THE Cocktail EFFECT

How pesticide mixtures may be harming human health and the environment

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Soil Association

PESTICIDE ACTION NETWORK UK

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Executive summary

UK citizens and the natural environment are being exposed to potentially harmful mixtures of pesticides.

These mixtures appear in our food, water and soil and can affect the health of both humans and wildlife. There is a growing body of evidence that pesticides can become more harmful when combined, a phenomenon known as the 'cocktail effect'. Despite this, the regulatory system designed to protect us from pesticides only looks at individual chemicals and safety assessments are carried out for one pesticide at a time.

For the first time, this report examines to what extent the cocktail effect is a problem in the UK and the potential impact upon human health and the environment. It describes the failures of our regulatory system to protect us from the cocktail effect and makes recommendations for what needs to change.

The cocktail effect demands urgent attention. Over a third of all the fruit and vegetables tested by the UK government in 2017 and 2018 contained residues of more than one pesticide. In 2017, 87.5% of the pears tested contained pesticide cocktails, with 4% containing residues of nine or more different chemicals. One sample of raspberries was found to contain one 'known carcinogen', one 'probable carcinogen' and two 'possible carcinogens', two endocrine disruptors (EDCs) which interfere with hormone systems and can cause cancerous tumours and birth defects, one developmental toxin which can have adverse effects on sexual function and fertility and one neurotoxin which can negatively affect the nervous system and nerve tissue. Multiple residues were found in more than three-quarters of grapes tested in 2018, with one sample containing traces of fourteen different pesticides. Pesticide cocktails are not only found in fruit and vegetables. In both 2017 and 2018, roughly a quarter of all food items tested by the government (which include animal products and grains) contained pesticides cocktails. In 2017, this included more than half of rice and a quarter of bread.

While this report was able to rely on government testing for the data on food residues, there is currently no official monitoring of pesticide cocktails in the environment and the only information available is from a small number of independent academic studies. One UK study on bumblebees found that 43% had detectable levels of more than one pesticide, with traces of seven pesticides found in one individual. A study of soil in 11 European countries found UK sites had the second highest diversity of pesticide residues. Around 67% of the UK samples had multiple residues, 25% had more than six, with around 4% continuing traces of more than ten pesticides. UK water appears to be no less contaminated. A study revealed that 66% of samples taken from seven river catchments contained over ten pesticides. Two small rivers in East Devon were found to contain residues of up to 24 pesticides and six veterinary drugs.

The prevalence of pesticide cocktails in our food and in the natural environment is associated with rising pesticide use in the UK. Between 1990 and 2016, the area of UK land treated with pesticides (treated area multiplied by number of applications) increased by almost two-thirds (63%). Many of the UK's most important crops are receiving more and more pesticide treatments. For example, the average hectare of oilseed rape or cereals, such as wheat and barley, was treated with pesticides twice as many times in 2016 as in 1990. For potatoes, the average number of treatments has almost trebled. The toxicity of pesticides has also increased over time so that many of the chemicals now being used are more toxic then their older equivalents. For example, some neonicotinoid insecticides are 10,000 times more toxic than the most notorious insecticide in history, DDT.

As the toxic load borne by citizens and the natural environment increases, a growing body of evidence is revealing the extent of pesticide-related harms. Recent studies on global insect declines and the biodiversity crisis name direct and indirect impacts of pesticides as key drivers. A glimpse at the state of nature in the UK is no less alarming. Wildlife such as butterflies, bees, farmland birds, and hedgehogs are all struggling. Meanwhile, pesticides have never been so unpopular, with 78% of the UK public wanting the government to provide more support to British farmers to reduce their use.

