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Assessment of Hungarian Consumers' Exposure to Pesticide Residues Based on the Results of Pesticide Residue Monitoring between 2017 and 2021

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Abstract: The short-term intake (ESTI) of pesticide residues in Hungarian consumers was assessed based on 2331 test results obtained during the 2017–2021 monitoring program on frequently analyzed apples, sour cherries, table grapes, peaches, nectarines, peppers, and strawberries (23.5% of all samples taken from 119 crops). The age-specific consumption data were obtained from national food consumption surveys (2009 and 2018–2020). The exposure was characterized by Hazard Quotient and Hazard Index considering the acute reference doses of pesticide residues detected in the samples. When ESTI was calculated with all detected "single" residues and a variability factor of 3.6, recommended for evaluation of monitoring results, the HI only exceeded 1 for children <3 years old eating grapes (1.50–1.81). HI was <1 when any of the six foods were eaten together within one day. Between forty and fifty percent of samples contained 2–23 residues. Though the individual residue concentrations were below the corresponding MRLs, multiple residues being present in one sample resulted in maximum HI values in apples (1.14); grapes (6.57); peaches and nectarines (2.57); strawberries (2.74); and peppers (10.44). Residues with low ARfD values contributed the most. Applying HI is simple, but provides only point estimates; therefore, it should only be used in first-tier risk assessment.

Keywords: pesticide residues; pesticide residue monitoring; multiple residues; acute exposure assessment; hazard index; food consumption surveys

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1. Introduction

Food is a potential source of exposure of the general population to pesticide residues. The use of pesticides by farm workers, especially without appropriate protective clothing, can be its major source. At the global level, total pesticide trade reached approximately 5.9 million tons in 2018 and showed about a 5.5% annual increase in 2020–2021 with an approximate value of USD 43.3 billion [1–3]. The generally inherently toxic pesticide active ingredients and formulated products undergo extensive toxicological tests before introduction by the primary manufacturers according to OECD guidelines [4,5]. The competent authorities of national governments regulate the use of pesticides to various extents. Countries with advanced registration systems conduct their own evaluation of the experimental bioefficacy, toxicological, and other relevant data before the authorization of a pesticide [6–9]. Countries with limited resources accept the evaluations of the advanced ones or the FAO/WHO Joint Meeting on pesticide residues (JMPR) and adopt the Codex maximum residue limits (MRLs) [10–12].

Pesticide residues in food and environmental samples are monitored in many countries to various extents [13]. One of the main objectives of the monitoring program is to provide data on the dietary exposure assessment of consumers. For instance, the European Food Safety Authority (EFSA) annually evaluates the acute and chronic exposure of the European population [14] based on the results of the national as well as the European coordinated multiannual control programs [15]. The composition of the pesticide residues that should be used for dietary exposure is often different from those defined for enforcement purposes [16,17]. The definition of residues for risk assessment includes all relevant residue components (parent compound and metabolites) that significantly contribute to the toxic effects of a pesticide. On the other hand, the residue definition for enforcement purposes includes fewer residue components to reflect the residue levels at and after harvest. It is purposely set as simple as possible to facilitate the monitoring of pesticide residues in hundreds of thousands of samples taken from marketed commodities [17]. Therefore, the results of pesticide residue monitoring programs should be used for risk assessment while noting the potential differences. Detailed explanations of the calculation of short-term (ESTI) and long-term daily intakes with deterministic [18] and probabilistic methods are well described in several publications [19–23].

Pesticide residue monitoring results revealed that a substantial proportion of samples contain multiple residues. In Hungary, 36–50% of samples contained multiple residues ranging from 2 to 23 during 2017–2021 [13]. The frequency of multiple residues was in the same range in European countries. The average frequencies were 29% (2018), 28% (2019), and 28.9% (2020) of the samples analyzed within the national and European coordinated residue testing programs. The maximum number of residues was found in a strawberry sample (35) in 2020 and a dried vine fruit sample (28) in 2020 [14].

The EFSA Panel on Plant Protection Products and their Residues suggested a methodology for grouping pesticides based on phenomenological effects and recommended cumulative assessment groups (CAGs) concerning the effects on the thyroid and nervous system [23]. Retrospective dietary exposure assessments were conducted for two groups of pesticides that have acute effects on the nervous system [19,20] using the 2014–2016 European monitoring data [24].

The US EPA published a guidance document on considering chemicals having a common mechanism of toxicity [25], and established CAGs for groups of chemicals of the same chemical structure and common mechanism/mode of action: organophosphorus compounds [26], N-methyl carbamates [27], pyrethrins/pyrethroids [28], and chlorotriazines [29].

Both EFSA and USEPA apply the dose addition principle which assumes that the effects of the individual components in the mixture are independent (i.e., are additive rather than synergistic or antagonistic) and no interaction among the compounds within the mixture is expected at low levels of exposure. EFSA's Expert Panel recommended using the dose addition also for the assessment of mixtures of dissimilarly acting chemicals, irrespective of their presumed modes of action [30].

The cumulative risk of organophosphorus, carbamate insecticides, and triazole fungicides was assessed by applying the relative potency factors [25], for instance, using the Brazilian, Chinese, German, Hungarian, Danish, and Dutch consumption data [22,31–38].

The Hazard Index (HI) method can be used for the characterization of the cumulative risk of pesticide residues [37–39]. The HI method assumes that the effects following cumulative exposure can be predicted by the mathematical model of dose addition. The effect of a mixture of compounds is estimated by adding up the exposures to the individual compounds corrected for their respective potencies [39].

A potential risk is identified if the HI is higher than 1.

Dietary risk assessment is usually performed by applying consumption data in the edible portion of raw or processed agricultural commodities. Composite food should be disintegrated into components in which the pesticide residues were determined. Comprehensive food composition databases are available that can be used as guidance in the lack of detailed composition information [40,41]. The first systematic collection of food consumption data goes back to 1795 in Great Britain [42] and 1898 in the USA [43]. By 1898, USDA investigators had made studies of food consumption in over 300 families. These studies provided the basis for the collection of household expenditure data. The purpose of consumption and expenditure surveys was primarily to obtain information on the nutritional status of the families, develop dietary guidelines, assess public health and food security, etc. [42–44]. Survey methods have been refined during the past few years with the main aim of evaluating the nutritional status of a population, i.e., the intake of energy, macronutrients, micronutrients, and bioactive compounds.

Dietary surveys, based on data collection from individuals, are the only surveys that provide information on the distribution of food consumption in well-defined groups of individuals and are therefore preferred for the estimation of dietary exposure within the risk assessment process. Survey methodologies range from recalling the intake from the previous day (24 h recall) to keeping a record of the consumption of food and beverages over one or more days (dietary record). The number of survey days varied from one to seven in European countries during the last two decades. The most frequently used methods are the 24 h dietary recall, dietary records, household consumption and expenditure surveys, and biomarker assessment [45]. The individual surveys are often complemented with food frequency or food propensity questionnaires. Survey characteristics affect the quality of the measurement of food consumption within households. Thus, it is important to identify best practices for designing surveys that collect food data [46,47].

Methodological differences used in the surveys render these data unsuitable for direct country-to-country comparisons. To facilitate the uniform food consumption data collection, the EFSA issued two guidance documents [48,49]. The detailed description of the recommended methods described in the Guidance on the EU Menu Methodology [49] was elaborated by two international consortiums [50,51] and finalized with the involvement of the EU Menu Working Group. This guidance document [49] focuses on methods to harmonize and increase the quality of the food consumption data submitted to EFSA for use in assessments of exposure to food-borne hazards and nutrients. The core target population includes all persons aged between 0 and 74 years, and residents in a given country. The minimum recommended number of participants in each age group is 260.

