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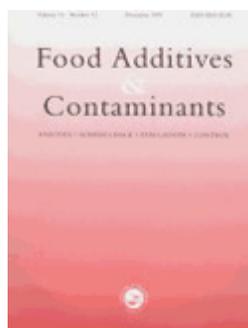
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Safe apples for baby food production: search for pesticide preparations leaving minimum residues

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1 Safe apples for baby food production: search for pesticide preparations 2 leaving minimum residues

3 4 **Abstract**

5 Altogether 19 pesticide preparations were used according to agricultural practice within 6
6 trials in apple orchards. Using gas chromatography-mass spectrometry (GC-MS) and liquid
7 chromatography-tandem mass spectrometry (LC-MS/MS) methods, premature Golden
8 Delicious apples collected 64, 50, 36 days before harvest and matured fruit were examined
9 for residues of active ingredients. No residues of triflumuron, triazamate, chlorpyrifos,
10 etofenprox, fenoxycarb, kresoxim-methyl, cyprodinyl, difenoconazole and thiram were
11 detected in the first sampling, also the levels of chlorpyrifos-methyl, penconazole,
12 tebuconazole and tolylfluanid dropped during the pre-harvest interval. Detectable, residues
13 of pyridaben, thiacloprid, trifloxystrobin and tetraconazole in harvested fruits were below
14 0.01 mg kg⁻¹, which is the maximum concentration of residues acceptable by baby food
15 producer in any raw material to be processed. The only residues exceeding this
16 concentration were captan and teflubenzuron. Based on these data, farmers may choose the
17 pesticides for optimal treatment plants whilst enabling production of safe crop suitable for
18 baby food production.

19
20 **Keywords:** apples, pesticides, baby food, fruit production, gas-chromatography-mass
21 spectrometry, liquid-chromatography- tandem mass spectrometry

22 23 **Introduction**

24
25 Various abiotic factors such as unfavourable temperature, moisture, nutrients, soil
26 conditions and/or phytotoxic environmental chemicals as well as several infectious disease
27 agents represented mainly by biotic pathogens such as fungi, bacteria, viruses, nematodes,
28 mycoplasmas etc. may cause damage to food crops (Hamilton 2004). To maintain healthy,
29 productive plants and prevent losses of stored crops, producers should recognize what pests
30 to look for, understand pest biology, use appropriate preventive measures, and apply last
31 but not least timely efficient pesticide preparations when needed. In general, after

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3 1 elimination of targeted pests, modern pesticides are designed to dissipate due to various
4 2 environmental factors and detoxication processes taking place in treated plants.
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9 4 However, under certain circumstances, even if applied in accordance with Good
10 5 Agriculture Practice (GAP), residues of pesticides can still be detected in treated crops
11 6 (Hajslová 1999). Consumers' exposure to such hazardous chemicals is of growing health
12 7 concern, specifically in the case of infants and young children that represent the most
13 8 vulnerable population group – not only because of their high food intake per body weight
14 9 unit but also due to yet undeveloped detoxication mechanisms. With respect to these facts,
15 10 a uniform Maximum Residue Limit (MRL) as low as 0.01 mg kg⁻¹ was established by EU
16 11 Directive for any pesticide residue in processed cereal-based foods and baby foods for
17 12 infants and young children (Commission Directive 1999/39/EC).
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26 14 It should be noted that EU Maximum Residue Limits (MRLs) applying to common
27 15 products of plant origin are often higher than 0.01 mg kg⁻¹. According to an internationally
28 16 accepted strategy, their values are based not only on toxicologically acceptable levels, but
29 17 also on evaluation of residue data from supervised field trials carried out according to the
30 18 principles of Good Agricultural Practice (GAP). Experience shows that GAP-based MRLs
31 19 are generally lower than MRLs derived from toxicological end-points (Hamilton 2004).
32 20 The overview of EU legislation concerned with pesticides and their MRLs is shown at
33 21 http://europa.eu.int/comm/food/plant/protection/pesticides/legislation_en.htm and
34 22 http://ec.europa.eu/food/plant/protection/pesticides/index_en.htm, respectively.
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44 24 A significant decrease in pesticide residues typically occurs during technological
45 25 operations such washing, steam boiling, thermal sterilisation etc. employed for
46 26 industrial/household fruits and/or vegetable processing (Cano et al. 1987; Cabras et al.
47 27 1990; Mahajan et al. 1992; Cabras et al. 1993; Holland et al. 1994; Ong et al. 1996; Cabras
48 28 et al. 1997; Burchat et al. 1998; Cabras et al. 1998a, 1998b, 1998c; Will et al. 1999; Cabras
49 29 et al. 2000; Panagiotis EA et al. 2000; Rassmussen et al 2003; Yirong-Su et al. 2003).
50 30 Despite this fact, in view of the large number of registered pesticides representing various
51 31 chemical classes and (consequently) a wide range of physico-chemical properties, the
52 32 possible transfer of some (more persistent) residues into the final product cannot be
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1 avoided. To prevent such a risk and to ensure the quality of fruit/vegetable baby food, baby
2 food producers are nowadays reluctant to process any raw materials containing residues
3 exceeding 0.01 mg kg⁻¹ limit (even though the “common” MRL for particular crop is not
4 exceeded). To our knowledge, the current practice of major baby food producer is to check
5 all batches of components prior to processing; thus the risk of marketing a product (baby
6 food) containing violative residues is minimized. Thus, strategies relying on “dilution” of
7 contaminated batch by residues free raw material and/or degradation of occurring
8 pesticides during processing chain are not represent common approach.

9
10 Under these conditions, close collaboration between industry and farmers was established
11 to facilitate a supply of crops containing low residue or residue free requirements.
12 Although the use of organic crops might represent a conceivable option, this may not be a
13 realistic solution in view of the global demands for raw materials. Therefore, a careful
14 choice of agricultural practices namely selection of low input, non-persistent pesticide
15 preparations is a critical issue in this context. It should be noted that in addition to
16 documentation submitted by producers within the pesticides registration process, there are
17 a large number of papers documenting a decline of various pesticide residues following
18 respective food plant/crop treatment, however, due to a largely variable climatic conditions
19 as well as with respect to differences in application practices, such information is only
20 tentative and cannot be considered as fully generic (Holland et al. 1994, Rasmussen et al.
21 2003, Gambacorta et al. 2005, Cengiz et al. 2006).

22
23 In our study, extensive field experiments concerned with optimisation of apples production
24 are presented. The aim of this work was to identify the optimal strategy for apple tree
25 protection providing efficient control of pests (plant diseases) and, at the same time leaving
26 undetectable or very low pesticide residues not exceeding 0.01 mg kg⁻¹.

27 28 **Materials and methods**

29 *Field work*

30 Golden Delicious apples examined in this study for pesticide residues were obtained from
31 our project partner Research and Breeding Institute of Pomology, Holovousy Ltd., Czech
32 Republic. The field experiment was performed at the orchard Sady Rokos Petrovicky,

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3 1 Jicín, Czech Republic. The standard agricultural practices (pruning, fertilizing, and soil
4 management) were carried out on the plots during the season. Golden Delicious apple trees
5 2
6 (24 years old) were situated in spacing 5 x 3 m (approximately 650 trees per ha),
7 3
8 experimental area was 0.25 ha. The overview of pesticide preparations including some
9 4
10 relevant characteristics are summarized in Table I. A tractor mounted sprayer Tifone
11 5
12 Vanguard 1070 equipped with the Albus ATR nozzles was used for the pesticide
13 6
14 applications; the volume was 400 L per ha and the operating pressure 1.3 MPa.
15 7
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17 9 In April 2004, pesticide treatment started on the whole experimental orchard. In June 2004,
18 10
19 experimental orchard was divided into six field experiments representing six differences in
20 11
21 pesticide preparation treatments (the frequency of applications was higher compared to
22 12
23 standard practice). The detailed overview of pre-harvest treatment of apple trees performed
24 13
25 in the year 2004 is summarized in Table II.
26 14

27 15 Four samplings of fresh apples were carried out, 14, 28, 42 and 78 days (i.e. in August 2,
28 16
29 August 16, August 30 and in October 5, respectively) after the last application of pesticide
30 17
31 preparations. In total 24 samples were obtained. Sampling was performed by randomly
32 18
33 hand-picking of fruits (approximately 3 kg of apples per sample) from various places of the
34 19
35 experimental fields according to the standard operating procedure elaborated in compliance
36 20
37 with Commission Directive 2002/63/EC.
38 21