There is also a growing body of evidence showing that pesticide cocktails can have significantly more harmful effects than individual chemicals. Several pieces of research conducted on human cells and tissues have highlighted that combined actions of pesticide mixtures can lead to the creation of cancer cells and disruption of the endocrine system, which produces hormones that regulate metabolism, growth and development, tissue function, sexual function, and reproduction, among other things. Studies conducted on mice and rats have revealed similar results. Pesticide mixtures have been associated with obesity and impaired liver function, even when the doses of individual chemicals are below the safety levels set by regulators. Studies looking at insects, fish and birds echo these results. A recent study has shown that a certain insecticide touted as a 'safe' replacement for neonicotinoids and a commonly used fungicide combine to be more toxic to bees than when they appear alone. These studies provide compelling evidence that pesticide mixtures and the cocktail effect should be of major concern with respect to their effects on human health and the environment.

Despite the prevalence of pesticide cocktails, and the evidence that they can be more harmful than individual pesticides, the UK's regulatory system continues to assess the safety of one chemical at a time. Safety assessments of pesticide residues in our food are based on analysis of individual chemicals. This not only ignores the potential risks to human health associated with pesticide mixtures found on one item (an apple, for example) but also those found in one dish (such as a fruit salad) let alone an entire day's worth of food. Add to this the likelihood that both rural and urban residents are exposed to other pesticides which are directly applied in their locality (be it for agriculture in the countryside or weed control in towns and cities), and the widely-held belief that our system is fit-for-purpose in terms of protecting our health from pesticides begins to sound highly questionable.

Our regulatory system is equally ill-equipped to protect our natural environment from pesticide cocktails. The system ignores the cocktail effect, and fails to assess, monitor or limit the sum total of pesticide residues to which the environment and wildlife are exposed. Pesticide usage statistics are gathered for weight, spray hectares, and numbers of treatments, but national figures on the diversity of pesticides used on crops are not readily accessible. Even the limited monitoring that does take place, which has tended to focus on water, looks at individual pesticides of concern and ignores mixtures. The government doesn't monitor for pesticide cocktails in soil or the extent to which pollinators or other wildlife are being exposed. There is also a growing realisation that it isn't just pesticides that are of concern – wildlife is being exposed to cocktails of other chemicals in branded pesticide products along with other unnamed ingredients in pharmaceuticals, chemicals leaching from plastics, and even illicit drugs.

While researchers have begun to explore systems to monitor and assess the cocktail effect, these are unable to accurately assess the full spectrum of health and environmental impacts resulting from long-term exposure to hundreds of different pesticides. Pesticides appear in millions of different combinations in varying concentrations in our food and landscape. It is arguably impossible to create a system sufficiently sophisticated to be able to assess, let alone protect us, from the cocktail effect. The only way to minimise the risk to health and environment is therefore to hugely decrease our overall pesticide use, thereby reducing our exposure to pesticide cocktails.

The UK's planned departure from the European Union provides an opportunity to put in place measures to support farmers to significantly reduce pesticide use and transition to agroecological systems, which place robust Integrated Pest Management (IPM) at their heart. Genuine IPM is as an approach to managing pests, diseases or weeds under which chemical pesticides are used only as a last resort, if at all. Properly implemented, whole farm agroecological systems employing IPM can effectively deal with harmful pests and diseases whilst maintaining high levels of food production and farmer income. It is sometimes claimed that most farmers in the UK are already using IPM. This is far from true, since most conventional farming continues to rely on pesticides as a first line of defence. In reality, the support farmers need to adopt IPM and to transition to agroecological systems simply isn't in place.

In order to better protect human health and environment from the cocktail effect, this report makes some **key recommendations** for the UK government. (For a full list of recommendations see page 29)

The UK government urgently needs to:

- Ensure that no weakening of UK pesticide regulations or standards occurs as a result of Brexit, including through trade negotiations with non-EU countries, and that in turn food imports meet these same UK standards.

- Introduce measures to support UK farmers to transition to whole farm agroecological systems that include genuine and holistic Integrated Pest Management (IPM), of which organic and agroforestry are well defined examples. Most notably:
  - Use future farmer payments under the Environmental Land Management Scheme (ELMS) to incentivise and reward farmers.
  - Create a new independent extension service for research, development and dissemination of IPM techniques.
  - Facilitate farmer-to-farmer learning on agroecology and IPM.