In Hungary, two food consumption surveys were implemented by the Hungarian Food Safety Office (HFSO) in 2009 [52,53] and 2018–2020 [54] following the methodology recommended by EFSA (2009 and 2014, respectively).

Food consumption data (Fi (kg edible portion of food/kgbw)) and the estimated maximum residue levels (MRL (mg residue/kg food)) were first used to calculate the Theoretical Maximum Daily Intake for pesticide residues (TMDI = MRL × Fi) by the JMPR and then considered by the first meeting of the Codex Committee on Pesticide Residues in 1966 [55]. TMDI should not exceed the "tolerable maximum daily intake" (TDI) defined by WHO. The TDI is comparable to the ADI (Acceptable Daily Intake (mg residue/kgbw/day)). Where detailed national food consumption data are not available, the FAO/WHO IEDI (international estimated daily intake) calculation template [56] based on the 17 cluster diets [57] can be used. Alternatively, the EFSA Primo 3 intake calculation template can be applied [58], though it will only provide an intake assessment based on European food consumption data.

The objectives of our work are to evaluate the acute exposure of Hungarian consumers resulting from the single and multiple residues detected in the most frequently sampled six fruits and vegetables (apples, table grapes, strawberries, sour cherries, peaches and nectarines, and peppers) during 2017–2021 [13]. The exposure of consumers was estimated by applying the food consumption data obtained with the national dietary surveys carried out according to the methodologies recommended by EFSA [48,49].

2. Materials and Methods

2.1. Analyses of Samples

Pesticide residues were determined by the specialized analytical laboratories of the National Food Chain Safety Office in samples acquired as part of the national and EU–coordinated multi-annual monitoring programs [59,60]. The samples were taken according to the European Union directive [61]. The laboratories had accreditation according to ISO EN 17025 standard [62] and performed rigorous internal quality control to comply with the European Guidance document [63]. Over 600 pesticide residues and specified metabolites were screened in the samples with 0.002–0.008 mg/kg limits of detection by applying the suitable variants of the well-established QuEChERS methodology [64–66] in combination with GC-MS/MS and LC-MS/MS detection, or specific individual methods for substances which could not be recovered with the multi-residue methods applied. The residues of the parent compound and its metabolites were determined as specified by the EC regulations for enforcement purposes. Those cases where the specified metabolites were determined and included in the reported results are indicated with "sum" in Table S4. The screened substances were divided into groups based on their physical–chemical properties and elution times in the chromatographic columns. The recoveries of all screened substances were determined regularly with the analyses of different groups of the screened substances following a rolling program. The individual recovery values and their averages were within the acceptable range [63].

Though the accuracy and reliability of residue data for evaluation of compliance with legal limits have been proven at various levels, they have two limitations in the use of dietary risk assessment. Namely, the definition of residues for enforcement purposes does not cover all toxicologically significant metabolites or degradation products that are included in the definition for risk assessment. Secondly, the residue concentration reported based on the portion of commodity analyzed [67] in monitoring programs is not the same as the residue concentration in the edible portion. The average losses in preparing the edible portions of cherries, peaches, and peppers are about 5%, 14%, and 18%, respectively [68]. For strawberries and table grapes, the loss is <5%. The edible portions of these crops are practically the same as the portions of commodities analyzed [67]. Since the results of monitoring programs are reported on a whole-product basis, they lead to somewhat overestimated exposure of consumers if the consumption data are recorded in terms of edible portions.

2.2. Dietary Surveys

The results of two Hungarian national food consumption surveys conducted by the Hungarian Food Safety Office were utilized in this article.

The 1st food consumption survey was carried out between February and June 2009 to obtain data for quantitative food safety risk assessment and to gain information on the nutrition status of the Hungarian population [52,53]. Considering the methodology suggested by EFSA [48], the participants were recruited randomly conforming to age, gender, and residence criteria from those taking part in the annual National Household Budget Survey (HBS) of the Hungarian Central Statistical Office (HCSO) (Table S1). The skilled interviewers of HCSO who visited the recruited people at their homes had received special training in collecting food consumption information before the start of the survey. Food picture books showing different portion sizes, common household measuring tables and example record sheets assisted the participants in providing reliable information. Self-reported body weight and height data were also recorded. In addition, dietary records on 3 non-consecutive days and food frequency questionnaires were completed.

The data processing and evaluation of the results were carried out by skilled dieticians who recorded the food items into NutriComp Diet (Étrend) software [68–70] specially adapted for the survey. It contained a wide scale of foodstuffs, traditional Hungarian and well-known international recipes, and those used widely spread in the mass catering sector too. After a thorough verification procedure, daily energy and nutrient intakes were calculated using the weighted average of the three days [68]. Recipes were disaggregated into raw materials, and even macro- and micronutrients were calculated using the recipe composition database of the software. Valid consumption records were obtained from 1360 males and 1717 females (<1–101 years) during the 14,976 consumption recording days indicating a response rate above 61.7%.

The second survey which included toddlers, other children, adolescents, adults, and the elderly was conducted between 2018 and 2020 [54] (Table S1).

(1) using the EFSA EU MENU methodology [49]. The sampling frame was the same as that used by the HCSO for the implementation of the annual HBS. The participants were randomly selected by using a stratified sampling method based on age and gender. The survey extended to all regions of the country, covering four seasons and all days of the week. The dietary pattern of the whole year was represented, including the periodically consumed foods as well, paying attention to their seasonal variation. Participants were asked to provide information on their food consumption for two non-consecutive days, a minimum of 10 days apart. The 24 h food diary method, followed by a computer-assisted personal or telephone interview, was applied. Information on the consumption of some less frequently eaten foods and the frequencies of food supplements was collected by applying a short, self-administered Food Propensity Questionnaire. The information on the physical activity of the subjects was obtained from the completed short International Physical Activity Questionnaire. The measurement of the body mass and height of the participants was carried out during the personal interview. The fieldwork was executed by contracted dietitians using dietary software called NutriComp. Its food and recipe database was updated and pre-coded according to EFSA's FoodEx2 food description and classification system. The response rates were between 67 and 74%.

The edible portions of food items were reported and recorded in both surveys. The age and gender distribution of the participants of the two surveys is shown in Tables S2 and S3.

Conversion of Composite Food to Primary Components

The NutriComp programs used in the nutritional studies [53] contained the ingredients of nearly 6000 national and international recipes. If necessary, the basic recipe file could be extended or modified by adding the ingredients of specially prepared foods consumed by the study participants.

The exact weight of the cleaned edible portion of the foods consumed per meal per day was recorded for later data processing. For complex foods and recipes, the raw weight of all ingredients of the recipe prior to the food preparation technology was calculated, taking into account the portion size consumed. The sum of the raw weights of the same foods consumed alone and calculated from the composite recipes provided the final daily consumption data.

2.3. Calculation of Short-Term Intake

The short-term intake was calculated from the large portion (LP (kg edible food item/day)) obtained from the food consumption survey and the 97.5th percentile or maximum residues detected in the samples. The LP is obtained from the average body mass of the corresponding population age group and the 97.5th percentile of the edible portion of consumed food (kg/kgbw/day). The 97.5th percentile consumption can be calculated ideally from $\geq$120 residue data that enables estimating the 97.5th percentile with 95% probability by applying the Harrell–Davis (HD) method [71,72]. For $\leq$30 consumption data, the rounded calculated percentile values were close to the highest one. Noting the uncertainty of the estimation of the 97.5th percentile from small datasets, nevertheless making the best use of available data for $n < 30$ data points, the maximum consumed portion was used instead of the 97.5th percentile to calculate the large portion size. The same approach was used for selecting the residue data.

