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CROP PROTECTION

Deterministic and probabilistic risk of strawberry consumption with pesticide residues

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ABSTRACT: *Repeated presence of strawberries amongst produce with pesticide residues results in questionings related to the risks involved by its consumption. Deterministic and probabilistic risk assessment methods might be used depending on the available data. In the present study, both methods were used to estimate risks of pesticide intake by strawberry consumption. Strawberry samples along two years were analyzed via the multiresidue method. Results of active ingredients* (a.i.) *concentrations were organized and used for calculations for intake estimates. On the deterministic method, intake was calculated based on the data of* a.i. *concentration and consumption data coming from an online questionnaire and body weight between 5 and 70 kg. On the probabilistic method, the concentrations of* a.i. *and body weight of 60 kg were evaluated in two scenarios: a) consumption data from an online questionnaire or b) consumption data retrieved from Family Budget Survey of the Brazilian Institute of Geography and Statistics. In the 62 strawberry samples, 38* a.i. *were quantified and in 25 samples the residue analyses were considered satisfactory and 37 had an unsatisfactory outcome. In the deterministic approach, 23% of the* a.i. *had a calculated intake higher than the acceptable daily intake (ADI) and risk concentrated in body weights between 5 and 30 kg. The risk is low when considering a body weight of 60 kg. All* a.i. *tested in the first scenario of the probabilistic method pointed towards some possibility of intake being higher than the ADI. In the second scenario, only the* a.i. *procymidone exceeded the ADI.*
Key words: *dietary risk, agrochemical residues, fruit intake.*

Risco determinístico e probabilístico no consumo de morangos com resíduos de agrotóxicos

RESUMO: *A frequente presença do morango entre os alimentos com resíduos de agrotóxicos acima do limite máximo ou não autorizados gera uma série de questionamentos em relação aos riscos envolvidos no seu consumo. Nos processos de avaliação do risco podem ser utilizados métodos determinísticos e probabilísticos dependendo dos dados disponíveis. O objetivo deste trabalho foi conduzir uma avaliação determinística e probabilística do risco de ingestão de agrotóxicos através do consumo de morangos. Para tanto, 62 amostras de morangos foram analisadas através do método de multiresíduos entre os anos de 2018 e 2019. Os resultados de concentração dos ingredientes ativos foram organizados e utilizados para os cálculos de estimativa da ingestão. No método determinístico a ingestão foi calculada com base nos dados de concentração dos ingredientes ativos das amostras de morangos, dados de consumo provenientes de um questionário* online *e pesos corporais entre 5 e 70 kg. No método probabilístico foram utilizados os dados de concentração dos ingredientes ativos das amostras e peso corporal de 60 kg nos cenários um e dois, onde, no primeiro, os dados de consumo utilizados foram os dados do questionário e no segundo os dados de consumo de morango provenientes da Pesquisa de Orçamentos Familiares. Nas 62 amostras de morango analisadas foram detectados 38 ingredientes ativos, sendo 25 amostras consideradas satisfatórias, e 37 insatisfatórias. Entre os ingredientes ativos detectados, 40% não têm seu uso autorizado para a cultura. Na avaliação determinística, 23% dos ingredientes ativos apresentaram ingestão calculada superior a ingestão diária aceitável em pelo menos um cenário, estando o risco concentrado nos pesos corporais entre 5 e 30 kg, sendo o risco baixo quando considerado o peso corporal de 60 kg. Todos os ingredientes ativos testados no primeiro cenário da avaliação probabilística apresentaram alguma possibilidade de a ingestão ser superior a ingestão diária aceitável, enquanto que para o segundo cenário apenas o ingrediente ativo procimidona superou a ingestão diária aceitável. Entre os modelos estudados, o primeiro cenário da avaliação probabilística foi o que apresentou a maior probabilidade de provocar intoxicação e procimidona foi o ingrediente ativo mais frequentemente detectado nas amostras, e que apresentou as maiores chances de oferecer risco à saúde.*
Palavras-chave: *risco dietético, resíduos de agrotóxicos, ingestão diária de frutas.*