- Introduce a clear, quantitative target for significantly reducing the overall use of pesticides in agriculture.

- Phase out all non-agricultural uses of pesticides and ban public authorities from spraying next to homes, schools and playgrounds.

- Establish robust environmental and human health monitoring systems for pesticide use which moves beyond the focus on individual pesticides and is able to assess combined toxic load.

- Conduct government-funded research into the effects of pesticide cocktails on the natural environment, wildlife and human health.

Until the government takes action, farmers will struggle to get off the 'pesticide treadmill', and UK citizens and our natural environment will continue to be exposed to potential harm. It is time to bring this damaging, decades-long experiment – in which we are blindly exposed to pesticide cocktails without any sense of the true consequences – to an end.

Introduction - setting the scene

Rising UK pesticide use

Pesticide use in the UK has risen significantly in the past three decades. While the total weight of pesticides applied to UK farmland has decreased, lighter and more toxic chemicals are being applied more frequently across an enlarged area of land.[1] Humans, wildlife and the environment are being exposed to a heightened toxic load and to mixtures of pesticides which interact to produce the 'cocktail effect'.

The assertion that pesticide use in the UK is decreasing[2] does not stand up to scrutiny. Analysis of UK Government data[3] reveals that the overall area of UK land being treated with pesticides (treated area multiplied by number of applications) increased by almost two-thirds between 1990 and 2016, with significant increases in the area of land treated with fungicides and herbicides (the area of land treated with insecticides fell slightly across this period).[4,5]

Pesticides are not only being applied across a greater area of land, they are being applied more frequently. In 1990, only 21% of oilseed rape and 30% of cereals (such as wheat and barley) were treated with pesticides more than four times in growing season. By 2016, those figures had increased to 80% for oilseed rape and 55% for cereals. Across the same period, the average number of times a hectare of oilseed rape or cereals was treated with pesticides nearly doubled. Potatoes are on average receiving almost three times the number of treatments today that they received in 1990.[7]

Many of the pesticides applied to UK farmland today are also more toxic than their older equivalents. For example, some neonicotinoid insecticides are 10,000 times more toxic than the most notorious insecticide in history, DDT.[8] Using a less extreme example, deltamethrin – an

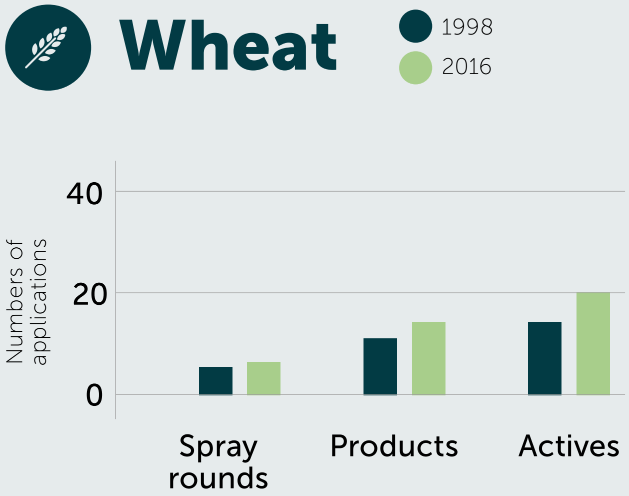
Figures taken from UK Government data:[6]

	Area treated ha 1990	Area treated ha 2000	Area treated ha 2016	% increase in area treated from 1990 to 2016
All pesticides	44,981,520	59,063,553	73,172,193	+63%
Fungicides	21,471,678	27,298,559	36,369,847	+69%
Herbicides	14,438,110	20,287,443	23,099,598	+60%
Insecticides	5,926,245	5,084,694	5,126,906	-13%