The method of the calculation of the short-term intake depends on the relation of the median unit mass of food items and the large portion consumed [18]. If the median unit mass is smaller than their large portion size, the following equation is used for the calculation of the short-term intakes.

$$ESTI = (Ue \times HR \times v + [(LP - Ue) \times HR])/bw \quad (1)$$

where Ue is the median unit mass of the edible portion [kg], HR is the upper 97.5th percentile of residues detected in composite samples [mg/kg], LP is the large portion (97.5th percentile of eaters) in kg food per day, bw is the average body mass of the age groups of participants (kg) interviewed during surveys, and v is the so-called variability factor reflecting the unit to unit variability of residues in natural units in the composite samples [18,73]. For comparison and providing the worst-case scenario, the variability factors of 7 recommended by EFSA for medium-size (25–250 g) crops [74], or 3.6 agreed by the EU Member States to use for monitoring data [30] were also applied in our calculations in addition to the generally applicable variability factor of 3 recommended by the FAO WHO Joint Meeting [17].

For small fruits and vegetables (median unit mass < 25 g, e.g., cherries, strawberries), the residue measured in the composite sample represents the residues in consumed food:

$$IESTI = (LP \times HR)/bw \quad (2)$$

However, where the mass of the edible portion of the crop unit is larger than the large portion size the variability of residues in crop units has to be considered:

$$IEST = (LP \times HR \times v)/bw \quad (3)$$

EFSA applies a variability factor of 5 in such cases [74].

The distribution of unit masses of selected food items marketed in Hungary [35] is summarized in Table 1. The size of cherries and strawberries was not measured in this study but obtained from the Internet. The typical maximum and median unit masses of strawberries are 19 and ≤12 g. Cherries are smaller (max 6–8 g). Equation (5) is used for the calculation of IESTI for these crops.

Table 1. Descriptive statistics of mass distribution of selected food items.

	Unit Mass of Medium-Sized Items [g]						
	No.	**Maximum**	**P0.975**	**Average**	**Median**	**P0.025**	**Min**
Apples	922	475	345	222	220	105	87
Grapes	717	1291	1106	308	265	50	19
Nectarines	313	316	180	139	143	94	11
Peaches	73	301	284	197	208	102	17
Peppers, bell	289	298	278	218	218	159	86
Peppers, green	492	199	152	76	64	34	5

The typical maximum and median unit mass of strawberries are 19 and ≤12 g. Cherries are smaller (max 6–8 g).

2.4. Cumulative Acute Exposure of Consumers

The hazard index (HI) is designed for the risk assessment of substances that have the same kind of adverse effect or common mode of action. The principle of dose addition is used for the compounds irrespective of the presumed modes of action [30]. It is calculated as the sum of hazard quotients (HQ). The HQ is the ratio of the exposure of a pesticide to the reference value, e.g., the daily intake and the corresponding ADI (TDI) for the estimated chronic or short-term intake, and the ARfD for acute exposure assessment.

The hazard quotients and the hazard index were calculated by applying the acute reference doses. We used the reference values published by EFSA for cumulative risk assessment groups [19,23,24].

$$HQc = \frac{EDI}{ADI} \quad (4)$$

$$HQa = \frac{ESTI}{ARfD} \quad (5)$$

$$HI = \sum HQ \quad (6)$$

The cumulative dietary risk was calculated for food–pesticide residue combinations that were selected from those likely to lead to the highest exposure. A potential risk is identified if the HI is higher than 1. Where the results of monitoring programs are used, the 97.5th percentile of residues can be applied to represent the high residue for the acute exposure assessment.

3. Results

3.1. Summary of the Results of Pesticide Residue Monitoring during 2017–2021

Pesticide residues were determined in 9924 samples. Table 2 shows the summary of the number of samples, the residues tested, and their distribution in relation to the corresponding MRL values.

In view of the very large database, we selected six commodities (apple, table grape, sour cherry, peach and nectarine, strawberry, and pepper (green and red)) for the detailed evaluation of the results. To simplify the following tables, these commodities are briefly mentioned as apples, cherries, grapes, peaches, peppers, and strawberries. They were relatively frequently sampled and often contained multiple residues. The maximum residues detected in selected samples, their MRLs, and ARfD values are summarized in Table S4 in the Supplementary Materials. Concerning the acute exposure of consumers, specific attention was given to the samples containing multiple residues (minimum two residues in each sample). A summary of multiple residues detected in individual samples of all commodities is given in Table 3. Table 4 shows the maximum number of multiple residues detected in individual samples taken from the selected commodities. The numbers of samples and residues investigated in the selected commodities are given in Table 5.

Table 2. Summary of the analytical tests carried out between 2017 and 2021.

Commodity [1]	Number of		Proportion of Occurrence		
	Samples [2]	Analytes [3]	R > MRL [4]	MRL ≥ R ≥ LOQ [5]	R < LOQ [6]
All commodities	9924	622	1.0%	53.0%	45.9%
Apples	833	617	0.1%	74.1%	25.8%
Cherries	122	583	0.8%	78.7%	21.3%
Grapes	411	618	0.2%	80.5%	19.2%
Peaches	349	593	0.3%	66.2%	33.5%
Peppers	616	621	0.6%	48.4%	51.0%
Strawberries	225	601	1.3%	74.2%	24.4%

Notes: [1]: Commodities included in the sampling program. [2]: Number of samples investigated. [3]: Total number of residues screened in the samples. The scopes of the analytical methods were decided based on the prior information available. Consequently, not all samples were tested for all analytes. [4]: Percentage of samples containing residues above the MRL. [5]: Percentage of samples containing detectable residues <MRL. [6]: Percentage of samples without detectable residues (limit of quantification).

Table 3. Summary of multiple (≥2) residues detected in individual samples of all commodities.

Year	Total No. of Samples Analyzed	Samples with Multiple Residues	Max. No. of Residues
2017	1902	761 (40%)	23
2018	1995	820 (41%)	13
2019	1842	916 (50%)	15
2020	1750	625 (36%)	16
2021	1666	719 (43%)	11

Table 4. Maximum number of multiple residues found in the selected commodities.

Commodity	Maximum Number of Multiple Residues Found in Samples Per Years				
	2017	2018	2019	2020	2021
Apples	10	13	8	9	11
Cherries	10	10	6	6	6
Grapes	12	11	11	11	7
Peaches	6	6	7	9	5
Peppers	7	11	7	8	8
Strawberries	7	9	11	7	9

Table 5 summarizes the number of samples taken from the selected commodities that contained more than one residue in detectable concentration and the number of residues investigated in the samples.

Table 5. The number of samples [1] and residues investigated in the selected commodities.

	2017		2018		2019 Number of		2020		2021	
	Samples	RES	Samples	RES	Samples	RES	Samples	RES	Samples	RES
Apples	73	42	101	38	107	39	89	38	103	40
Cherries	16	18	16	21	10	12	8	10	9	13
Grapes	20	42	17	31	17	35	13	42	6	27
Peaches	3	12	10	26	9	19	12	25	4	10
Peppers	5	15	6	27	3	13	6	32	5	21
Strawberries	33	27	35	37	36	34	3	11	20	26

Notes: [1]: Samples containing multiple residues; RES: type of residues investigated in various samples.

The number of residues present in individual samples varied. Most frequently 3–6 different residues were detectable in the samples. Figure 1 shows the relative frequency of multiple residue ranges in selected food items.

3.2. Summary of Consumption Data

The main characteristics of the food consumption surveys are summarized in Tables S2 and S3.

The large portion sizes of the edible part of the food consumed in a day (kg food/kgbw/day) were calculated from their 97.5th percentile except for consumption days <10. For these cases, the maximum amount of food recorded was used. For consumption days from 10 to 30 the Harrell–Davis method [71,72] was used, while, in other cases, the Excel built-in function was used for the calculation. During the 2009 survey, certain foods were not consumed; consequently, their large portions were not calculated. The large portion (LP) consumptions are presented in Tables S2 and S3.