INTRODUCTION

Strawberry (*Fragaria x ananassa Duch*) is a fruit species of high social and economic importance in Brazil. Nonetheless, the species is persistently amongst produce with pesticide residues according to the main national monitoring programs: a) Residues and Contaminants Control Plan in Products of Plant Origin (PNCRC Vegetal) of the Brazilian Ministry of Agriculture, Livestock and Supply and b) the Program

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of Pesticide Residue Analysis in Food (PARA) of the National Health Surveillance Agency (ANVISA) of the Brazilian Ministry of Health (ANVISA, 2016).

The recurrent presence of strawberries in the lists of produce with pesticide residues motivates questions on the risks involved in the consumption of the fruit. Nowadays in Brazil, the risk evaluations are based on toxicological aspects established in the registration procedures at the competent authorities: Ministry of Health, Ministry of Agriculture, Livestock and Supply, and Ministry of Environment.

In the estimates of exposure to active ingredients present in food, three elements are obligatory: the concentration of the active ingredient ($mg.kg^{-1}$), the amount consumed (kg) and the body weight (kg) of individuals or population under analysis. Data on the concentration of active ingredients are obtained from the analyses for the presence of pesticides and the quantified concentrations are compared to existing toxicological parameters.

The amounts of consumed food are accessed from data of food supply or individual consumption. The latter is the ideal source to ponder exposure to chemicals in the diet (JARDIM & CALDAS, 2009). Data on individual body weight should be used when available and, if not available, the average body weight of the population shall be used (WHO, 1997).

For estimates of pesticide intake through the diet, the deterministic or probabilistic models should be used. The deterministic model makes use of fixed values of concentration and consumption such as the average, median or 97.5 percentile. The advantage of the method is the simplicity and the consequent promptness in the calculations.

Conversely, the probabilistic model is capable to integrate variables of consumption/body weight and concentration of residues granting the characterization of uncertainty (EPA, 2001). In this model, random values might be either removed or variables inserted using appropriate mathematical models that apply predominantly the Monte Carlo probabilistic techniques.

Therefore, in the present research the risk of pesticide ingestion through the consumption of strawberries was assessed via the deterministic and probabilistic models. The risk characterization was based on the acceptable daily intake (ADI).

MATERIALS AND METHODS

The present evaluation was elaborated based on the results of pesticide residue analyses of samples collected at the distribution center at Porto Alegre (CEASA-RS), the capital city of the southernmost state in Brazil. Strawberry consumption data were obtained from both the Family Budget Survey by the Brazilian Institute of Geography and Statistics (IBGE) and a questionnaire organized by the authors in 2019.

The risk evaluation was divided in different phases in accordance of the World Health Organization (WHO): hazard identification, hazard characterization, exposure assessment and risk characterization (WHO, 1997).

Hazard identification

To identify the active ingredients as potential hazards in strawberries, 62 samples were collected in the state-growers pavilion at the CEASA-RS from August 2018 up to November 2019. Only samples of fruit from strawberry fields of the state of Rio Grande do Sul were collected.

The collecting of samples, transport to the laboratory and analyses were headed by an accredited private laboratory located in the vicinity of Porto Alegre. All the procedures followed standard operational procedures for agrochemical residue analyses established by ANVISA in the Manual to Collect Samples of the National Plan for the Control of Residues and Contaminants in Vegetable Crops (BRASIL, 2013).

Multiresidue analyses were performed in the accredited laboratory and for every group of active ingredients, standard operating procedures based on the official AOAC 2007.1 method were applied. The residues were quantified by High Performance Liquid Chromatography coupled to Mass Spectrometry (HPLC-MS) and Gas Chromatography coupled to Mass Spectrometry (GC-MS). These methodologies enable each strawberry sample to be analyzed for the presence of 238 distinct active ingredients. Concentrations are expressed in $mg\ kg^{-1}$ or ppm (parts per million).

