 c	5,03 b	5,42 e	5,24 cd	5,29 d
Sample 005	3,89 a	4,12 ab	4,32 b	5,51 f	4,53 a	4,97 d	5,29 e	6,62 g

* a, b, c... – means marked with the same letters do not differ statistically significantly at 5% error (Tukey test)

Similar relationships were obtained for the global migration, with the application of 20% acetic acid as the simulant liquid (Tab.7-8). In the standard conditions (10 days, 40°C), global migration varies from 6.50 mg/dm^2 to 8.00 mg/dm^2. When comparing to the previously discussed results, we may see the increase of the global migration in 20-% acetic acid. In this case, also in the samples marked with numbers 001 and 005, global migration increased together with the employment of higher power and together with the prolongation of the time of the microwave effect on the tested material. Values obtained for the applied power of 1000 W and 10 minutes were near to exceeding the permissible limit, i.e. 10 mg/dm^2. We should, however, mention that the obtained results were still found within the standard.

TAB.7. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO 20-% ACETIC ACID

Tested samples	Global migration (mg/dm²)
	Test conditions – 10 days 40°C
Sample 001	6.50
Sample 002	7.20
Sample 003	8.00
Sample 004	7.43
Sample 005	6.69

TAB.8. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO 20-% ACETIC ACID

Tested samples	Global migration (mg/dm²) / Test conditions – 10 days 40°C							
	Time of microwave effect; 800 W				Time of microwave effect; 1000 W			
	2 min	3 min	5 min	10 min	2 min	3 min	5 min	10 min
Sample 001	6,45 a	6,87 b	7,13 c	7,49 d	6,47 a	7,12 c	7,47 d	8,71 e
Sample 002	7,31 a	7,41 b	7,38 b	7,56 d	7,46 c	7,53 d	7,55 d	7,62 e
Sample 003	8,13 a	8,21 b	8,42 c	8,50 ???	8,28 b	8,31 b	8,44 c	8,64 d
Sample 004	7,39 b	7,27 a	7,41 b	7,53 c	7,44 b	7,57 d	7,72 e	7,81 f
Sample 005	6,74 a	7,02 b	7,21 d	7,69 g	7,12 c	7,67 e	8,51 f	8,80 h

* a, b, c... – means marked with the same letters do not differ statistically significantly at 5% error (Tukey test)

TAB.9. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO 20% ACETIC ACID, WITH THE APPLICATION OF MICROWAVES

Tested samples	Global migration (mg/dm^2)
	Test conditions – 10 days 40°C
Sample 001	6.54
Sample 002	7.13
Sample 003	7.44
Sample 004	6.98
Sample 005	8.01

2. The highest results of the global migration were recorded for the samples with the application of 20-% acetic acid as the simulant liquid.
3. It was shown that the application of microwaves has the impact on the increase of the global migration from the tested samples. The time of the exposure of the effect of microwaves as well as the employed power had the influence on the increase of the global migration from the packaging to the simulant liquids.

TAB.10. GLOBAL MIGRATION FROM THE TESTED PACKAGING TO 50-% ETHANOL WITH THE USE OF MICROWAVES

Tested samples	Global migration (mg/dm^2) / Test conditions – 10 days 40°C							
	Time of microwave effect; 800 W				Time of microwave effect; 1000 W			
	2 min	3 min	5 min	10 min	2 min	3 min	5 min	10 min
Sample 001	6,49 ^{a}	6,51 ^{b}	6,51 ^{b}	6,53 ^{b}	6,55 ^{c}	6,51 ^{b}	6,62d	6,64d
Sample 002	7,21 ^{a}	7,34 ^{b}	7,33 ^{b}	7,41 ^{c}	7,19 ^{a}	7,35 ^{b}	7,42c	7,61d
Sample 003	7,39 ^{a}	7,46 ^{b}	7,55 ^{d}	7,50 ^{c}	7,49 ^{b}	7,62 ^{e}	7,66f	7,71g
Sample 004	7,12 ^{a}	7,16 ^{b}	7,26 ^{d}	7,21 ^{c}	7,21 ^{c}	7,35 ^{e}	7,68f	8,01g
Sample 005	8,23 ^{a}	8,29 ^{b}	8,31 ^{b}	8,34 ^{c}	8,34 ^{c}	8,52 ^{d}	8,61e	8,77f

* a, b, c... – means marked with the same letters do not differ statistically significantly at 5% error (Tukey test)

Tables 9-10 show the results of the global migration with the application of 50-% ethanol as the simulant liquid. The conditions of the test were adequate to the remaining simulant liquids. The tests revealed that all the examined samples were found within the standard what is evidence of the possibility of applying them in the storage of food, containing alcohol. The highest migration was recorded for packaging 005, i.e. 8.77 mg/dm^2, somewhat lower for sample 004 - 8.01 mg/dm^2 and the lowest one was found for 001 – 6.64 mg/dm^2.

CONCLUSIONS

1. In the present paper there was demonstrated that all the tested samples of reusable packaging intended to store and heat up food products were found within the standard of global migration amounting to 10 mg/dm^2.