40 22 [Insert Table I about here]
41 23

44 24 [Insert Table II about here]
45 25

47 26 *Weather*

49 27 Weather conditions were monitored during the whole season by automatic weather station
50 28
51 at 15 min intervals. Temperatures, humidity and precipitations since April 2004 till October
52 29
53 2004 were recorded. For an overview of average values counted during the pre-harvest
54 30
55 interval, see Figure 1.
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58 32 [Insert Figure I about here]
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5 2 *Chemicals*
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7 3 (i) Certified pesticide standards (purity in the range 94-99.5%) were obtained from Dr.
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9 4 Ehrenstorfer GmbH (Germany). Pesticides stock solutions were prepared by dissolving
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11 5 neat standards in toluene for analyses carried out by gas chromatography - mass
12
13 6 spectrometry (GC-MS) and acetonitrile for examinations employing liquid chromatography
14
15 7 - tandem mass spectrometry (LC-MS/MS). Working standards S_{1G} and S_{1L} consisting of
16
17 8 mixtures of target pesticides were prepared from stock solutions of individual pesticides
18
19 9 (concentrations of individual pesticides were 1 µg ml⁻¹). Other working standards S_{2G}, S_{3G},
20
21 10 S_{4G}, S_{5G}, S_{6G} and S_{2L}, S_{3L}, S_{4L}, S_{5L}, S_{6L} were obtained by dilution 2x, 10x, 20x, 100x, 200x
22
23 11 of S_{1G} and S_{1L} respectively. For spiking, solutions in ethylacetate for GC-MS and in
24
25 12 acetonitrile for LC-MS/MS with concentration corresponding to S_{3G}/S_{3L} were prepared.
26
27 13 (ii) Organic solvents for pesticide residue analysis were purchased from Scharlau, Spain
28
29 14 (ethyl acetate), Merck, Germany (cyclohexane, toluene and methanol) and Sigma-Aldrich
30
31 15 (acetonitrile).
32
33 16 (iii) Anhydrous sodium sulphate obtained from Penta, Czech Republic was dried at 600°C
34
35 17 for 7 h and then stored in a tightly closed glass container prior to use.

35 18 *Apparatus*

36
37 19 (i) Warring Blender (Warring, USA) was used to homogenize fresh apples.
38
39 20 (ii) Ultra-Turrax homogenizer (IKA, Werk, Germany) was used for extraction of apple
40
41 21 homogenate.
42
43 22 (iii) Automated high performance gel permeation chromatography system (HP GPC) Aspec
44
45 23 XL (Gilson, France) equipped with PL gel column (600 x 7.5 mm, particles size 10 µm,
46
47 24 50Å ; Polymer Laboratories Ltd., UK) was used for purification of crude apple extracts.
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49 25 Polytetrafluoroethylene (PTFE) filters (5 µm; National Scientific, USA) were used for
50
51 26 filtration of crude extracts prior to the clean-up.
52
53 27 (iv) Vacuum rotary evaporator Büchi Rotavor (Büchi, Switzerland) was used for removing
54
55 28 of organic solvents from crude extracts and “pesticide fraction” after HP GPC clean-up.
56
57 29 (v) High Performance Liquid Chromatograph (HPLC) 2695 Alliance module (Waters, UK)
58
59 30 coupled to tandem mass spectrometric detector Quattro Premier XE (Waters, UK) was used
60
31 for determination of more polar pesticides.
32

(vi) Gas chromatograph (GC) 6890N (Agilent, USA) equipped with a mass-selective detector 5975 Inert XL with quadrupole analyzer (Agilent, USA) and autosampler (7683 Series) was used for determination of GC amenable pesticides.

Analytical methods

The scope of two multi-residue methods described below (LC-MS/MS and GC-MS) covered all the pesticides involved in this study with the exception of thiram compound representing the group of ethylene bisdithiocarbamates (EBDCs). These contact fungicides are according to legislation requirements determined as a carbon disulphide (CS₂). Accredited method (ISO 17025) consisting of the following steps was used for examination of apples: (i) solid phase micro extraction (SPME) for absorption of CS₂ (degradation product of EBDCs) from headspace of sample digested by hydrochloric acid in the presence of stannous chloride and (ii) GC-MS identification/quantification of analyte thermally desorbed in GC injector port. Since in none of samples residues of thiram were detected (LOD of method was 0.5 µg kg⁻¹), no more detailed description is provided here.

LC-MS/MS method

Sample preparation

3 kg of unwashed fresh apples (representing field sample) delivered to laboratory were homogenized using a Warring Blender homogenizer. 12.5 g of homogenate were mixed with 50 ml of acetonitrile and extracted for 2 min with Ultra-Turrax homogenizer. The suspension was filtered under vacuum; the filtrate cake was washed with 3 x 10 ml of acetonitrile and then evaporated on a vacuum rotary evaporator. 15 ml of methanol were added into the evaporation flask and the volume was quantitatively transferred into 50 ml volumetric flask and made-up with methanol. Samples were prior to injection filtered through PTFE filters. The matrix content in crude extract was 0.25 g ml⁻¹.

LC-MS/MS identification/quantification

LC separations were carried out on a reversed phase column Discovery C₁₈ (150 x 3 mm, 5 µm). The sample temperatures as well as column temperature were maintained at 25°C. The mobile phase contained water (A) and methanol (B) and the flow rate was 0.3 ml min⁻¹. Gradient was employed, starting composition of 50% B, rising linearly 100% B over 6

1 min then held for 11 min at 100% B followed by 10 min re-equilibration to initial mobile phase composition. Injection volume 20 μl was used in all separations.

Identification/quantification of target analytes was performed using a Quattro Premier tandem quadrupole mass spectrometer. The detector was operated in a positive electrospray (ES+) ionisation mode. Multiple reaction monitoring (MRM) conditions (collision energy and cone voltage) were optimised for each pesticide during infusion (5 $\mu\text{l min}^{-1}$) of individual pesticide solution (1-5 $\mu\text{g ml}^{-1}$) into the mobile phase flow (A:B 50:50, (v/v), 0.3 ml ml^{-1}). All experiments were realised employing the following parameters: capillary voltage 3.5 kV, extractor voltage 4 V, source temperature 120°C, desolvation temperature 250°C, cone gas flow 100 L h^{-1} and desolvation gas flow 700 L h^{-1} (both gasses were nitrogen). Argon was used as a collision gas (3.3 $\times 10^{-3}$ mbar). Tuned and optimised MS/MS transitions as well as specific cone voltages and collision energies are summarized in Table III. Analytes were divided into time segments based on their elution characteristics. The MS/MS transitions were monitored in the multiple reaction-monitoring (MRM) mode at the same dwell time 0.005 s, inter-channel delays, and inter-scan delays of 10 ms for all transitions.

Generated experimental data were processed using MassLynx software version 4.0 Service Pack 4, Software Change Note #462.

[Insert Table III about here]

GC-MS method

Sample preparation

3 kg of unwashed fresh apples (representing field sample) delivered to laboratory were homogenized using a Warring Blender homogenizer. A 25 g of homogenized apples were weighed in a glass beaker, after addition of 100 ml ethyl acetate and 75 g of anhydrous sodium sulphate the sample was extracted for 2 minutes with the Ultra-Turrax homogenizer at 10 000 rpm. The suspension was filtered under vacuum through the layer of anhydrous sodium sulphate, the beaker and filtrate cake were rinsed with 3 \times 25 ml of ethyl acetate. Combined filtrates were evaporated using vacuum rotary evaporator (temperature max.

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3 1 40°C, pressure 220 mbar) to volume circa 25 ml. Concentrated crude extract was
4
5 2 transferred into volumetric flask and the final volume was made up with cyclohexane to 50
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7 3 ml (matrix concentration 0.5 g ml⁻¹).

8 9 4 *HP- GPC purification*

10 5 Samples were filtered through PTFE filters prior to purification. Crude extracts were
11
12 6 purified employing automated high performance gel permeation chromatography system.
13
14 7 The following conditions were used for sample clean-up: mobile phase ethyl acetate-
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16 8 cyclohexane (1:1), flow rate 1 ml min⁻¹, injection volume 2 ml, collected “pesticide”
17
18 9 fraction 14.5-31 ml. Purified pesticide fraction was evaporated using vacuum rotary
19
20 10 evaporator (temperature max. 40°C, pressure 220 mbar) almost to dryness, the residual
21
22 11 solvent was removed with a gentle stream of nitrogen. After addition of 1 ml of toluene,
23
24 12 sample was ready to GC-MS analysis. The content of original matrix was 1 g ml⁻¹.

25 13 *GC-MS identification/quantification*

26 14 All separations of GC amenable pesticides were carried out on capillary column DB-5MS
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28 15 (60 m x 0.25 mm x 0.25 µm). Pulsed splitless injection was used (pressure pulse 60 psi,
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30 16 pulse period 2 min, inlet temperature 250°C, injection volume 1 µl). Oven temperature
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32 17 program started at initial temperature 90°C (hold 2 min), 5°C min⁻¹ to 180°C then 2°C min⁻¹
33
34 18 to 280°C (hold 5 min). Helium was used as a carrier gas at a constant rate 19 cm s⁻¹. MSD
35
36 19 detector was working in electron ionization mode (EI), ion source temperature 230°C, MS
37
38 20 Quad temperature 150°C. Identification/quantification was performed in the Selected Ion
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40 21 Monitoring mode (SIM), see Table IV. All GC-MS chromatographic data were processed
41
42 22 using ChemStation® Software (D.02.00 SP1, Agilent, USA)

43 23 *Matrix - matched standards*

44 24 Matrix-matched standards used for calibration were prepared from untreated apples. Blank
45
46 25 extracts were prepared according to the above described LC-MS/MS and GC-MS
47
48 26 procedures. For LC-MS/MS, 100µl of working standard solution S_{1L}-S_{6L} were added to
49
50 27 900µl of blank apple extract prior to analysis. As for GC-MS, residue after evaporation of
51
52 28 solvent from purified blank apple extract was re-dissolved in 1ml of appropriate standard
53
54 29 working solution S_{1G}-S_{6G} for following analysis.