The outcomes of the residue analyses were classified as satisfactory when no pesticide residue or below maximum limit of residues (MLR) was determined. In Brazil, the MLR is a parameter only for fresh consumption vegetable crops, available in the monographs of the active ingredients provided by ANVISA. Unsatisfactory samples are samples in which the quantified residues were either above the MRL or the active ingredients are not authorized for use on strawberries at national level.

It is important to indicate that the multiresidue method used by the accredited laboratory has a Limit of Quantification (LOQ). The LOQ stands for the lowermost concentration of a substance that is possible to be determined with precision and accuracy by means of a given analytical procedure. Whenever residues are below the LOQ, it is considered that the sample does not contain residues of that active ingredient.

Hazard characterization

In the phase of hazard characterization were identified the toxicological parameters of every active ingredient quantified in the residue analyses. The ADI is the amount of an active ingredient present in food that might be ingested on a daily basis for a lifespan without any risk to the consumer. Important to emphasize is, according to ANVISA (2019), that such statement is based on the present-day knowledge and the amounts are expressed in milligrams of the active ingredient per kg of body weight (mg.kg^{-1}).

Therefore, the ADI is the safety parameter used in the analyses of estimates of risk associated to ingestion of pesticide residues in food (CALDAS & SOUZA, 2000; ADEWOLE et al., 2021; MEDINA et al., 2021).

Exposure assessment

A chronic exposure was only calculated for the active ingredients when an irregular situation was detected: residue beyond the MLR or not authorized active ingredient for use in strawberry fields at national level. The Brazilian legislation specifies that when for a specific crop the MLR is not yet defined, the residue limit is extrapolated from another crop with similar use and consumption pattern. Nonetheless, the presence of not authorized residues on strawberries constitutes an irregularity and risk analyses were performed even when the MLR was below the limit established for a related crop.

Data on strawberry consumption were obtained from a questionnaire in which the most frequent amount of consumed strawberries in every meal were calculated: 0.05, 0.1, 0.25 or 0.148 kg/*per capita*. Also data from the Family Budget Survey of the Brazilian Institute of Geography and Statistics of the years 2008 and 2009 (IBGE, 2011) were used to obtain average annual strawberry consumption by the population of two Brazilian regions: South (0.357 kg/*per capita*) and North (0.021 kg/*per capita*). Both values represent the maximum and minimum consumption of strawberries in the country. The data of the Family Budget Survey were divided by the number of days (365) and expressed in kg day^{-1} to calculate the ingested amount of fruit.

The deterministic evaluation of exposure was calculated according to the equation 1 of JARDIM & CALDAS (2009) using only data from the questionnaire. The daily pesticide residue intake is defined as the sum of the concentrations of active ingredients present in food (Ri) expressed in mg kg^{-1} multiplied by the amount of consumed food (Ci) expressed in kg.

$$Ingestion = \sum(Ri \times Ci) \qquad \text{(Equation 1)}$$

In the probabilistic exposure evaluation, pesticide ingestion was calculated according to the probabilistic model of JARDIM & CALDAS (2009). The data of irregular active ingredients either because of exceeding the MRL or not authorized molecules and the data of consumption both deriving from the questionnaire and from the Family Budget Survey were organized in spreadsheets and distributions were prepared using the software @Risk (*Palisade Corporation*, version 7.6). That software was chosen because of the possibility of data analyses in distinct arrangements for the reason that it favors delineating distributions built on historical data of a specific input. The software @Risk runs the analysis through Monte Carlo simulations generating an assortment of possible results deriving from the inserted parameters and informing the probability of their occurrence (PALISADE BRASIL, 2019).

The software @Risk allows more than 65 diverse distributions that might fit the data. As a result, the choice of the distribution occurred based on the best-fit adjustment. *Uniform* distribution was used for data on strawberry consumption and *Exponential* distribution was used for data of active ingredient concentration.