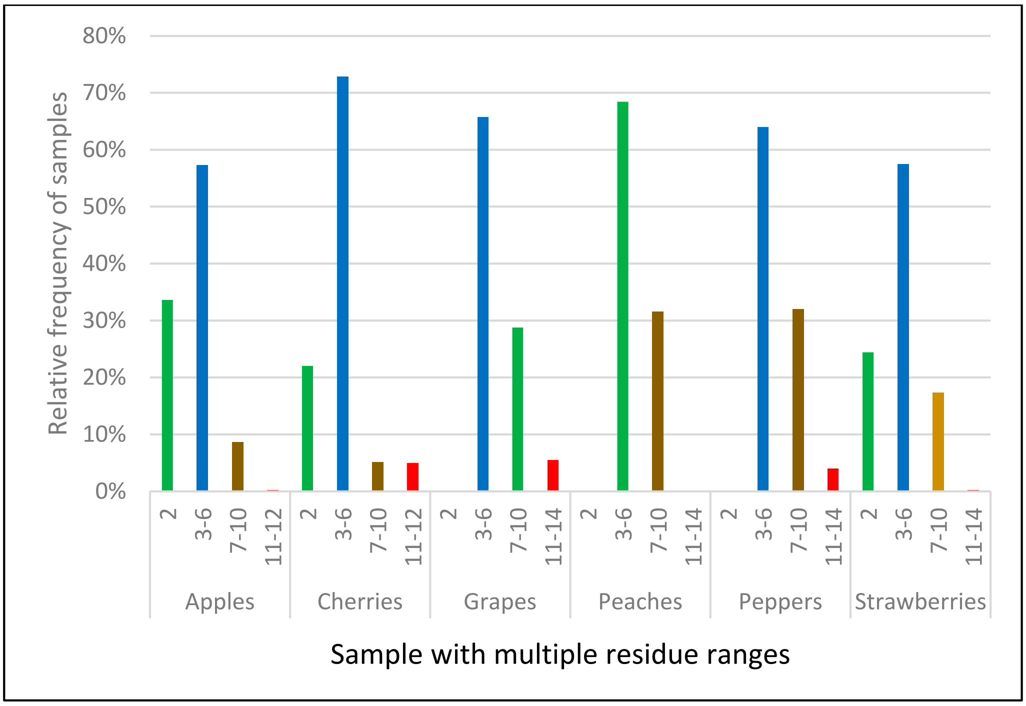

Figure 1. Relative frequency of residues detected in the selected commodities during 2017–2021.

3.3. Estimation of Acute Exposure of Hungarian Consumers

The short-term intakes (ESTI) of consumers were calculated for the selected commodities using the 97.5th percentile of residues determined in them, and the large portion of consumptions obtained in the consumption surveys. The unit mass distribution of selected food items is given in Table 2. In the case of the apple, all residues were considered which had acute reference dose (ARfD) and were detected in a sufficient number of samples enabling the realistic calculation of their 97.5th percentile values (Table S2) with the Harrell–Davis method. For cherries (2), grapes (3), peaches (1), peppers (3), and strawberries (2) the ESTIs were calculated with the 97.5th percentile of the selected representative pesticide residues satisfying the above criteria and applying equations given in brackets.

The ESTI values for apple consumption calculated (Equation (1)) with a variability factor of 3, recommended by the JMPR [17,18,73], are shown in Table 6. The consumer's exposure is characterized by the hazard quotients (HQ). Since the highest short-term intake was observed for the age group of 1–2 years, the HQ values are given for this group in Table 6.

The ESTI was also calculated from the results of the 2009 consumption survey. Moreover, we examined the effect of the selection of variability factor on the outcome of the estimation. Therefore, the calculations were also performed with the variability factors of 7 recommended by EFSA for general use [74], and 3.6 agreed by the EU Member States for monitoring data [30,75]. Naturally, the ESTI calculated with $\nu = 7$ instead of 3 was higher and indicated HQ > 1 values for two substances. Because of the low ARfD values, the highest values obtained for the age group of 1–2 years represent the likely worst case of consumers' exposure (Table 7).

Table 6. The estimated short-term intake and HQ values based on apple consumption from the 2018–2020 survey.

		Age	1–2	2–3	3–9	9–18	18–64	64–74	1–2
		BW [kg]	11.1	13.6	17.6	50.5	79.6	81.5	
		LP [kg]	0.32	0.32	0.47	0.73	0.48	0.52	
Residues	P0.975 (mg/kg)	ARfD (mg/kgbw/day)	ESTI						HQ
Acetamiprid	0.12	0.025	0.0082	0.0067	0.0062	0.0028	0.0014	0.0014	0.33
Captan sum	1.02	1.3	0.070	0.057	0.053	0.024	0.012	0.012	0.05
Carbendazim	0.094	0.02	0.006	0.005	0.005	0.002	0.001	0.001	0.32
Chlorpyrifos-Methyl	0.055	0.1	0.004	0.003	0.003	0.001	0.001	0.001	0.04
Difenoconazole	0.112	0.16	0.008	0.006	0.006	0.003	0.001	0.001	0.05
Dithianon	0.163	0.12	0.011	0.009	0.008	0.004	0.002	0.002	0.09
Etofenprox	0.175	1	0.012	0.010	0.009	0.004	0.002	0.002	0.01
Fluopyram	0.182	0.5	0.012	0.010	0.009	0.004	0.002	0.002	0.02
Fluxapyroxad	0.07	0.25	0.005	0.004	0.004	0.002	0.001	0.001	0.02
Indoxacarb	0.08	0.125	0.005	0.004	0.004	0.002	0.001	0.001	0.04
Lambda-Cyhalothrin	0.045	0.005	0.003	0.003	0.002	0.001	0.001	0.001	0.62
Methoxyfenozide	0.139	0.1	0.010	0.008	0.007	0.003	0.002	0.002	0.10
Pirimicarb	0.09	0.1	0.006	0.005	0.005	0.002	0.001	0.001	0.06
Pyraclostrobin	0.074	0.03	0.005	0.004	0.004	0.002	0.001	0.001	0.17
Tebuconazole	0.148	0.03	0.010	0.008	0.008	0.003	0.002	0.002	0.34
Thiacloprid	0.118	0.02	0.008	0.007	0.006	0.003	0.001	0.001	0.40
Thiamethoxam	0.045	0.5	0.003	0.003	0.002	0.001	0.001	0.001	0.01

Table 7. Comparison of HQ values calculated based on apple consumption for the age group of 1–2 years with variability factors of 3, 3.6, and 7.

Compound	**ARFD (mg/kgbw/Day)**	**Survey Year**	**BW (kg)**	**LP (kg)**	**HQ (ν = 3)**	**HQ (ν = 3.6)**	**HQ ν = 7**
Lambda-Cyhalothrin	0.005	2009	12.11	0.322	0.85	0.99	**1.82**
		2018–2020	11.1	0.323	0.62	0.72	0.99
Thiacloprid	0.02	2009	12.11	0.322	0.56	0.65	**1.19**
		2018–2020	11.1	0.323	0.4	0.47	0.87

BW: Body mass.

Since the body mass of age groups and LP of apple consumption derived from the two surveys are very similar, the increase in the HQ values clearly indicates the effect of conceptual difference in the establishment of the variability factors by the two (European Commission and CODEX) bodies [74,76]. The HQ values for all age groups were less than 1 when the more realistic variability factor of 3.6 was used for all age groups and pesticide residues.