55 30 56 57 31 *Quality Assurance*

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3 1 For recovery tests, apple homogenates were spiked by pesticide mixture (spikes
4 concentration corresponded to 0.1 mg kg⁻¹) and then processed as described for LC-MS/MS
5 and GC-MS analyses. Quality control procedures for pesticide residues analysis (Document
6 N° SANCO/10232/2006) were applied in setting LOD and LOQ values. The latter one was
7 the lowest calibration level (LCL) and corresponded for particular analyte to 3 x LOD.
8 Under these conditions, LOQs were the minimum concentrations of analytes that was
9 possible to quantify with acceptable accuracy and precision.
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18 9 The methods described above are accredited according to ISO/IEC 17025. As a part of
19 external Quality Assurance, laboratory has been successfully participating in proficiency
20 tests - Food Analysis Performance Assessment Scheme (FAPAS[®]) and European
21 proficiency testing within the pesticide monitoring programme. Performance characteristics
22 of applied analytical methods are summarized in Table IV.
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28 15 [Insert Table IV about here]
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32 17 **Results and discussion**

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34 19 As mentioned in the introduction, where fruit is intended for baby food production, careful
35 attention has to be paid to selection of pesticide preparations matching specific
36 requirements for obtaining low or residue-free crop. Since baby food producers tolerate
37 only residues not exceeding 0.01 mg kg⁻¹ in the raw material, fundamental changes of
38 treatment strategy might have to be adopted in this aspect to produce acceptable raw
39 material. To identify “high residue” pesticides that should be in particular case eliminated
40 from the further use, monitoring of apples grown by several farmers under common
41 conventional practices was carried out in the first phase of our experiments.
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51 28 *Monitoring study of fresh apples*

52 29 As shown in our previous study conducted in years 2001-2003 (Stepán et al. 2005), almost
53 no violation of MRLs occurred. Nevertheless, 60 % from 220 batches of apples delivered
54 by farmers contained detectable pesticide residues, 48% of them exceeded baby food MRL
55 0.010 mg kg⁻¹ and therefore had to be used for other purposes than baby food production.
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5 2 The most troublesome pesticides in this respect were phosalone, chlorpyrifos-methyl,
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7 3 captan, tolylfluanid and fenitrothion. Following the analysis of a data set generated within
8
9 4 this 3-year pilot study, farmers were advised to search for replacing preparations containing
10
11 5 these with other ones. As a consequence of modified treatment practices, significant
12
13 6 decrease of organophosphorus insecticide residues (phosalone, and fenitrothion) were
14
15 7 observed, while no changes in captan and tolylfluanid incidence were found. The search for
16
17 8 “new” preparation resulted in increased occurrence of trifloxystrobin residues. Overall, the
18
19 9 farmers` effort to improve treatment plans was documented by decrease of positive samples
20
21 10 number to 54% (i.e. only 15% exceeded baby food MRL of 0.01 mg kg⁻¹ in 2004). It
22
23 11 should be noted that climatic conditions did not differ significantly in this crop year from
24
25 12 previous ones.

26
27 14 Considering large variation (both qualitative and quantitative) in contamination patterns
28
29 15 among apples supplied by individual farmers, the need to harmonize treatment plans with
30
31 16 the aim to further improve crops quality become evident.

32 17 33 18 *Degradation of pesticide residues in pre-harvest interval*

35 19 To get more knowledge on the fate of individual pesticides, extensive experiments were
36
37 20 carried out in 2004, see Table II. All 19 pesticides studied covered the range of
38
39 21 preparations most commonly applied within apple trees treatment during the pre-harvest
40
41 22 interval. However, there are also other registered pesticide preparations which are
42
43 23 conceivably used for apple trees protection.

44 24
45
46 25 It should be noted that only very few studies are available in the scientific literature, none
47
48 26 of them covering the spectrum of pesticides involved in our study. Actually, the only
49
50 27 available data relevant to our experiment are those summarized in reports
51
52 28 (<http://www.who.int/ipcs/publications/jmpr/en/>) of the Joint Meeting of the FAO Panel of
53
54 29 Experts on Pesticide Residues in Food and Environment and the WHO Core Assessment
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56 30 Group of Pesticide Residues, JMPR (similar data have to be submitted by applicants for
57
58 31 active ingredients review process currently dealt by European Food Safety Authority,
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60 32 EFSA).

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5 2 Figures 2-10 document the dynamics of pesticides involved in our study. In the sampling
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7 3 carried out 14 days after the last pesticide application, residues of fungicides (captan,
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9 4 tetraconazole, trifloxystrobin, penconazole, tebuconazole and tolylfluanid) and insecticides
10
11 5 (pyridaben, chlorpyrifos-methyl, thiacloprid and teflubenzuron) were detected. In following
12
13 6 pre-harvest interval successive decline of residues was observed, although the rate of
14
15 7 dissipation varied largely. Since it is impossible to generalize the fate of the whole set of
16
17 8 pesticides investigated, behavior of individual compounds is discussed in separated
18
19 9 paragraphs below (Figures 2-9). Figure 10 summarizes concentration levels of pesticides
20
21 10 found in harvested apples within all 6 field experiments (FE 1 , FE 2, FE3, FE 4, FE 5 and
22
23 11 FE 6).

24 25 13 *Captan*

26
27 14 As shown in Figure 2, the residues of captan, the main fungicide widely used for control of
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29 15 apple scab (*Venturia inaequalis*), were either not detected (FE 5 and FE 6) or already fairly
30
31 16 well below the MRL (3 mg kg^{-1}) at the first sampling, even in an experiment with two
32
33 17 treatments (FE 2, FE 3 and FE 4). Successive decrease of captan occurred and at the time
34
35 18 of harvest its residues at 0.01 mg kg^{-1} level were detected in only two samples (FE 2 and
36
37 19 FE 4).

38
39 21 It is worth noting that the relative decrease rate was higher in FE 2, FE 3 and FE 4
40
41 22 compared to FE 5 and FE 6 in which longer time elapsed since the last treatment with
42
43 23 Merpan 80 WG preparation. No significant differences in residue levels were found in the
44
45 24 third sampling regardless the application rate and date of application, residues were
46
47 25 between $0.01 - 0.02 \text{ mg kg}^{-1}$.

48
49 27 Considering the data obtained from the Canadian study for JMPR (Captan residues in food:
50
51 28 1984 evaluation), we obtained significantly lower content of captan residues. Whereas
52
53 29 content of captan in Canadian apples was in the range $0.6 - 2.9 \text{ mg kg}^{-1}$ some 30 days after
54
55 30 its application, in apples carried out within our experiments its concentration did not
56
57 31 exceed 0.1 mg kg^{-1} in 33 days after captan treatment.

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3 1 [Insert Figure 2 about here]
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5 2 *Pyridaben*
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7 3 Although applied at the same rate and the same date, pyridaben residues in apples from
8
9 4 individual experiments differed largely at the time of the first sampling. While relatively
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11 5 rapid decrease of residues occurred in FE 1 with no detectable residues at the harvest time,
12
13 6 in FE 2 despite the lower concentration in the first sampling, traces of pyridaben were
14
15 7 detectable even in harvested apples (see Figure 3).
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17 9 [Insert Figure 3 about here]
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21 11 *Chlorpyrifos-methyl*
22

23 12 Residues of insecticide chlorpyrifos-methyl used for crop protection against codling moths
24
25 13 (*Cydia pomonella*) and sawfly insects (*Hymenoptera*, *Haplocampa testudinea*) dropped in
26
27 14 both FE 3 and FE 5 below the MRL (0.50 mg kg⁻¹) in all experiments even before the end
28
29 15 of the safety period. As can be seen from Figure 4, further degradation of residues occurred
30
31 16 and residues were close to or below the baby food MRL. Harvested apples collected 78
32
33 17 days after the last Reldan 40 EC application in FE 3 and FE 5 did not contain any
34
35 18 chlorpyrifos-methyl residues. In apples from experiment FE 1, residues were not detected
36
37 19 even during the pre-harvest interval (61 days).
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39 20