Characterization of risk

In the deterministic method, the characterization of risk of chronic intoxication for every active ingredient in an irregular situation was calculated according the equation 2. The ingestion centered on the ADI in mg kg^{-1} body weight made use of the range of 5 kg and 70 kg.

$$\%\ ADI = \frac{Ingestion\ x\ 100}{ADI\ x\ body\ weight} \qquad \text{(Equation 2)}$$

Where the ingestion is the value calculated in the equation 1 is expressed in mg kg^{-1} and ADI the reference toxicological parameter.

In the probabilistic method, the characterization of risk was processed preparing an evaluation model of risk presented in the table 1. The calculations were performed by inserting the equations according the distributions with a best

Table 1 - Evaluation model of risk based on data of residues of pesticides concentrations in strawberry samples collected in 2018 and 2019 at the Central Distribution Center at Porto Alegre, the capital city of the state of Rio Grande do Sul based on data of a questionnaire or of the Family Budget Survey of the year 2010. Consumption data are the variable components of scenarios 1 and 2.

Scenarios	Symbol	Variable and unit	Equation
1	Cm	Average concentration (mg kg^{-1})	RiskExpon (Cm)
	Qq	Consumption questionnaire (g kg pc^{-1*})	RiskUniform (Qq minimum; Qq maximum)
	Rr1	Risk in every intake Scenario 1 (%)	RiskOutput()+1-(1-Cm x Qq)
2	Cm	Average concentration (mg kg^{-1})	RiskExpon (Cm)
	Qibge	Consumption IBGE** (g kg pc^{-1})	RiskUniform(Qibge minimum; Qibge maximum)
	Rr2	Risk in every intake Scenario 2 (%)	RiskOutput()+1-(1-Cm x Qibge)

*pc = body weight
**Brazilian Institute of Geography and Statistics

fit for every data set generating a distribution of probabilities of occurrence for every set.

The Monte Carlo simulations were run with 100.000 iterations in between consumption data and concentrations of the 10 active ingredients with highest frequency in a nonconforming condition. Two scenarios were envisioned for every active ingredient. In the first scenario, the amount of ingested strawberries was grounded on the minimal and maximal amount of 50 g and 250 g in every meal, respectively. In the second scenario, consumption data were grounded on the Family Budget Survey from which the average intake of two Brazilian regions were used: North and South that correspond to minimal and maximal intake.

Results of the simulations were compared to the ADI of the active ingredients. Furthermore, the probability of ingestion of a specific pesticide was determined in the situation of an intake beyond the ADI for every one of the active ingredients.

RESULTS AND DISCUSSION

From the 62 collected strawberry samples 25, *i.e.* 40%, were up to the official regulatory guidelines and 37, *i.e.* 60%, nonconforming concerning pesticide residues. Amongst the samples considered satisfactory in only three (5% of the whole set of samples) no quantifiable pesticide residue was detected and in 35% of the samples (22) residues were below the maximum residue limit (MRL). On the contrary, amongst the 37 non-conforming samples, 18% (11 samples) presented residues of pesticides not permitted for use in strawberry production and 13 samples (21%) presented both not authorized active ingredients for strawberry production and residues above the MRL (Figure 1).

BEMPAH et al. (2012) conducted a similar study in Ghana where they analyzed 309 samples of various fruits and vegetables and the results revealed that 51.0% of the samples had pesticide residues below the maximum residue limit (MRL), while 9.8% of the samples had residues above the MRL. Results of the study by RIBEIRO et al. (2021) revealed that 62.3% of the samples collected in the state of Minas Gerais, Brazil, had pesticide residues, of which 22.6% had unsatisfactory results in accordance with the legislation. In the study by PARK et al. (2021), 17,977 samples of leafy vegetables collected in South Korea were analyzed and 15.7% of the samples had pesticide residues and 2.4% exceeded the MRL.