The hazard quotients were also calculated for the other selected commodities. Table 8 includes examples for HQ obtained with a variability factor of 3.6, the results of the 2018–2020 consumption survey, and the 97.5th percentile of residues of three pesticides representing a wide ARfD range: acetamiprid (0.025), fluopyram (0.07), and difenoconazole (0.16). In view of the lowest ARfD values amongst the detected pesticide residues in the examined commodities, the calculated HQ values represent the worst-case scenario of the exposure of consumers based on the food containing a single pesticide residue.

Table 8. Hazard quotients calculated with a variability factor of 3.6 and the residues detected in the selected commodities.

	HQ for Age Groups					
	1–2	**2–3**	**3–9**	**9–18**	**18–64**	**64–74**
Cherries						
Acetamiprid	0.078	0.030	0.072	0.017	0.027	0.014
Fluopyram	0.006	0.002	0.005	0.001	0.002	0.001
Grapes						
Acetamiprid	**1.50** [a]	**1.81** [a]	0.66	0.50	0.23	0.38
Difenoconazole	0.798	0.963	0.351	0.265	0.125	0.200
Fluopyram	0.083	0.101	0.037	0.028	0.013	0.021
Peaches						
Acetamiprid	0.456	0.659	0.436	0.204	0.066	0.131
Fluopyram	0.034	0.049	0.033	0.015	0.005	0.010
Peppers						
Acetamiprid	0.072	0.087	0.203	0.094	0.060	0.087
Difenoconazole	0.012	0.014	0.033	0.015	0.010	0.014
Fluopyram	0.004	0.005	0.011	0.005	0.003	0.005
Indoxacarb	0.152	0.186	0.432	0.200	0.127	0.186
Strawberries						
Pyraclostrobin	0.085	0.360	0.105	0.030	0.031	0.018
Trifloxystrobin	0.011	0.045	0.013	0.004	0.004	0.002

[a]: Note that HQ values are higher than one indicating potential health risk.

3.4. Estimation of the Cumulative Acute Exposure of Consumers

Through their daily diet, consumers may be subject to the combined acute effect of pesticide residues in several ways:

- One food item contains more than one residue;
- The food items consumed within one day contain the same or different residues;
- The foods contain multiple residues.

A large proportion (40–50%) of samples contained 2–23 residues during the period of 2017–2021 (Table 3). Up to 13 different residues (Table 4) were detected in the selected commodities. The largest numbers of residues given in brackets were detected in single apple (13), grape (12), peach and strawberry (9), and pepper (7) samples.

The acute reference doses established by EFSA [21–23] or JMPR [76] expert panels were considered for the calculation of cumulative exposure. The hazard quotient (HQ) and the hazard index (HI) were used to quantify the exposure which can be used for a mixture of chemicals regardless of the class, mechanism/mode of action, or target organ/system toxic effects [30,77].

3.4.1. Cumulative Exposure from Residues Exceeding the MRL Values

Of the large number of samples (>500–700) of selected commodities only six contained residues above the MRL (Table 9).

Table 9. Summary of multiple residues exceeding the MRL values.

Crop	Origin	Analyte	MRL	Highest Residue	No. of Residues Detected
Cherries	Hungary	Dimethoate/ omethoate	0.02	0.052	2
Peppers	Turkey	Chlorpyrifos	0.01	0.058	8
	Turkey	Chlorpyrifos	0.01	0.036	4
Strawberries	Hungary	Tebuconazole	0.02	0.17	9
	Hungary	Flonicamid	0.03	0.32	3
	Hungary	Propamocarb	0.01	0.064	4

ARfD values were available for seven residues in peppers and four substances in strawberries. The critical parameters are summarized in Table 10.

Table 10. ARfD values and residues detected in peppers and strawberries.

Active Substances	ARfD	Peppers	Strawberries
		Residues [mg/kg]	
Acetamiprid	0.025	0.17	
Boscalid	NA	0.12	0.13
Chlorpyrifos-methyl	0.1 NAP	0.058	
Cyprodinil	NA		0.29
Etoxazole	NA		0.038
Flonicamid (sum)	0.025		0.32
Hexythiazox	NA		0.017
Indoxacarb	0.005	0.11	
Methoxyfenozide	0.1	0.082	
Penconazole	0.5		0.014
Picoxystrobin	NAP		0.209
Pyraclostrobin	0.03	0.026	0.029
Pyridaben	0.05	0.064	
Spirotetramat (sum)	1.0	0.033	
Tebuconazole	0.03		0.17
Trifloxystrobin	0.5		0.057

Notes: NA: No ARfD value established. NAP: not authorized, no ARfD reported by European Commission.

The hazard index was calculated utilizing the 2018–2020 dietary survey results. The short-term daily intakes were estimated based on Equation (3) (LP > median unit weight) for peppers and Equation (2) for strawberries. Moreover, a variability factor of 3.6 was used. The results are summarized in Table 11.

Table 11. Hazard indices calculated from multiple residues in peppers and strawberries.

Age Groups	1–2	2–3	3–9	9–18	18–64	64–74
Peppers	0.19	0.25	0.16	0.08	0.05	0.07
Strawberries	0.37	0.37	0.46	0.13	0.13	0.08

In the case of both commodities, the HI values were below 1 for all age groups indicating that the exceedance of MRLs does not necessarily raise health concerns.

3.4.2. Cumulative Exposure from Food Items Consumed within One Day

A consumer may be exposed to pesticide residues by eating several foods containing the same pesticide residue(s). Evaluation of the 2018–2020 dietary survey revealed that a maximum of four items of the selected six were consumed within one day. The relative frequency distribution of the number of foods consumed in one day is shown in Figure 2.

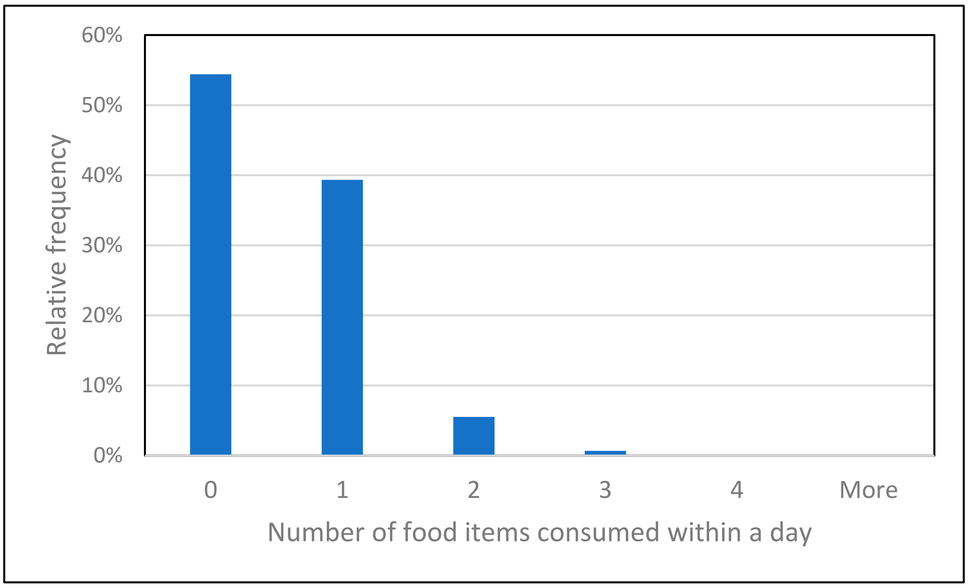

Figure 2. Relative frequency distribution of the number of food items consumed within one day.

Figure 2 indicates that none of the selected six food items were consumed on about 54% of the 5229 survey days, while four items were eaten only on four different days (0.08%). Besides the number of food items, their total consumed amount will also affect the cumulative exposure. The highest amounts of daily consumption (g/kgbw/day) are given in Table 12.

Table 12. Amount of food (g/kgbw) consumed on one day during the 2018–2020 survey.