39 21 [Insert Figure 4 about here]
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42 23 *Teflubenzuron*
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44 24 Teflubenzuron is an insecticide recommended against tortricid (*Tortricidae*) that can cause
45
46 25 mechanical damage to ripe fruits, which can consequently be a “gate” for secondary
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48 26 putrefactive diseases (*Alternaria*, *Nectria*, *Phytophthora*) during apple storage. As shown in
49
50 27 Figure 5, repeated application of Nomolt 15 SC resulted in a fairly high content of
51
52 28 teflubenzuron in FE 2 contrary to single application in case of FE 3 and FE 4 in the first
53
54 29 and second samplings. In none of the experiments was the MRL (0.5 mg kg⁻¹) exceeded
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56 30 even in the first sampling. Among the first and second samplings only a slight decrease of
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58 31 teflubenzuron content was observed, probably due to lack of precipitation that might
59
60 32 remove some surface residues (see Figure 1). In the following pre-harvest time the content

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3 1 of teflubenzuron declined during apple maturation. No residues were detected in FE 3
4 harvested apples. However, in FE 2 and FE 4 ripe apples, teflubenzuron at concentration
5 levels exceeding the baby food MRL was found. This can be attributed to the relatively
6 high stability of this compound (The Pesticide Manual 2002).
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12 6 [Insert Figure 5 about here]
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15 8 *Thiacloprid*

16 9 Thiacloprid belongs to the very limited group of in-season insecticides allowed to be
17 applied at the early pink stage of trees development to control beetles (*e.g. Anthonomus*
18 *pomorum*), codling moths (*Cydia pomonella*), rosy apple aphids, green aphids and to help
19 mite suppression (IPM Commercial Apples, Insect, Disease and Weed Control
20 Recommendations for 2006). Thiacloprid was applied in all FE 1, FE 2, FE 3 and FE 4
21 once, three times in FE 5 and twice in FE 6. Since the treatment was carried out in early
22 May, in line with expectation low concentrations correlating with application rate were
23 obtained in FE 1, FE 2, FE 3 and FE 4. Interesting is that these were detected even 111
24 days after Calypso 480 SC application (i.e. 97 days after safe period elapsed). Nevertheless,
25 in time of harvest, no residues were detected. Significant differences in thiacloprid contents
26 in the first sampling date was found in the case of repeated applications carried out in FE 5
27 and FE 6 (see Figure 6). However, its content rapidly declined during pre-harvest interval
28 and only trace amounts (0.003 mg kg^{-1}) were found in ripe apples.
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43 23 [Insert Figure 6 about here]
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46 25 *Tebuconazole and tolylfluanid*

47 26 Tebuconazole and tolylfluanid were applied together as Hattrick pesticide preparation (see
48 Table I) against apple scab (*Venturia inaequalis*) in FE 5 and FE 6. Relatively high
49 persistency was recognized for tebuconazole. Residues of this fungicide exceeded the baby
50 food limit even in the third sampling (55 days beyond safety period). Nevertheless, these
51 were not detected in the harvested fruits (see Figure 7a). As compared to tolylfluanid, this
52 was found only in FE 6 at very low concentration level already in the first sampling (see
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3 1 Figure 7b) and dissipated during the pre-harvest time; in harvested apples no tolylfluanid
4 2 residues were detected.

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9 4 [Insert Figures 7a and 7b about here]

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12 6 *Tetraconazole*

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14 7 As shown in Figure 8, residues of tetraconazole used as a protection against apple scab and
15 8 powdery mildew were well below the MRL (0.5 mg kg⁻¹) in the first sampling in
16 9 experiments with three (FE 2 and FE 3) and four (FE 4) treatments; in FE 6 tetraconazole
17 10 was not detected. A decline of tetraconazole residues occurred in following pre-harvest
18 11 time; in harvested apples only low concentrations levels (0.005 mg kg⁻¹) were observed at
19 12 field experiments repeatedly treated (FE 2, FE 3 and FE 4).

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26 14 [Insert Figure 8 about here]

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30 16 *Trifloxystrobin*

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32 17 As shown in Figure 9, the residues of trifloxystrobin were detected in all samples FE 1, FE
33 18 2, FE 3, FE 4, FE 5 and FE 6 in the first sampling. Since applied at the same date and same
34 19 application rate in FE 2, FE 3, FE 4 and FE 5, similar concentrations were found contrary
35 20 to repeated applications in FE 1 and FE 6 resulting in higher contents of trifloxystrobin in
36 21 the first sampling. While relatively continuous decline of residues was identified in FE 1
37 22 and FE 6 with no (FE 6) or trace (FE 1) residues in harvested apples, in samples with lower
38 23 treatment (FE 2, FE 3, FE 4 and FE 5), the reduction in residue levels was not so distinct,
39 24 although the baby food limit was not exceeded.

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47 26 [Insert Figure 9 about here]

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51 28 *Penconazole*

52 29 The fungicide penconazole applied only in FE 5, was detected in the first sampling (33
53 30 days after the last Topas 100 EC application) at trace concentration levels (0.005 mg kg⁻¹).
54 31 In harvested apples no penconazole residues were found.

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59 33 *Overview of pesticide degradation in field experiments FE 1 – FE 6*
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3 1 Field experiments were carried out aimed at identifying pesticide preparations that ensure
4 effective crop protection and yet at the same time leave very low residues. Based on 6 field
5 2 experiments described in this study, a set of data enabling evaluation of both the
6 3 degradation rate and levels of terminal residues in matured apples was obtained. The main
7 4 observations resulting from this study are summarized below.
8 5

9 6 • In the *first sampling*, carried out before or immediately after the pesticides safety
10 7 period has elapsed, only 10 pesticides (46% of 22 active ingredients applied) were
11 8 detected; 8 of them exceeded or were at 0.01 mg kg^{-1} . Those were fungicides captan in FE
12 9 1, FE 2, FE 3 and FE 4, tetraconazole in FE 2, FE 3, FE 4 and FE 5, trifloxystrobin in FE 1
13 10 and FE 6, tebuconazole in FE 5 and FE 6; insecticides pyridaben in FE 1 and FE 2,
14 11 teflubenzuron in FE 2, FE 3 and FE 4, chlorpyrifos-methyl in FE 1, FE 3 and FE 5 and
15 12 thiachloprid in FE 5 and FE 6. On the other hand, the levels of penconazole in FE 5 and
16 13 tolylfluanid in FE 6 were found below baby food MRL; similarly low were thiachloprid,
17 14 tetraconazole and trifloxystrobin in some experiments. Residues of triflumuron, triazamate,
18 15 chlorpyrifos, etofenprox, fenoxycarb, kresoxim-methyl, cyprodinyl, difenoconazole and
19 16 thiram were not detected at all.
20 17

21 18 • In the *second sampling*, 9 pesticides were found (penconazole in FE 5 was not
22 19 detected anymore); 8 residues of active ingredients still exceeded 0.01 mg kg^{-1} in some
23 20 experiments (captan, pyridaben, teflubenzuron, thiachloprid, tebuconazole, trifloxystrobin,
24 21 tetraconazole and chlorpyrifos-methyl). Since the previous sampling, contents of
25 22 chlorpyrifos-methyl in FE 1 and tetraconazole in FE 3 and FE 5 declined fairly below baby
26 23 food MRL.
27 24

28 25 • Also in the *third sampling*, 9 pesticides were detected, nevertheless only 5 of them
29 26 exceeded 0.01 mg kg^{-1} (captan, pyridaben, teflubenzuron, thiachloprid and tebuconazole).
30 27 Residues of chlorpyrifos-methyl in FE 3 and FE 5, tebuconazole in FE 5, trifloxystrobin in
31 28 FE 1, FE 5 and FE 6 and tetraconazole in FE 2 and FE 4 dropped below this value since
32 29 second sampling.
33 30

34 31 • When assessing the residues situation at the harvest time (the *fourth sampling*), each
35 32 of the treatment regimes resulted in detectable residues (see Figure 10). In total, 6
36 33 pesticides i.e. 27% of active ingredients applied for the treatment of apple trees were
37 34 detected.
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3 1 The lowest contamination was observed in FE 1, FE 3 and FE 6, where residues of only
4 one pesticide, well below 0.01 mg kg^{-1} was found (trifloxystrobin in FE 1; tetraconazole in
5 FE 3 and thiacloprid in FE 6). Field treatment FE 5 resulted in the occurrence of two
6 detectable pesticides (trifloxystrobin and thiacloprid) in matured apples. Similarly to FE 1
7 and FE 6, the concentration levels of residues found in these samples were well below the
8 baby food MRL. On the other hand, baby food producers' requirements were not fulfilled
9 in FE 2 and FE 4, where "the worst" contamination situation was found. In both these field
10 experiments tefubenzuron exceeded 0.01 mg kg^{-1} and residues of captan were also present
11 close to this critical concentration level. Besides, additional pesticide residues were found;
12 these were pyridaben, tetraconazole, trifloxystrobin in FE 2 and tetraconazole and
13 trifloxystrobin in FE 4 - all of them below 0.01 mg kg^{-1}

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25 13 Regarding the effectiveness of crop protection against pests, all six treatment regimes were
26 also evaluated for the occurrence of apple scab (*Venturia inaequalis*). No significant
27 differences among the quality of apples obtained from individual field experiments were
28 recognized. The extent of apple scab was only about 5% higher in our experiments
29 compared to "conventionally" treated apples (regimes conducted in accordance with GAP
30 leaving residues complying with MRL which may be, however, in some cases higher than
31 0.01 mg kg^{-1}).