Microwaves may affect the food packaging materials, causing their heating what, in turn, may change their physical and chemical properties. The fundamental mechanism by the help of which microwaves heat up the food consists in causing vibrations of water particles present in food, generating heat energy. The mentioned heat may be transferred on the packaging material having the contact with food and may cause the changes such as softening of melting of the polymers, especially when the discussed materials are not designed so as to resist the microwave temperature.

4. All the tested materials are suitable for the storage of hydrated food and alcohol-containing foods.

BIBLIOGRAPHY

1. R. Accorsi, A. Cascini, S. Cholette, R. Manzini, C. Mora, Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study. International Journal of Production Economics 152 (2017) 88-101.
2. I. Antonopoulos, G. Faraca, D. Tonini, Recycling of post-consumer plastic packaging waste in the EU: Recovery rates, material flows, and barriers. Waste Management 126 (2021) 694-705.
3. A.J.J. Bergman, S. Heindel, K. Jobling, A. Kidd, R.T. Zoeller, Endocrine disrupting chemicals – Summary for decision-makers. United Nations Environment Programme and the World Health Organization (2012).
4. Ellen McArthur Foundation, 2016. The new plastics economy. Rethinking the future of plastics. Ellen McArthur
5. European Commission. A European Strategy for Plastics in a Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; European Commission: Brussels, Belgium, 16 January 2018; Available online: https://eurlex.europa.eu/legalcontent/EN/TXT/?uri=COM%3A2018%3A28%3AFIN (accessed on 15 April 2024).
6. European Commission. Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Implementation of the Circular Economy Action Plan. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0190 (accessed on 15 April 2024).
7. European Parliament. 2016. Implementation of the food contact materials regulations. https://www.europarl.europa.eu/doceo/document/TA-8-2016-0384_EN.pdf?redirect.
8. R. Franz, F. Welle, Recycling of Post-Consumer Packaging Materials into New Food Packaging Applications—Critical Review of the European Approach and Future Perspectives. Sustainability 14 (2022) 824. https://doi.org/10.3390/su14020824
9. A. Gallego-Schmid, J.M.F. Mendoza, A. Azapagic, Improving the environmental sustainability of reusable food containers in Europe. Science of the total environment, 628 (2018) 979-989.
10. K.M. Grob, E. Biedermann, M.R. Scherbaum, M. Roth, K. Rieger, Food contamination with organic materials in perspective: Packaging materials as the largest and least controlled source? A view focusing on the European situation. Critical Reviews in Food Science and Nutrition 46 (7) (2006) 529-35.
11. M. Lisińska-Kuśnierz, Oczekiwania konsumentów dotyczące opakowań a realizacja ich potrzeb społeczno-ekonomicznych. Zeszyty Naukowe UEK 874 (2011) 89-100. (in English:The expectation of the consumers concerning the packaging and implementation of their social and economic needs. Scientific Papers UEK)
12. M. Mahmoudi, I. Parviziomran, Reusable packaging in supply chains: A review of environmental and economic impacts, logistics system designs, and operations management. International Journal of Production Economics 228 (2020) 107730.
13. C. Matthews, F. Moran, A.K. Jaiswal, A review on European Union's strategy for plastics in a circular economy and its impact on food safety. J. Clean. Prod. 283 (2021) 125263.
14. R.D. Meijere, 2019. Cocktail effect makes chemicals more toxic. Accessed April 13, 2024.
15. A.C. Mendes, G.A. Pedersen, Perspectives on sustainable food packaging:– is bio-based plastics a solution? Trends in Food Science & Technology 112 (2021) 839-846.
16. C. Nerin, E. Canellas, P.Vera, Plasticizer migration into foods. Reference Module in Food Science (2018).
17. C. Nerın, M. Aznar, D. Carrizo, Food contamination during food process. Trends in Food Science & Technology 48 (2016) 63-8.
18. Plastics Europe, 2020. Plastics – the Facts 2020. An analysis of European plastics production, demand and waste data.
19. PN-EN 1186-3:2023-01 Materiały i wyroby przeznaczone do kontaktu z produktami spożywczymi -- Tworzywa sztuczne -- Część 3: Metody badań ogólnej migracji w wyparowujących płynach modelowych (In English: PN-EN 1186-3:2023-01 Materials and products intended to come into contact with food – Plastics – Part 3: The testing methods of global migration in evaporating simulant liquids)
20. ROZPORZĄDZENIE KOMISJI (UE) 2020/1245 z dnia 2 września 2020 r. w sprawie zmiany i sprostowania rozporządzenia (UE) nr 10/2011 w sprawie materiałów i wyrobów z tworzyw sztucznych przeznaczonych do kontaktu z żywnością. (In English: Commission Regu;ation (EU) 2020/1245 of 2 September 2020 amending and correcting Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food)
21. ROZPORZĄDZENIE KOMISJI (UE) NR 10/2011 z dnia 14 stycznia 2011 r. w sprawie materiałów i wyrobów z tworzyw sztucznych przeznaczonych do kontaktu z żywnością.(In English: Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic material intended to come into contact with food)
22. S. Sarkar, K. Aparna, Food packaging and storage. Research Trends in Home Science and Extension AkiNik Pub 3 (2020) 27-51.
23. M. Weber Macena, R. Carvalho, L.P. Cruz-Lopes, R.P. Guiné, Plastic food packaging: perceptions and attitudes of Portuguese consumers about environmental impact and recycling. Sustainability 13 (17) (2021) 9953.