It is important to highlight that the present study evaluated only strawberry samples, which due to their greater susceptibility to attack mainly from fungi, viruses and mites are subject to the application of pesticides to control these potential pathogens. Thus, it is likely that the lower rate of non-compliance with the legislation found in the cited studies can be attributed to the fact that they all evaluated at least twelve different foods, where there are probably some types that do not depend so much on the use of pesticides such as strawberries separately.

The values of acceptable daily intakes of the nonconforming active ingredients, *i.e.*, the molecules that were determined with concentrations above the maximum residue limit or not permitted for use in strawberry production are listed in table 2. These values were used for the calculations of deterministic

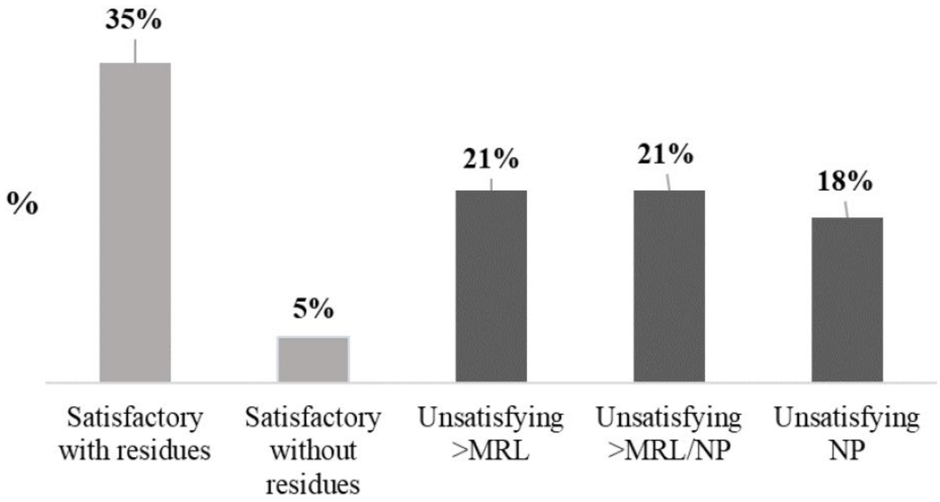

Figure 1 - Results of pesticide residue analyses of 62 strawberry samples collected in the years 2018 and 2019 at the Central Distribution Market in Porto Alegre, the capital city of the southernmost state in Brazil.

and probabilistic characterizations of risks. LOPES & ALBUQUERQUE (2018) in their review of the impact of pesticides on human and environmental health, concluded that exposure to pesticides can damage cell-defense mechanisms, body pain, respiratory disorders, liver and hormonal changes, changes in male and female reproductive systems, hearing loss, depression, anxiety, suicide and fetal death.

The use of unauthorized active ingredients for the crop is a challenge for technicians who provide assistance to growers of minor crops, such as strawberries. In Brazil, minor crops are defined as “Insufficient Phytosanitary Support Crops” with a shortage or reduced number of registered a.i. A limitation for the legal prescription of pesticides necessary for the phytosanitary control in these crops due to the high rate of unauthorized active ingredients detections.

The deterministic calculations of the acceptable daily intake are organized in table 3 and related to the amounts of ingested strawberries in every meal for specific body weights. The deterministic calculation of risk was performed for every active ingredient in an irregular situation. Nonetheless, only the active ingredients that had an ingestion above 100% of the ADI are listed. These active ingredients correspond only to 4.52% of the total amount of calculated ADI´s. The value of ADI was extrapolated, especially when the considered body weight was 5 kg and the amount of consumed strawberries was of 250 g. These assumptions correspond to 32% of the scenarios with an intake beyond ADI.