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39 21 [Insert Figure 10 about here]

40 41 42 23 **Conclusion**

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46 25 Considering the requirements of baby food producers for safe raw material with pesticide
47 residues not exceeding 0.01 mg kg^{-1} , treatment regimes FE 1, FE 3, FE 5 and FE 6 might
48 be considered as an appropriate apple protection strategy, since only traces of active
49 ingredients (tetraconazole, thiacloprid and trifloxystrobin) were contained in crops at the
50 time of harvest. Residues of captan and teflubenzuron, active ingredients of pesticide
51 preparations used for treatment in experiments FE 2 and FE 4, exceeded 0.01 mg kg^{-1} and
52 their use in farms supplying apples for baby food production should be carefully
53 considered. On the other hand, the use of cyprodinyl, chlorpyrifos, chlorpyrifos-methyl,
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3 1 difenoconazole, etofenprox, fenoxycarb, kresoxim-methyl, penconazole, pyridaben,
4 2 tebuconazole, thiram, triazamate, triflumuron, and tolylfluanid in apple orchards seems – in
5 3 terms of contamination - free of problems, no residues were detected in harvested fruit. It
6 4 should be noted that employing treatment regimes aimed at minimization of residues in
7 5 harvested crops did not result in its lower quality in terms of damage caused by pests.
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14 7 In any case, follow-up validation of these recommendations has to be carried out under
15 8 conditions specific for particular locality. It is believed that at the end of long-term
16 9 experiments specific guidelines for farmers supplying apples to baby food producers will
17 10 be developed.
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Table I: Overview of pesticide preparations used in field experiments and physico-chemical properties of their active ingredients

Mode of action	Commercial product	Active ingredient (content)	Content in preparation	MRL (mg kg ⁻¹)	Safety period (days)	Physico-chemical properties of active ingredient		
						Molecular weight	log K _{ow}	Water solubility (mg l ⁻¹)
insecticides	Alsystin	triflumuron	480 g/l	1	28	358.7	4.91 (20 °C)	0.025 (20°C)
	Aztec 140 EW	triazamate	140 g/l	0.1	7	314.4	2.15 (pH 7, 25 °C)	399 (pH 7, 25°C)
	Calypso 480 SC	thiacloprid	480 g/l	0.3	14	252.7	-	185 (20 °C)
	Nomolt 15 SC	teflubenzuron	150 g/l	0.5	28	381.1	4.30 (20°C)	0.019 (23°C)
	Oleoekol	chlorpyrifos	30 g/l	0.5	-	350.6	4.7	1.4 (25°C)
		coleseed oil	75%	-	-	-	-	-
	Trebon 10 F	etofenprox	100 g/l	1	28	376.5	7.05 (25°C)	<1 (25°C)
	Insegar 25	fenoxycarb	25%	0.05	60	301.3	4.07 (25°C)	7.9 (pH 7.55-7.84, 25°C)
	Reldan 40 EC	chlorpyrifos-methyl	400 g/l	0.5	28	322.5	4.24	2.6 (20°C)
Sanmite 20 WP	pyridaben	20%	0.1	42	364.9	6.37 (25°C)	0.012 (24°C)	
fungicides	Discus	kresoxim-methyl	50%	0.2	35	313.4	3.40 (pH 7, 25°C)	2 (20°C)
	Domark 10 EC	tetraconazole	100 g/l	0.5	14	372.1	3.56 (20°C)	156 (pH 7, 20°C)
	Euparen Multi	tolyfluanid	50%	1	7	347.3	3.90 (20°C)	0.9 (20°C)
	Foligreen	agricultural micronutrient (N, P, K, B, Fe, Mn, Zn, Mg, Co, Cu, Mo)						
	Hatrick	tebuconazole	10%	0.5	28	307.8	3.70 (20°C)	36 (pH 5-9, 20°C)
		tolyfluanid	40%	1	28			
	Champion 50W	Cu(OH) ₂	77%	10	-	97.6	-	2.9 mg/l (pH 7, 25°C)
	Chorus 75 WG	cyprodinil	750g/kg	1	28	225.3	4.0 (pH 9.0, 25°C)	20 (pH 5.0, 25°C)
	Merpan 80 WG	captan	80%	3	35	300.6	2.80 (25°C)	3.3 (25°C)
	Score 250 EC	difenoconazole	250 g/l	0.02	49	406.3	4.20 (25°C)	15 (25°C)
	Solubor	Na ₂ B ₈ O ₁₃ ·4H ₂ O	> 98 %	-	-	412.52		9.7% (20°C)
Thiram Granuflo (F)	thiram	80%		14	240.4	1.73	18 (room temperature)	
Topas 100 EC (F)	penconazole	100 g/l	0.2	35	284.2	3.72 (25°C)	73 (20°C)	
Zato 50 WG	trifloxystrobin	500 g/kg	0.5	14	408.4	4.50 (25°C)	610 (25 °C)	

Table II: Field experiments: time-schedule of pesticide preparations use and treatment rates

Application date 2004	Codes of experiments (Field Experiment FE 1 - 6)					
	FE 1	FE 2	FE 3	FE 4	FE 5	FE 6
April 7	Champion 50 WP (4.0 kg ha ⁻¹)* Chorus 75 WG (0.2 kg ha ⁻¹), Domark 10 EC (0.25 l ha ⁻¹), Oleoekol (10.0 l ha ⁻¹) Zato 50 WG (0.15 kg ha ⁻¹) Thiram (3.0 kg ha ⁻¹), Domark 10 EC (0.25 l ha ⁻¹), Solubor (1.5 kg ha ⁻¹) Discus (0.2 kg ha ⁻¹), Calypso 480 SC (0.2 l ha ⁻¹) Zato 50 WG (0.15 l ha ⁻¹), Foligreen (1.0 l ha ⁻¹) Merpan 80 WG (2.0 kg ha ⁻¹), Foligreen (1.0 l ha ⁻¹)					
April 19						
April 26						
May 5						
May 11						
May 20						
May 28						
June 9	Score 250 EC (0.2 l) Insegar 25 (0.6 l kg)	Score 250 EC (0.2 l) Nomolt (1.0 kg)	Merpan 80 WG (2.0 kg) Trebun 10 F (0.5 l)	Domark 10 EC (0.4 l) Alsystin (0.25 kg)	Thiram (3.0 kg) Calypso 480 (0.2 l)	Hatrick (1.125 kg) Reldan 40 (1.25 l)
June 21	Score 250 EC (0.2 l)	Domark 10 EC (0.4 l)	Score 250 (0.2 l)	Domark 10 EC (0.4 l)	Hatrick (1.125 kg)	Zato 50 WG (0.15 kg)
July 1	Zato 50 WG (0.15 kg) Reldan 40 EC (1.25 l)	Merpan 80 WG (2.0 kg) Insegar 25 WG (0.6 kg)	Domark 10 EC (0.4 l) Nomolt 15 SC (1.0 kg)	Merpan 80 (2.0 kg) Nomolt 15 (1.0 kg)	Topas 100 (0.45 l) Calypso (0.2 l)	Hatrick (1.125 kg) Reldan 40 (1.25 l)
July 20	Sanmite 20 WP (0.75 kg) Insegar 25 WP (0.3 kg)	Sanmite 20 WP (0.75 kg) Nomolt 15 SC (1.0 kg)	Reldan 40 EC (1.25 l)	Aztec 140 EW (0.5 l)	Reldan 40 (1.25 l)	Calypso 480 (0.2 l)

* Per hectare dosage of applied pesticide preparation

Table III: Optimised MS/MS transitions parameters

Analyte	Transition (m/z)	Cone (V)	Colision (V)
diflubenzuron	311 > 158	25	10
	311 > 141	25	29
etofenprox	394 > 177	20	14
	394 > 135	20	26
pyrimethanil	200 > 107	54	24
	200 > 82	54	24
teflubenzuron	381 > 158	23	13
	381 > 141	23	13
thiacloprid	253 > 126	35	25
	253 > 186	35	13
triflumuron	359 > 156	29	16
	359 > 139	29	30

Table IV: Performance characteristics and monitored ions (m/z) of the analytical methods employed for apples analysis