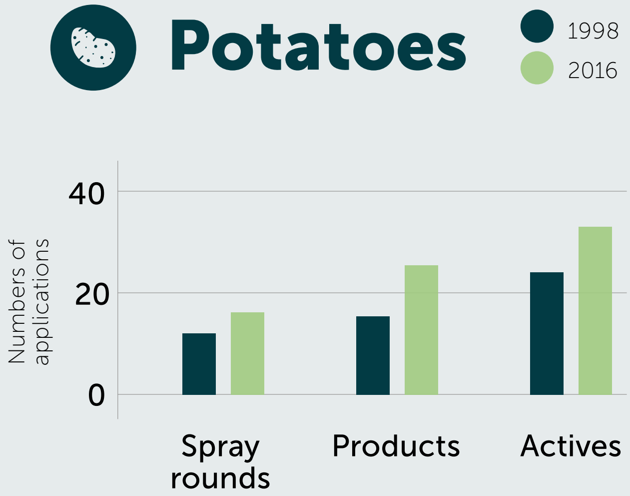
Number of applications (including repeat treatments) for four staple crops

(Source: Application data from government pesticide surveys and includes repeat treatments (tables 4a-4c) https://secure.fera.defra.gov.uk/pusstats/surveys/)

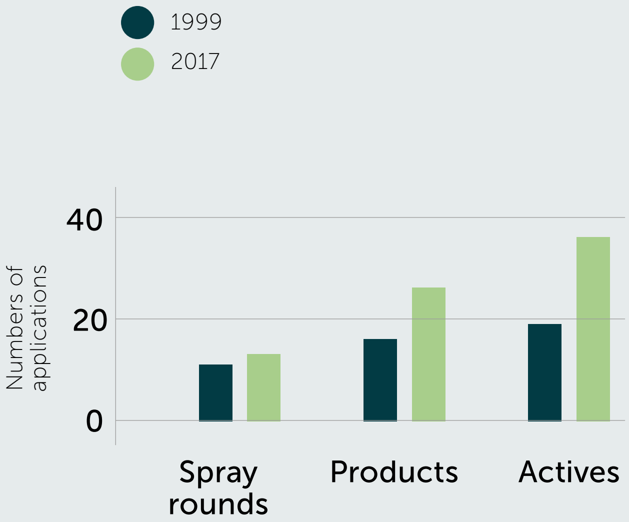
Wheat



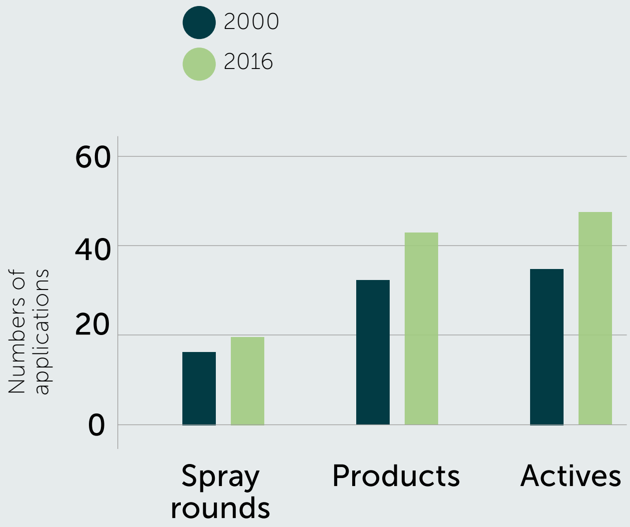
Potatoes



Onion & leeks



Dessert apples



insecticide which is authorised for use in the UK on a wide range of crops – is 360 times more toxic by weight than DDT.[9] As a result of this rising toxicity, much less of a chemical is required per application. The total weight of pesticides used in the UK has consequently decreased[10], but what matters is the total toxic load to which our health and environment are being exposed. The evidence indicates that the toxic load is rising[11], as are pesticide-related harms.