It becomes evident that very unlikely someone of only 5 kg body weight would consume about 250 g of strawberries in a single meal. However, the Abrasco report (CARNEIRO et al., 2015) states that intoxications are conceivable by way of breast milk, knowing that pesticides have the capability to disperse in the environment and some amount might accumulate in the human body, including breast milk. The authors assert as well that the consumption of contaminated breast milk can cause health problems to newborns due to their vulnerability for being at developmental stages and for feeding almost exclusively on breast milk until 6 months of age.

Table 2 - Active ingredients determined in 62 strawberry samples and the corresponding acceptable daily intake (ADI). Samples collected in the years 2018 and 2019 at the Central Distribution Market at Porto Alegre, the capital city of the southernmost state in Brazil, which were regarded as in an irregular situation because of a maximum residue limit (MLR) above the permitted concentration or a not permitted molecule (NA) for use in strawberry fields.

Active Ingredient	ADI (mg kg^{-1} body weight)
-----Irregular because of MRL-----	
Azoxystrobin	0.02
Carbendazim	0.02
Chlorfenapyr	0.03
Difenoconazole	0.6
Dithiocarbamate	0.03
Pyridaben	0.01
Procymidone	0.1
Thiamethoxam	0.02
-----Irregular because of NA-----	
2,4 D	0.01
Acetamiprid	0.024
Chlorothalonil	0.03
Cypermethrin	0.05
Clothianidin	0.09
Deltamethrin	0.01
Spiromesifen	0.018
Fenpyroximate	0.01
Phosmet*	0.005
Imidacloprid	0.05
Metalaxyl-M*	0.08
Pyraclostrobin	0.04
Pyriproxyfen	0.1
Propamocarb	0.1
Triazophos	0.001

*Active ingredient not permitted for use in strawberry fields.

For 30 kg body weight and above, the chances of ingesting active ingredients higher than the ADI are minor because for that weight there is a risk only at an intake of 250 g strawberries/day. When the average body weight is considered as 60 kg, none of the active ingredients in a nonconforming situation reached intake equivalent to 100% of the ADI. The maximum value for a person of 60 kg ingesting 250 g of strawberries would reach 51.5% of the ADI for the active ingredient procymidone.

Although, acceptable food intake is a highly conservative toxicological parameter, eight of the 35 active ingredients (23%) surpassed the ADI. One of these eight outperformed the ADI by 500% in one of the calculated scenarios, as shown in table 3. This situation raises concerns due to the concentration of an active ingredient in a single food (strawberries). In addition, an individual's daily diet consisting of many other items that may also contain pesticide residues increases the likelihood of ingesting certain active ingredients beyond safe intake doses.

Results disclosed in the present analysis are coherent with the results of similar studies, such as CALDAS & SOUZA (2000). The authors identified based on a deterministic risk assessment that the intake of active ingredients via the diet exceeded the ADI for 23 pesticides in at least one Brazilian metropolitan area. MARQUES & SILVA (2021) identified in their study that of the 283 active ingredients evaluated, 68 (24%) had a median intake that exceeded the ADI value.

The results of the probabilistic risks are presented in table 4. These are percentages derived from interactions via Monte Carlo simulations in

Table 3 - Results of deterministic risk assessment when pesticide ingestions are above the acceptable daily intake (ADI) based on estimates of ingested fruit considering molecules in an irregular situation in 62 samples collected in the years 2018 and 2019 at the Central Distribution Market in Porto Alegre, the capital city of the southernmost state in Brazil.