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Analyte	Method	Quantitation ion (m/z)	Confirmation ions (m/z)	LOD (mg kg ⁻¹)	Repeatability (RSD, %) at 0.100 mg kg ⁻¹	Recovery (%)
captan	GC-MS	149	79, 264	0.003	9	92
cyprodinil	GC-MS	224	210, 225	0.002	17	87
difenoconazole	GC-MS	323	207, 267, 281	0.002	4	95
etofenprox	LC-MS/MS	394 > 177	394 > 135	0.004	8	94
fenoxy carb	GC-MS	255	116, 186	0.003	10	97
chlorpyrifos	GC-MS	314	199, 258	0.003	8	94
chlorpyrifos-methyl	GC-MS	286	125, 288	0.003	7	93
kresoxim-methyl	GC-MS	206	116, 131	0.001	9	94
penconazole	GC-MS	248	159, 161	0.002	10	110
pyridaben	GC-MS	147	117, 309	0.003	5	72
pyrimethanil	LC-MS/MS	200 > 107	200 > 82	0.004	9	87
tebuconazole	GC-MS	250	125, 163, 252	0.002	8	89
teflubenzuron	LC-MS/MS	381 > 158	381 > 141.05	0.004	7	86
tetraconazole	GC-MS	336	159, 338	0.001	5	90
thiacloprid	LC-MS/MS	253 > 126	253 > 186	0.004	6	94
tolyfluanid	GC-MS	137	181, 238	0.003	5	100
triazamate	GC-MS	314	227, 242, 262	0.002	8	103
trifloxystrobin	GC-MS	131	116, 222	0.001	8	98
triflumuron	LC-MS/MS	359 > 156	359 > 139	0.004	6	89

Figure 1: Weather conditions in the pre-harvest period

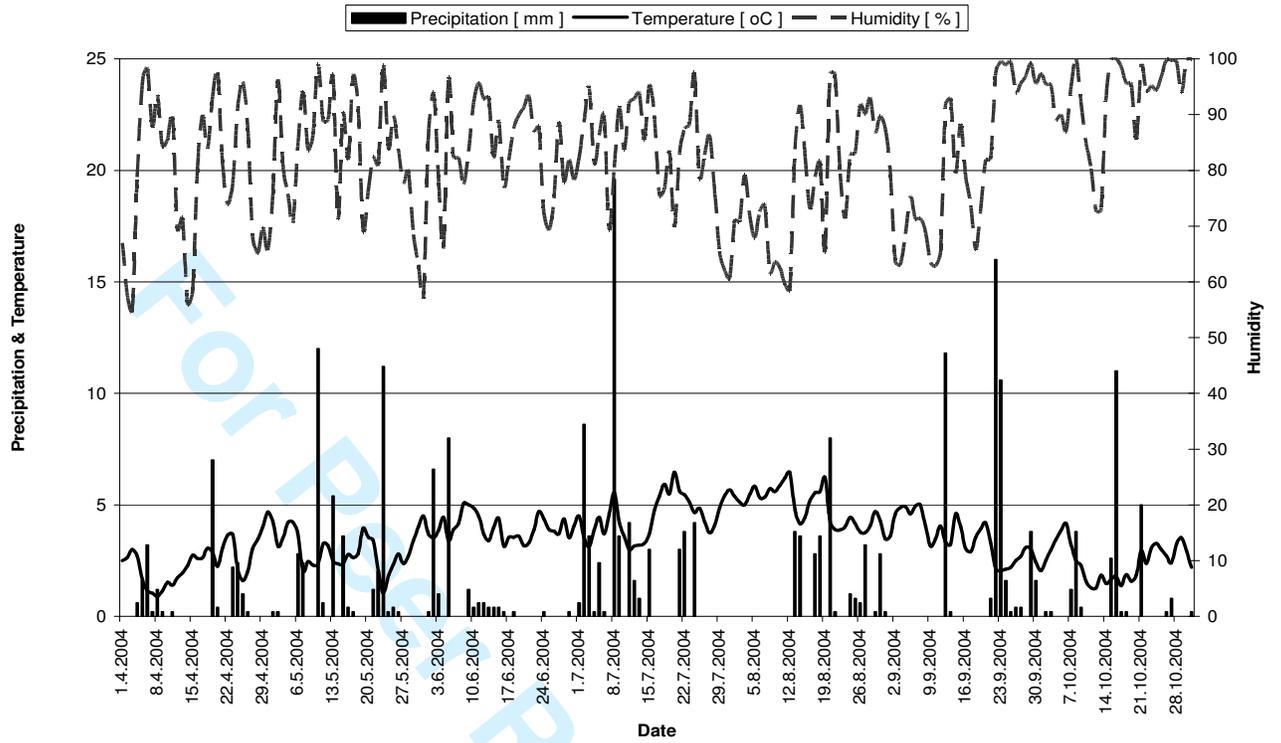
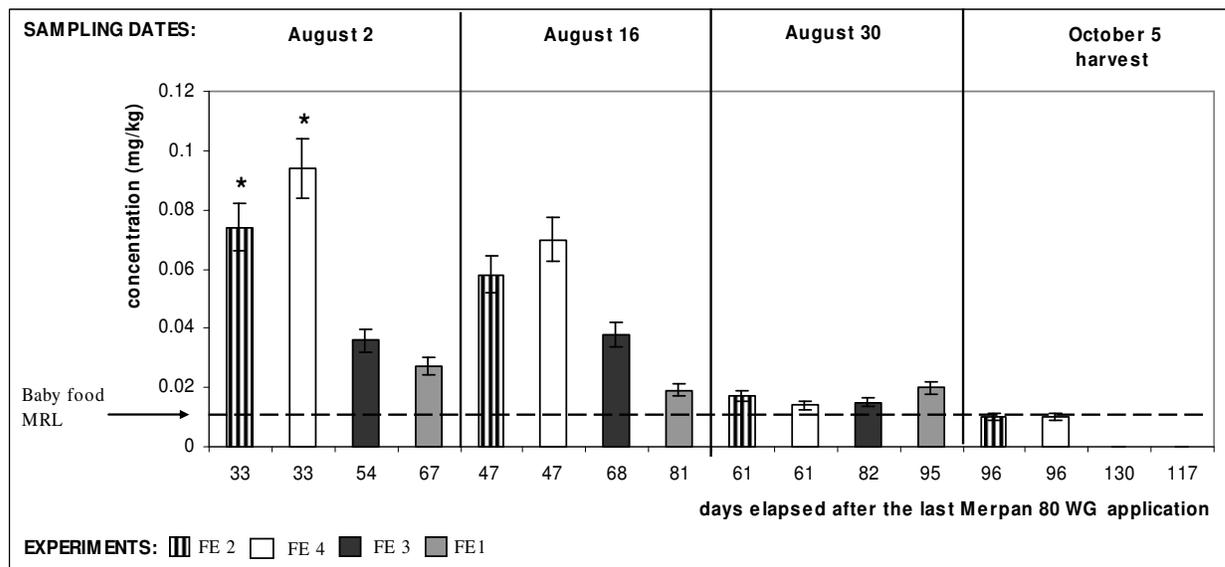
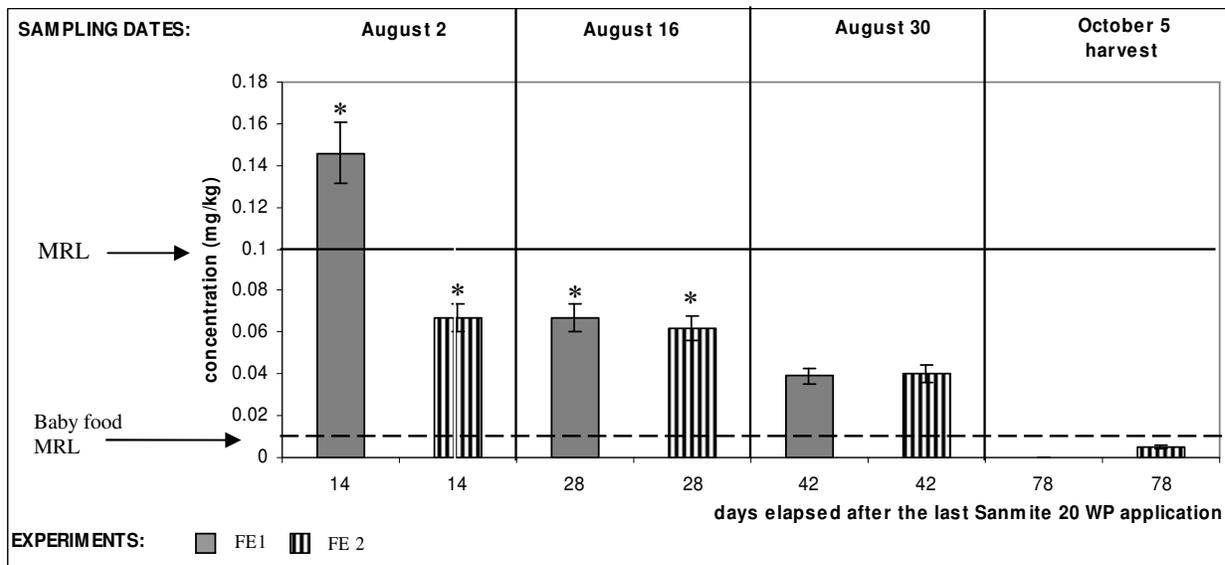


Figure 2: The dynamics of captan decrease between samplings in FE 1, FE 2, FE 3 and FE 4 (error bars express the expanded uncertainty of respective results).