Case	Daily Consumption g/kgbw/Day								
	Age	Bw [kg]	Apple	Cherries	Grapes	Peaches	Peppers	Strawberries	Sum
1	3.9	14	32.1		7.71				39.9
2	3.77	15.5	25.8			12.90			38.7
3	5.75	18	25.0		6.67				31.7
4	5.05	18.8	18.6			8.51			27.1
5	3.43	17	11.8		14.71				26.5
6	1.63	10	22.5	2					24.5
7	5.05	18.8	16.0			8.51			24.5
8	1.6	12	3.3					20.83	24.2
9	2.54	12.5	0.0	12				12.00	24.0
10	2.19	15	20.0				2		22.0
11	3.91	14	1.8		19.00				20.8
12	9.34	27	5.6					3.70	9.3

Table 12 indicates that the major contributors to the total amount of selected foods consumed are the apple–grape or apple–peach combinations that represent the upper 99.7% tail of the sum of consumption of the selected six food items during the 5629 survey days (Table 13). When strawberries are consumed the apple consumption is very low which can be explained by the seasonal variation in these fruits. The cherries and pepper did not contribute substantially to the sum.

Table 13. Consumption days and relative frequency of the sum (g/kgbw) of consumed food.

Food [1] g/kgbw	Frequency	
	Day	Proportion
20	5164	98.8%
30	45	0.9%
40	16	0.3%
90	3	0.1%
95	1	0.0%
More	0	
Sum	5629	

Note: [1]: Total mass of the selected 6 food items within a day.

The residue content of the individual lots varied. We assumed, as the worst-case scenario, that all residues detected in each fruit were present at their average concentrations on the day of their consumption. The residues detected in the samples taken from the six commodities and having ARfD values are summarized in Table 14.

Table 14. Residues detected in the samples of selected commodities.

	Number of Samples with Reported Residue Levels [1]				
	Apples	Grapes	Peaches	Strawberries	Peppers
Acetamiprid	162 (0.037)	36 (0.073)	40 (0.033)	3 0.030	39 (0.079)
Captan	118		12	7	
Carbendazim	27	12	10	6	
Chlorpyrifos	8	2	3		
Chlorpyrifos-methyl	13	5	2	1	
Cypermethrin	6	5	1	0	
Deltamethrin	1	1	4	2	
Difenoconazole	42 (0.041)	19 (0.108)	1 (0.017)	49 (0.064)	62 (0.070)
Fenoxycarb	5		2		
Fenpyroximate	12	0	0	0	
Flonicamid	29			1	
Fluopyram	88 (0.039)	44 0.085)	54 (0.048)	34 (0.086)	39 (0.049)
Fluxapyroxad	26	22			
Imidacloprid	1	16	9	2	
Indoxaxcarb	61 (0.021)	6 0.049)	16 (0.023)		13 0.048)
Lambda cyhalothrin	21	16	39	4	
Methoxyfenozid	83	30			
Penconazol	3	37	6	23	
Thiacloprid	54		6	19	

NA: not applicable. [1]: The average residues given in brackets were calculated with the reported LOQ values.

Based on the ARfD range (0.005–0.5) and the relatively large number of samples analyzed for the given residues, acetamiprid, difenoconazole, fluopyram, and indoxacarb were selected for the calculation of the cumulative exposure of the consumers. The ESTI was calculated with equations in brackets for apple, peach (1), grape (3), and strawberry (2). The results are summarized in Table 15.

Table 15. Hazard indices calculated based on the selected residues.

Cases	HI [1]				
	Apples	Grapes	Peaches	Strawberries	∑HI
1	0.70	0.167			0.87
2	0.56		0.279		0.84
3	0.54	0.144			0.69
4	0.40		0.184		0.59
5	0.25	0.318			0.57
6	0.49				0.49
7	0.35		0.184		0.53
8	0.07			0.125	0.20
9	0.00			0.072	0.07
10	0.43				0.43
11	0.04	0.411			0.45
12	0.12			0.022	0.14

[1]: The cumulative effect of the 4 selected residues that were present in the consumed food items. The hazard indices are well below one for each food. Even if two foods are consumed on one day, the sum of hazard indices is below one indicating that the combined consumption of these foods is unlikely to produce acute intake risk.

3.4.3. Examples of Cumulative Exposure Resulting from Multiple Residues below MRL

A large proportion of samples (30–50%) contained multiple residues. The number of residues present in the samples in detectable concentration varied. The following stepwise process was applied for selecting samples to estimate the acute cumulative exposure:

1. All residues that were investigated in the given type of sample were arranged in alphabetical order but only the first two columns were kept from Table S4;
2. The residue values detected in a sample were placed in the corresponding row of the sample residue matrix;
3. The residues that were detected but did not have an acute reference dose (ARfD) were deleted (crossed through in Table 16);
4. The residues originally present (NR_{al}) and remaining after removing those without ARfD value (NR_r) were counted, and their concentrations (mg/kg) summed ($\sum R_r$));
5. The ratio of measured residue concentration (R) to the ARfD values (R/ARfD) and their sum ($\sum$(R/ARfD)) were calculated;
6. Samples with high $\sum R_r$ and $\sum(R_i/ARfD_i)$ were selected for the calculation of ESTI, the hazard quotients (HQ_i), and the hazard index ($HI = \sum HQ_i$).

The process is illustrated with a simplified example using table grape residue data in Table 16.

The results of the analyses of samples containing multiple residues were screened based on the calculated values of $\sum R_r$ and $\sum$(R/ARfD) and taking into consideration the number of analytes detected (NR_{ALL}) and remaining (NR_r). The ESTI, HQ, and HI values were calculated for various combinations using the age group which gave the largest LP/bw value derived from the 2018–2020 survey. Some examples are given in Table 17. The table also indicates the residues that mainly contributed to the cumulative exposure.

Table 16. Selection of pesticide residues in table grapes for calculation of HQ and HI values.

		ΣR_r	**0.31**		**HI**
		NR_r	**6**		**5.33625**
S(R/ARfD)		**NR_{al}**	**11**		
Active Substances	**ARfD**	**Σ(R/ARfD)**	**8.45**	**ESTI**	**HQ**
****					
~~Azoxystrobin~~	~~NA~~				
~~Boscalid~~	~~NA~~		~~0.24~~		
****					
****					
~~Cyprodinil~~	~~NA~~		~~0.37~~		
Difenoconazole	0.16				
Dimethomorph (sum of isomers)	0.6				
Famoxadone	0.1				
~~Fenhexamid~~	~~NA~~		~~0.025~~		
Fenpyrazamine	0.3				
****					
~~Fludioxonil~~	~~NA~~		~~0.94~~		
Indoxacarb	0.005	4.4	0.022	0.002849	0.035617
Lambda-cyhalothrin	0.005	1.8	0.009	0.001166	0.233128
Methoxyfenozide	0.1	1.9	0.19	0.024608	4.921586
Penconazole	0.5		0.053	0.006864	0.068643
****					
Spirotetramat (sum)	1.0	0.011	0.011	0.001425	0.047489
Spiroxamine (sum of isomers)	0.1	0.23	0.023	0.002979	0.029789

Notes: ∑R: sum of residue concentrations. NR_i: number of residues with ARfD values. NR_{all}: number of residues detected in the sample. **** indicates substances that are not listed as they were not detected in the samples but are listed in Table S4. Crossed substances indicate those that were detected, but were not considered because they do not have ARfD values.

Table 17. Examples for the calculated highest cumulative acute exposure for age groups.