%ADI	BW* (kg)	Amount of ingested fruit (g)	Active ingredient	% ADI	BW* (kg)	Amount of ingested fruit (g)	Active ingredient
100.7	5	148	Azoxystrobin	167.5	5	250	Azoxystrobin
100.7	5	148	Carbendazim	170	5	250	Carbendazim
101.2	5	148	Acetamiprid**	170	5	250	Azoxystrobin
101.6	5	148	Procymidone	170.8	5	250	Acetamiprid**
102.9	30	250	Procymidone	171.5	5	250	Procymidone
106	5	100	Dithiocarbamate	179.8	5	148	Procymidone
106	10	250	Procymidone	180	5	100	Azoxystrobin
108.1	5	148	Thiamethoxam	182.5	5	250	Thiamethoxam
109.6	5	148	Azoxystrobin	182.9	10	148	Procymidone
109.6	10	148	Chlorfenapyr	185	5	250	Azoxystrobin
112.5	20	250	Azoxystrobin	185	10	250	Chlorfenapyr
115	5	250	Azoxystrobin	200	5	200	Spiromesifen**
118.5	5	148	Thiamethoxam	200	5	250	Thiamethoxam
119.8	10	250	Procymidone	212	5	250	Procymidone
120	10	250	Carbendazim	219.1	5	148	Chlorfenapyr
121.4	5	100	Procymidone	225	10	250	Azoxystrobin
123.5	5	50	Procymidone	239.5	5	250	Procymidone
123.5	10	100	Procymidone	240	5	250	Carbendazim
125	20	250	Spiromesifen**	247	5	100	Procymidone
125.6	5	148	Procymidone	250	10	250	Spiromesifen**
130	5	250	Azoxystrobin	265	5	250	Dithiocarbamate
132.5	10	250	Dithiocarbamate	266.5	5	148	Azoxystrobin
133.3	10	148	Azoxystrobin	296.1	5	148	Spiromesifen**
141.9	5	148	Procymidone	303.5	5	250	Procymidone
142.1	5	148	Carbendazim	308.8	10	250	Procymidone
148	5	200	Chlorfenapyr	365.7	5	148	Procymidone
148.1	10	148	Spiromesifen**	370	5	250	Chlorfenapyr
151.8	10	250	Procymidone	450	5	250	Azoxystrobin
154.4	20	250	Procymidone	500	5	250	Spiromesifen**
157	5	148	Dithiocarbamate	617.5	5	250	Procymidone

* Body weight
** Active ingredient not permitted for use in strawberry fields.

Table 4 - Percentages of interactions in which the ingested active ingredient is higher than the acceptable daily intake (ADI) in a context an individual consumes amounts of strawberries derived from data of on online questionnaire (scenario 1) or from data of the Family Budget Survey of the Brazilian Institute of Geography and Statistics (scenario 2).

Active Ingredient	Scenario	% of interactions with ingestion >ADI
Metalaxyl-M*	1	11.1
	2	0
Thiamethoxam	1	80
	2	0
Acetamiprid*	1	0.1
	2	0
Azoxystrobin	1	92
	2	0
Procymidone	1	99.3
	2	19.9
Pyraclostrobin*	1	80.4
	2	0
Clothianidin*	1	0
	2	0
Carbendazim	1	89.6
	2	0
Cypermethrin*	1	25.8
	2	0
Dithiocarbamate	1	82
	2	0

*Active ingredient not permitted for use in strawberry fields.

which the ingested active ingredient is higher than the value of ADI in the context of an individual consuming strawberries in the amounts detected in the questionnaire (scenario 1) or in the amounts determined in the Family Budget Survey (scenario 2). Only the results of the ten most frequent active ingredients in irregular concentrations of the nonconforming samples are listed.

All the active ingredients evaluated in scenario 1 had a high percentage, above 80%, of interactions in which the ingestion is exceeding the ADI. In the scenario 2, the majority of active ingredients except for the active ingredient procymidone, the percentages of ingestion higher than the ADI were null. Procymidone is the active ingredient with the highest potential risk as the chances for a negative health effect are of 99.3% when the amounts of consumed strawberries of the first scenario are considered. The potential risk is reduced (19.9%) in the case the amounts of consumed strawberries are retrieved from the Family Budget Survey (scenario 2). As the active ingredient has been determined in 66.1% of the analyzed samples, the ingestion above the ADI in both scenarios in the probabilistic evaluation is highly conceivable. In the deterministic evaluation in 36% of the interactions of the scenarios the ingestion would exceed the ADI.