* Safety period (35 days) has not elapsed yet

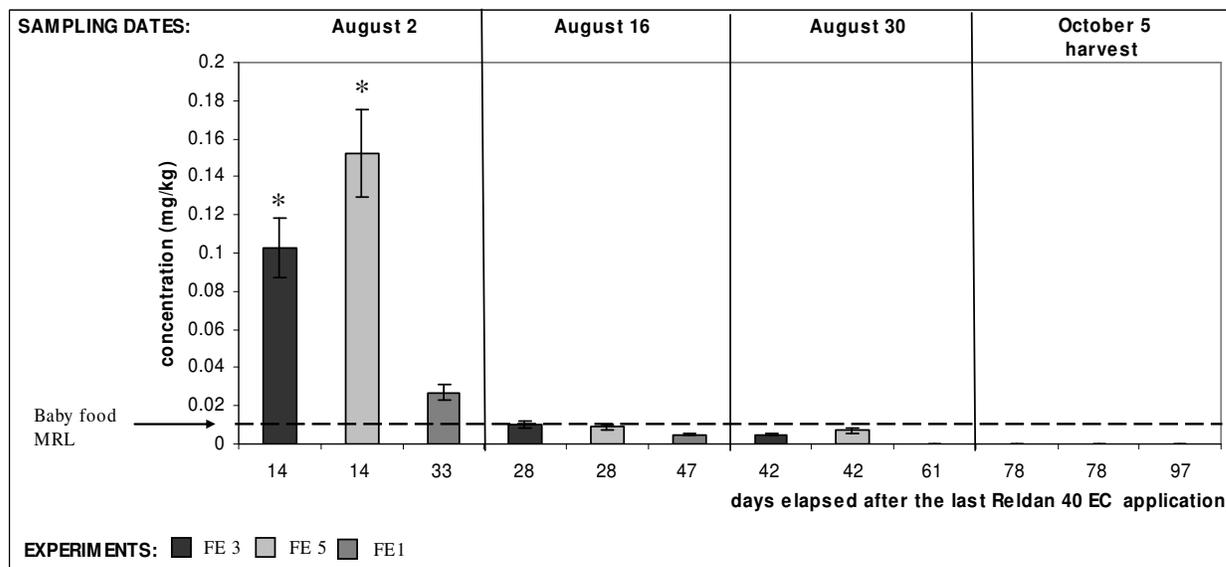
Figure 3: The dynamics of pyridaben decrease between samplings in FE 1 and FE 2 (error bars express the expanded uncertainty of respective results).



* Safety period (42 days) has not elapsed yet

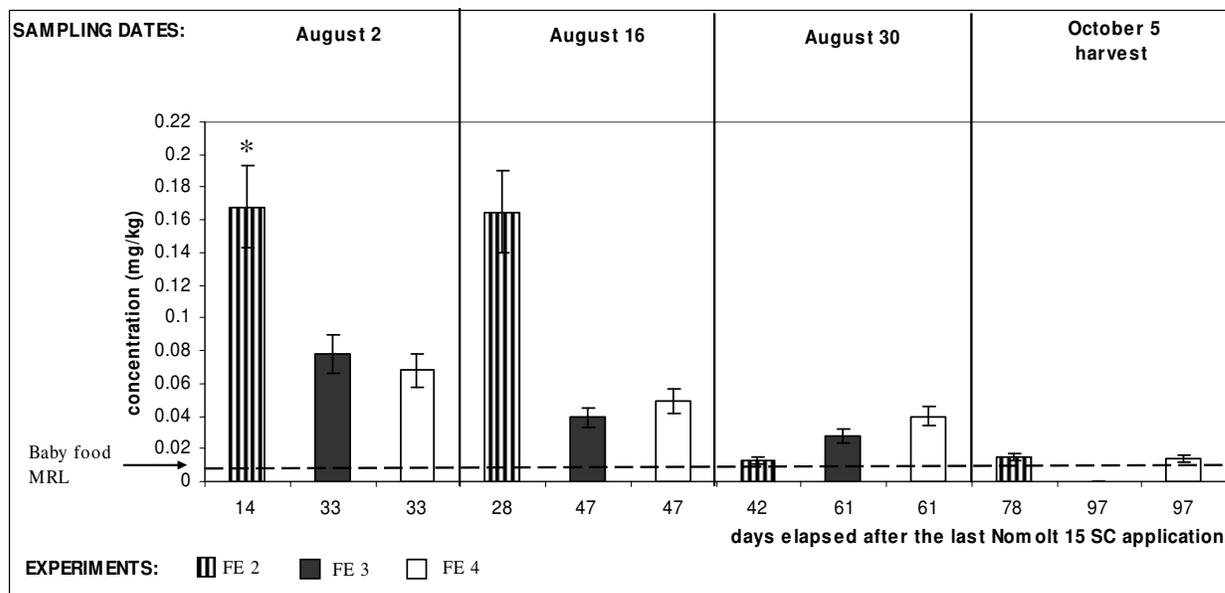
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Figure 4: The dynamics of chlorpyrifos-methyl decrease between samplings in FE 1, FE 3 and FE 5 (error bars express the expanded uncertainty of respective results).



* Safety period (28 days) has not elapsed yet

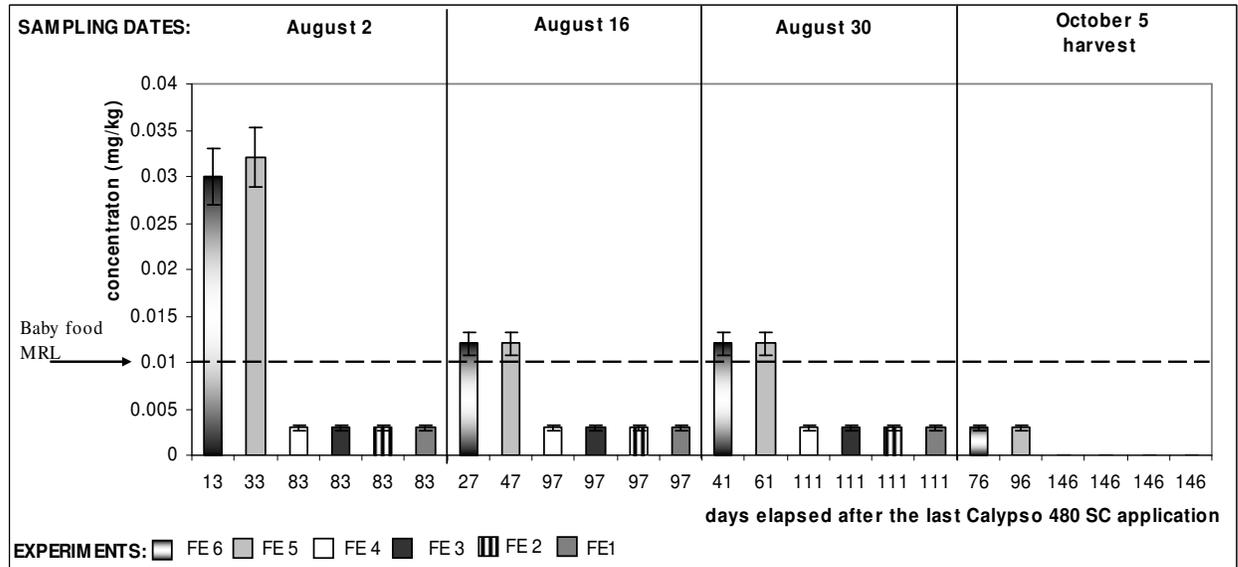
Figure 5: The dynamics of teflubenzuron decrease between samplings in FE 2, FE 3 and FE 4 (error bars express the expanded uncertainty of respective results).



* Safety period (28 days) has not elapsed yet

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Figure 6: The dynamics of thiocloprid decrease between samplings in FE 1, FE 2, FE 3, FE 4, FE 5 and FE 6 (error bars express the expanded uncertainty of respective results).



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Figure 7a: The dynamics of tebuconazole decrease between samplings in FE 5 and FE 6 (error bars express the expanded uncertainty of respective results).