			Apples, 1–2 Years		
Sample Code	**713531**	**764209**	**871718**	**100208**	**701284**
NR_{all}	8	5	8	8	3
NR_r	8	5	8	8	3
Rmax	0.9	0.81	0.61	0.15	0.35
∑(R/ARfD)	6.28	8.3	11.28	12.5	14.1
HI	0.51	0.67	0.74	1.1	1.14
CritAS1	Captan	Indoxa	Indoxa	Cyper	Thiab
CritAS2		Captan			Aceta

Table 17. *Cont.*

Grapes, 2–3 Years					
Sample Code	**709244**	**706623**	**734019**	**747619**	**870823**
NR_{all}	3	12	7	8	8
NR_r	8	9	2	2	3
Rmax	0.21	2.03	0.61	0.51	0.25
∑(R/ARfD)	15.44	50.75	22.26	15.6	6.94
HI	2	6.57	1.65	2.05	0.93
CritAS1	Aceta	Cyper	Actea	Aceta	Aceta
CritAS2	Indoxa	Delta	Pyrac	Pyrac	
Peaches, 2–3 Years					
Sample Code	**772309**	**880314**	**913511**	**914291**	**952444**
NR_{all}	7	9	5	6	8
NR_r	5	6	6	4	7
Rmax	0.236	0.23	0.11	0.245	0.43
∑(R/ARfD)	5.49	4.22	7.86	20.74	19.64
HI	0.72	0.55	1.03	2.7	2.57
CritAS1	Lanbd	Lambda	Lambda	Lamda	Deltam
CritAS2	Captan	Tebuco	Indoxa	Tebuco	Piridab
Strawberries, 2–3 Years					
Sample Code	**747732**	**743721**	**858610**	**814218**	**975290**
NR_{all}	6	4	9	11	7
NR_r	5	9	5	6	5
Rmax	1.42	0.67	0.59	0.326	0.29
∑(R/ARfD)	34.3	23.12	19.6	4.31	9.72
HI	2.74	1.85	1.64	0.35	0.77
CritAS1	Thebu	Thebu	Flonic	Pyraclo	Thiab
Crt AS2	Iprod		Thebu		Pyraclo
Peppers, 2–3 Years					
Sample Code	**653512**	**733476**	**803030**	**961507**	**961620**
NR_{all}	5	9	11	7	8
NR_r	4	5	9	4	7
Rmax	0.62	0.43	0.46	0.65	0.54
∑(R/ARfD)	24.8	13.3	21.7	13.8	31.8
HI	8.13	4.06	7.1	4.5	10.44
CritAS1	Lambda	Flonic	Indoxac	Aceta	Indoxa
CritAS2	Imidac		Flonicam		Aceta
Cherries, 1–2 Years					
Sample Code	**682237**	**679422**	**750295**	**973694**	**679512**
NR_{all}	3	8	3	6	4.00
NR_r	3	6	3	6	4.00
Rmax	0.06	0.505	0.14	0.35	0.25
∑(R/ARfD)	8.96	4.5	9.40	10.30	5.20
HI	0.14	0.14	0.14	0.16	0.08
CritAS1	Carbend	Pirimicarb	Carbe	Lambda	Tebuco
CritAS2	Thioph		Tebucon		Aceta

Abbreviation of residues with ARfD values in brackets: Aceta: acetamiprid (0.025); Captan (0.3); Carbend: carbendazim (0.02); Cyper: cypermethrin (0.005); Delta: Deltamethrin (0.01); Flonic: flonicamid (0.025); Indoxa: indoxacarb (0.005); Imida: imidacloprid (0.08); Ipro: iprodione (0.06); Lambda: lambda-cyhalothrin (0.005); Pyrac: pyraclostrobin (0.03); Pyrida: pyridaben (0.05); Tebuco: tebuconazole (0.03); Thiac: thiacloprid (0.02); Thioph: thiophanate-methyl (0.02).

Examining the tendencies, we found that the $\sum(R/ARfD)$ values provided the most reliable indication of high HI values, though we could not establish any direct relationship. The $\sum R_i$ and the ratio of NR_{all}/NR_r did not provide additional guidance for the selection. Compared to the large number of residues that were detected in the samples, relatively few, having low ARfD values, were the major contributors to the HI (Table 17).

4. Discussion

The results of the analyses of samples derived from the national pesticide residue monitoring programs conducted during 2017–2021 and the two national food consumption surveys (2009 and 2018–2020) provided the raw data for the assessment of the acute exposure of Hungarian consumers to pesticide residues. There are numerous articles dealing with single and multiple residues in fruits and vegetables around the world. Many of them include the estimation of dietary intake; however, their scopes are different. Variances in tested commodities as well as the methodological differences used in the surveys render these data unsuitable for direct country-to-country comparison and the results cannot be directly compared with our findings [78–103].

A detailed evaluation of the monitoring data was published recently [13]. Of the 119 commodities included in the sampling program apples, sour cherries, table grapes, peaches/nectarines, sweet peppers, and strawberries were selected for estimation of acute exposure. The edible portions of these fruits are close to the whole fruit sampled and result in less than 20% difference in the estimated intake values. These commodities were frequently sampled and analyzed for a wide range (12–42) of residues, thus providing sufficient data for intake calculations.

In the evaluation of the residue data, special attention was given to multiple (2–13) residues that were present in 40–50% of the samples. It should be noted that the residues of parent compounds, their metabolites, and isomers were determined according to the residue definitions for enforcement purposes published by the European Commission. These are sometimes different from those defined for risk assessment purposes. Since the ARfD values are established considering the effect of all toxicological significant residues and metabolites, the reported residue concentrations should only be adjusted with the mass ratio of the analytes reflecting the two definitions. Consequently, in such cases, we somewhat underestimated the short-term intake (ESTI) using the reported residue values. However, this deficiency does not affect our conclusions regarding the exposure of Hungarian consumers.

In critical cases, the relevant residue data should be obtained by the analyses of samples taken shortly after harvest applying specific individual methods that recover and quantify all residue components defined for risk assessment purposes. The extra expenses involved in method development, validation, sampling, and analyses should be carefully evaluated for cost/benefit ratio before such a project is undertaken.

The national food consumption surveys were conducted in 2009 and 2018–2020 according to the actual methodologies recommended by EFSA. Both studies involved subjects selected randomly from the sampling targets of the national household budget surveys considering the age, gender, and geographical distribution of the Hungarian population. The results indicate that the average body mass has increased, while the net consumption of fresh fruits and vegetables slightly decreased in the case of children of 4–10 years old in line with the Hungarian nutritional and physical activity studies [104,105]. The difference is not statistically significant. Such a difference can also be attributed to the seasonal variation in consumption that can be clearly seen in the consumption days of young children <3 years. The spread of consumption data indicated by their relative standard deviation was in the same range in both surveys. The intake calculations performed with the results of the two surveys, conducted with somewhat different methodologies, gave similar results indicating that both surveys provided suitable data for risk assessment.

The short-term daily intake was calculated with the methodology applied by the JMPR [18]. It provides a conservative point estimate of acute exposure based on the 97.5th percentile of residue data obtained from the monitoring program and the 97.5th percentile of consumed food normalized by the average body weight observed during the surveys. In case of limited input data points (≤10) the maximum observed values were used in the calculations to avoid underestimation of the intake. Moreover, the unit-to-unit variability in pesticide residues in medium- and large-size crops was accounted for by applying the so-called variability factor (VF) of 3 applied by the JMPR, the average variability of residues in market surveys (monitoring programs) (3.6) calculated by the EFSA Expert Panel, and 7 recommended by EFSA for medium and large crops for general use.

The short-term intake acute intake was calculated from those residues that had acute reference doses established by EFSA or the JMPR. The consumer's exposure was characterized by the hazard quotients (HQ = ESTI/ARfD) and the hazard index (HI = ∑HQ). The latter is based on dose addition and assumes no interaction among the residues present, and it can also be used when the substances have dissimilar modes of action [30,77].