The intake of active ingredients beyond the ADI represent a risk as the acceptable dose is considered safe and above which adverse health effects might befall. Those adverse effects depend on the dose and on the characteristics of the molecule. Moreover, the intoxication symptoms are diverse: nausea, shivers and breathing difficulties. Also, other serious problems such as paralysis, tumor development and even fatality with longstanding exposure have been reported (SILVA et al., 2019).

The reduction in the use of pesticides in the production system is essential given that the demands of the consumer market, which requires the supply of safe food, go beyond the safe use of pesticides. Some researchers point to organic agriculture or vegetable production without the use of pesticides as a possible solution to this demand. Yet it is likely that these systems will not be able to meet the human demand for food (JOUZI et al., 2017). Therefore, alternative measures to control pests and diseases have been studied, as is the recent case of the use of plant extract of *Schinus terebinthifolius* (pink pepper) in the mycelial growth of *Colletotrichum acutatum* on strawberry, which showed potential for an agroecological management of the pathogen (MELLO & ZACHARIAS, 2019).

Adjustments in strawberry postharvest management are also alternatives to reduce the use of pesticides. Currently, the use of synthetic chemical fungicides as a method to reduce postharvest diseases is the main way of decreasing microbial activity and, consequently, increasing the storage time of strawberries (SCHMITZ et al., 2019). Although, the use of these fungicides can be reduced by storing fruit at low temperatures, in a modified atmosphere or by using treatments that reduce the product's metabolism. GARCIA et al. (2012) obtained an increase in the shelf life of strawberries through the use of edible coating of the fruits with a film containing 3% of cassava starch.

Processes such as washing, thermal processing and chemical sanitization with chlorine-based compounds are the most common practices for removing pesticides from food. However, some pesticides are insoluble in water, which makes washing a partially reliable technique for eliminating pesticide residues (ORTIZ-HERNANDEZ et al., 2018). Furthermore, it has been suggested that chemical hygiene can generate several potentially carcinogenic by-products (PHAN et al., 2018).

Thermal treatments to remove pesticide residues are also used in some cases, but they can have negative effects on the physicochemical, nutritional and organoleptic properties (HEO et al., 2014) of some foods, especially those that are consumed *in natura* such as strawberries. Thus, research has been exploring new techniques for removing pesticides from food, such as the use of advanced non-thermal oxidation and cold plasma (GAVAHIAN et al., 2018; GAVAHIAN et al., 2021).

The calculations of intake and chronic exposure in the present study considered the amounts of ingested residues in one single meal as the consumption data from the questionnaire (scenario 1) refer to the portion of strawberries consumed at one go. Differently from the data of the Family Budget Survey where the volume of consumed fruit is divided by the number of days (365) considering that consumption is homogeneous throughout the year.

CONCLUSION

In the deterministic exposure assessment for body weights above 30 kg the risk of intake of pesticide residues under the evaluated circumstances is considered low. However, 23% of the analyzed active ingredients presented ingestion above the accepted daily intake dose in at least one scenario.

In the probabilistic risk assessment under the scenario 1, the ingestion of active ingredients above the accepted daily intake dose is surpassed by all the analyzed active ingredients pointing to a conceivable health risk. When data from the Family Budget Survey (scenario 2) are considered only the active ingredient procymidone unveiled a possibility of ingestion above the accepted daily intake concentration.

Procymidone is the active ingredient with highest risk potential. In the deterministic model, the active ingredient showed up in 36% of the scenarios in which the ingestion exceeds the accepted daily intake dose. In the probabilistic model that active ingredient might be a source health risks in either 99.3% or 19.9% for scenarios 1 and 2, respectively.

The elevated rates of residues in strawberries are proof of the need of including the species in residue monitoring programs and, lastly, the predictions of this study take into account the available data; however, more data are necessary in order to bring the mathematical predictions closer to reality.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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