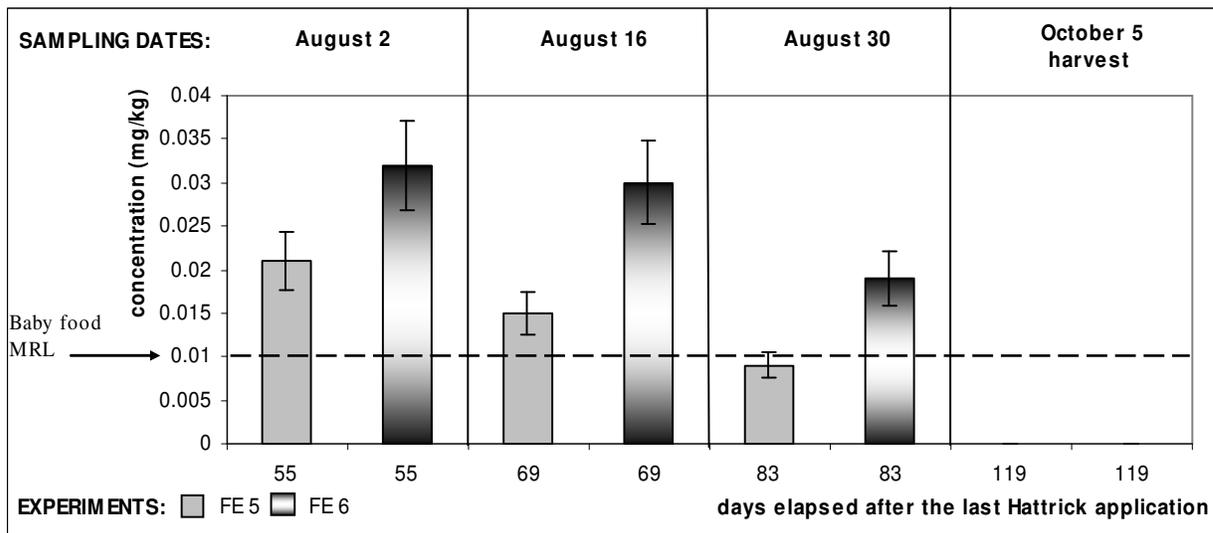


Figure 7b: The dynamics of tolylfluandid decrease between samplings in FE 6 (error bars express the expanded uncertainty of respective results).

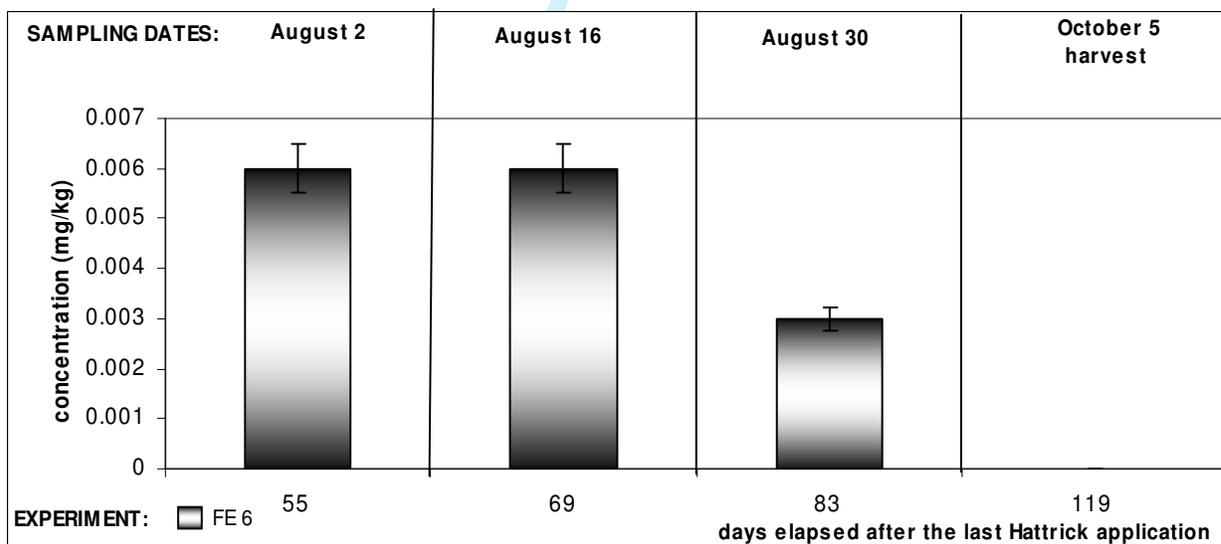
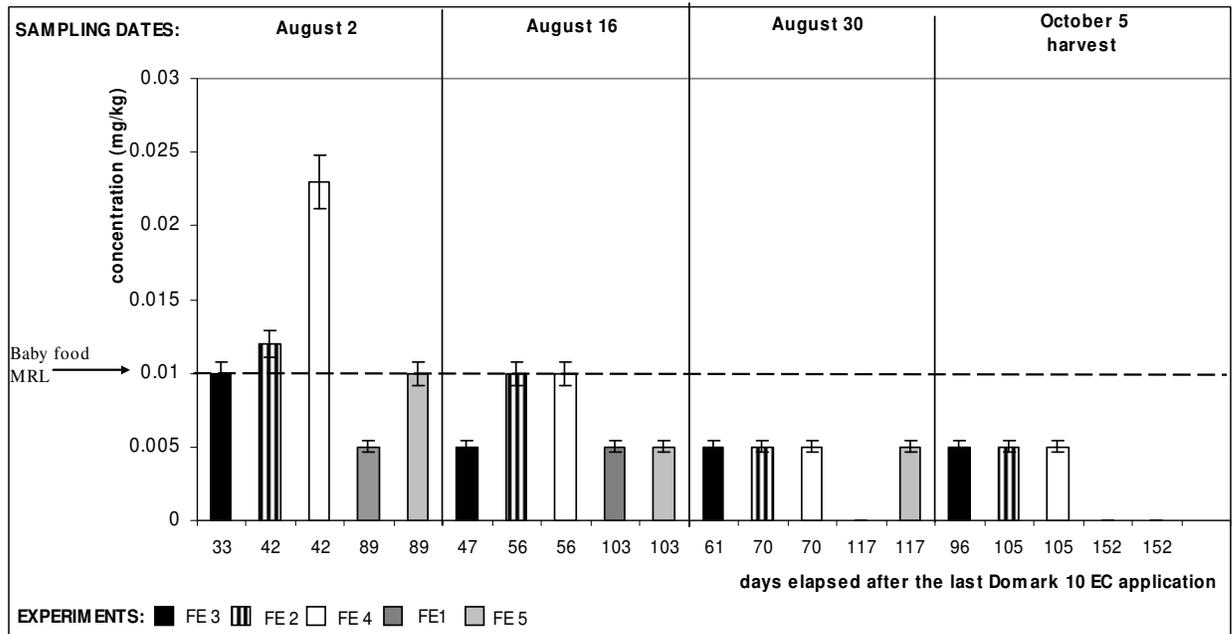
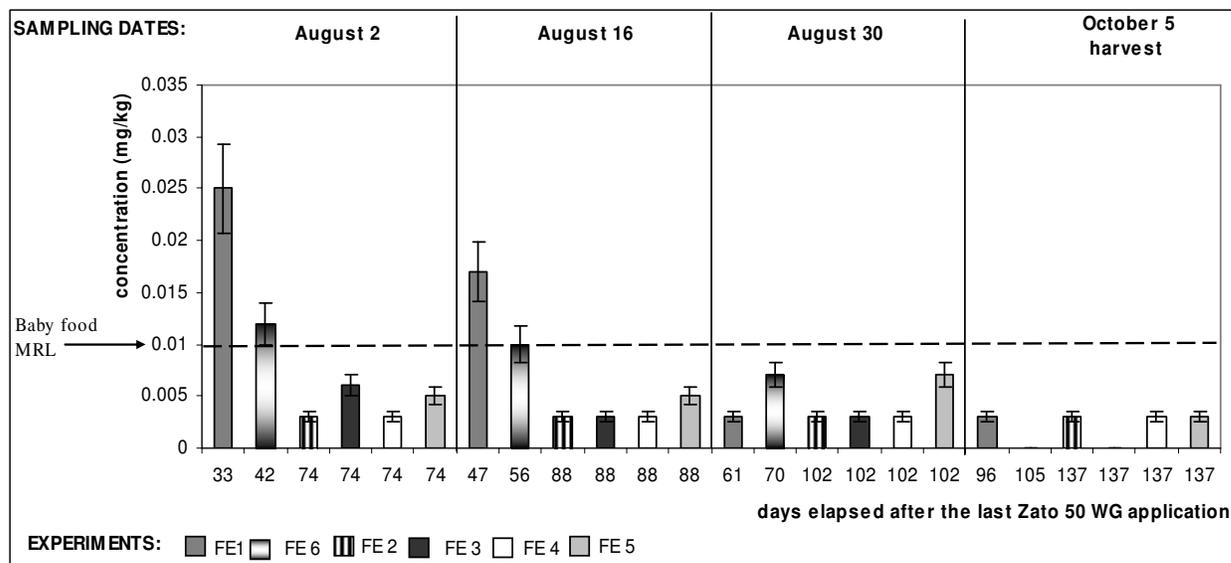


Figure 8: The dynamics of tetraconazole decrease between samplings in FE 1, FE 2, FE 3, FE 4 and FE 5 (error bars express the expanded uncertainty of respective results).



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Figure 9: The dynamics of trifloxystrobin decrease between samplings in FE 1, FE 2, FE 3, FE 4, FE 5 and FE 6 (error bars express the expanded uncertainty of respective results).



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Figure 10: Differences in the contents of pesticide residues in FE 1, FE 2, FE 3, FE 4, FE5 and FE 6 at the day of harvest (error bars express the expanded uncertainty of respective results).