4.1. Calculation of the Short-Term Intake (ESTI) Based on Single Residues Detected in Various Apple Samples

The ESTI was calculated from the 2018–2020 apple consumption data of the six age groups with those 17 pesticides that were detected in different apple samples. The ESTI was highest for the age group of 1–2 years. The corresponding HQ values ranged between 0.1 and 0.62 when a VF of 3 was applied. The results indicated that the ESTI is the highest for the youngest children and gradually decreases for older consumers. Since the highest three hazard quotient values (0.62, 0.40, 0.33) were well below 1, we can conclude, assuming that only one pesticide residue is detectable in a sample, that the current plant protection practice applied in domestically grown and imported apples does not cause any health risk even for the most sensitive age group.

The calculation was repeated with the consumption values obtained from the 2009 survey as well as applying VF values of 3.6 and 7. The highest HQ values were obtained for lambda-cyhalothrin (ARfD = 0.005) and thiacloprid (ARfD = 0.02). Based on the 2009 consumption survey data, they were 0.85, 0.99, and 1.82 for lambda-cyhalothrin, and 0.56, 0.65, and 1.19 for thiacloprid when a VF of 3, 3.6, and 7 was applied, respectively. The tendency was naturally the same in the case of the 2018–2020 survey data. The results clearly indicate the effect of the selection of VF on the estimated exposure. The risk assessors should decide on the targeted probability and percentage coverage of residues when selecting the VF values for making decisions based on monitoring data.

In addition to apples, the HQ values were also calculated with a VF of 3.6 for the other five food items based on the more complete 2018–2020 consumption data for the six age groups. The HQ values were below 1 for all pesticides except acetamiprid in grapes (1.5, 1.81) in the case of young children (<3 years). The calculated HQ values represent the worst-case scenario of the exposure of consumers based on their food containing a single pesticide residue.

4.2. Multiple Residue Data Assessment of Pepper and Strawberry Samples

The cumulative effects of pesticide residues were studied for different scenarios. Pepper and strawberry samples contained 5 residues above the MRL besides another 2–8 compounds. The HI values for residues in peppers were highest (0.25) in the age group of 2–3 years. For strawberries, the highest value (0.46) was obtained in the age group 3–9 years. The results indicate that the exceedance of MRLs does not necessarily raise health concerns.

4.3. Multiple Residue Data Assessment in One Food Item or Combined Consumption of Several Food Items within One Day

A maximum of four food items of the selected six were consumed within one day on four occasions (0.08%) from the 5229 survey days. The main contributors to the total amount eaten (g/kgbw/day) were the apple–grape and apple–peach joint presence. The cherries and peppers did not add substantially to the sum. The combined daily consumption of apples and grapes (39.9 g/kgbw/day) represents the 99.7 percent upper tail of daily consumption. For the calculation of cumulative exposure, we selected acetamiprid, difenoconazole, and fluopyram representing the ARfD range (0.025–0.5 mg/kgbw/day) of all pesticides that were detected and could be present in any of the six food items. Further on, we assumed that the food items contained the average concentration of all residues that were present in their samples because taking the 97.5 percentile of their residues would lead to unrealistically over-estimated short-term intake that might occur with 1.56×10^{-5} probability (in 0.0016% of the cases). The HI values calculated for the 12 largest amounts consumed from the six food items ranged from 0.07 to 0.84 g/kgbw/day. The results indicate that it is unlikely that the combined consumption of the five fruits and peppers would result in intake concern.

Since 30–50% of the samples analyzed contained more than one pesticide residue the cumulative exposure deriving from multiple residues was studied. The number of different residues varied in the samples. We considered that the ratio of residue measured (Ri) and the corresponding ARfDi value affect the ESTI and HQ values most, and their sum would influence the calculated HI values. Therefore, we screened the dataset based on the sum of Ri/ARfDi and the number of residues present in a given sample. Samples with high ∑Rr (mg/kg) and ∑(Ri/ARfDi) were selected for the calculation of ESTI using the 2018–2020 survey data, the hazard quotients (HQi), and the hazard index. The ∑(R/ARfD) values provided the most reliable indication of high HI values. However, no direct relationship was found. The evaluation of the results revealed, as expected, that the residues having low ARfD values contributed mostly to the HI values. The high Hi values ranged for apples (1.1–1.14), table grapes (2–6.6), peaches (2.6–2.7), strawberries (1.6–2.7), and peppers (4.1–10.4). Pesticide residues with ARfD values ranging from 0.005 to 0.06 mg/kgbw/day were the major contributors.

It is pointed out that none of the residues exceeded the corresponding MRLs nonetheless resulting in high HI values. Therefore, the samples were considered compliant. Concerning the calculated HQ and HI values, the JMPR (2009) concluded [106] that values above 1 should not necessarily be interpreted as a health concern because of the conservative assumptions used in the ARfD assessments. However, the authors consider that HI values in the range of 4–10 do raise concern and would require further actions for revisiting the recommended use of such pesticides.

4.4. Advantages and Limitations of the Assessment Using HI Values

Finally, it is reemphasized that the HI values calculated from the hazard quotients, or the other methods (relative potency factors, MOET) provide only a point estimate of the exposure and the probability of the occurrence of the given case cannot be reliably quantified. Only the two-dimensional Monte Carlo probabilistic approach would provide different scenarios that are associated with a quantitative measure of uncertainty (upper and lower boundary of the mean) at each percentile of the exposure distribution [19,20]. However, the point estimates of consumers' exposure based on the HI values taking into account their ARfD values provide a simple and generally applicable methodology that can be applied without having access to specific software and technical knowledge. Therefore, its use in the first-tier risk assessment is recommended.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agrochemicals2030026/s1, Table S1: The gender and age distributions of the participants of the two surveys; Table S2: Summary of Consumption Survey 2009; Table S3: Summary of Consumption Survey 2018–2020; Table S4: Summary of residues, their MRLs and ARfD values detected in the selected samples during 2017–2021.

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Abbreviations

ARfD	Acute reference dose
AS	Active substance
CAG	Cumulative Assessment Group
EFSA	European Food Safety Authority
ESTI	Estimated short-term intake
FAO	Food and Agriculture Organization
HI	Hazard index
HQ	Hazard quotient
HBS	Household budget survey
HCSO	Hungarian Central Statistical Office
IC	Index compound
JMPR	Joint Meeting on Pesticide Residues
HFCSO	Hungarian Food Chain Safety Office
LOD	Limit of detection
LOQ	Limit of quantification
MRL	Maximum residue limit
MOE	Margin of exposure (individual)
MOET	Margin of exposure (combined)
NOAEL	No Observed Adverse Effect Level
STMR	Supervised Trials Median Residue
US FDA	United States Food and Drug Administration
TDI	Tolerable maximum daily intake
WHO	World Health Organization

Nomenclature

Consumer day	From a total number of records in a food consumption survey those days on which an individual reported consuming the food or foods of interest.
Intake	For the purpose of food or feed risk assessment, the amount of a substance (including nutrients) ingested by a person or animal as part of their diet. This term does not refer to whole foods. The intake of whole foods is termed "food consumption".
LP	Highest large portion reported (97.5th percentile of eaters), in kg food per day.
HR	Highest residue in composite sample of edible portion found in the supervised trials used for estimating the maximum residue level, in mg/kg.
Ue	Unit weight of the whole commodity (as defined for MRL setting, including inedible parts).
TMDI	Theoretical maximum daily intake is a prediction of the maximum daily intake of, for example, a pesticide residue, assuming that residues are present at the maximum residue levels/limits and average daily consumption of foods per person.
Ui	Median unit weight of the edible portion, in kg.
ν (VF)	Variability factor, defined as the 97.5th percentile of residue level in the unit divided by the mean residue level for the lot of units of interest.

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