Increasing evidence of pesticides harming health and environment

These harms are well documented. The evidence linking pesticides to diseases such as cancer and Parkinson's increases year-on-year. Recent reports have revealed alarming global declines in insect populations, with more than 40% of insect species declining and a third endangered. Alongside habitat loss, pesticides have been identified as one of the key factors driving what has been coined the 'Insect Armageddon'.[12] A landmark UN report written by 550 experts revealed that one million species are at risk of extinction and that biodiversity loss on this scale is now posing a major threat to the survival of humanity. Again, pesticides were named as one of the drivers.[13]

This global picture is mirrored in the UK. One recent study found evidence of declines across a large range of UK pollinator species between 1980 and 2013. While some pollinators were found to have benefitted from recent agri-environment schemes, the study named pesticides as a major contributor to historical declines and as a "key threat" to pollinator populations today.[14] England has also lost 27% of its farmland butterflies since 1990.[15] The impacts of insect collapse are felt further up the food chain. Farmland birds have declined by 54% since 1970.[16] Hedgehog numbers have fallen by up to 50% in rural areas since 2002 and are now estimated to total just one and a half million[17] compared with 30 million in the 1950s.[18]

Where there is evidence of harm resulting from pesticide use, the focus has often been on individual pesticides or classes of pesticides. Little attention has been given to the combined impact of all the various pesticides that humans and wildlife are exposed to and how they may be interacting. This report presents evidence that the cocktail effect should be of considerable concern. Multiple pesticide residues are found both in the natural environment and in the food we eat, but safety assessments are only carried out for individual chemicals and our regulatory system is unable to take account of, let alone protect us, from the possible interactions between different pesticides. Despite a growing body of evidence indicating that the cocktail effect should be of concern (see page 21), little attention is being given to the impact pesticide cocktails are having on health, wildlife, and the environment.

Opportunities for change

Brexit poses both threats and opportunities in this regard. Departure from the European Union heightens the risk of an increase in pesticide-related harms, including those resulting from the cocktail effect. But Brexit, and the associated re-design of UK agriculture, also presents the opportunity to incentivise and support farmers to reduce and phase out pesticide use.[19]

Helpful policy levers are already in place. In 2018, the UK Government published its 25 Year Environment Plan which committed to reduce pesticide use and place Integrated Pest Management (IPM) at the heart of its approach.[20] Properly understood, IPM sits at the heart of whole farm agroecological systems as an approach to managing pests, diseases or weeds under which chemical pesticides are used only as a last resort, if at all. It sits in contrast to usual agricultural approaches in which pesticides are the first weapon of choice for dealing with unwanted organisms. Properly implemented, holistic agroecological IPM systems can effectively deal with harmful pests and diseases whilst maintaining crop yields and farmer income.[21] Organic agriculture can be viewed as an exemplar of robust agroecological IPM.

It is sometimes claimed that most farmers in the UK are already using IPM.[22] This is far from true, since most conventional farming continues to rely on pesticides as a first line of defence.[23] In reality, the majority of British arable farmers employ only a limited number of IPM methods and are missing out on the benefits from adopting whole farm agroecological systems.[24] IPM should not be viewed as one technique, but as a suite of tactics that should be used in a holistic way before, during, and after the growing of a crop.[25] Until now, the UK has adopted a piecemeal approach that cherry picks individual IPM techniques. Brexit presents the opportunity to shift to whole system agroecological approaches.

As this report highlights, pesticide mixtures and the cocktail effect are of pressing concern. With pesticide use in the UK continuing to rise, against a global and local backdrop of declining biodiversity, the time is ripe for a radical re-orientation of agricultural policy and practice. Farmers must be empowered to transition to holistic agroecological systems employing robust IPM. This would be a popular move – polling has shown that 78% of the UK public want the government to provide more support to British farmers working hard to reduce their pesticide use.[26] This report outlines the steps the UK Government must take to support farmers in this transition, and to protect citizens, wildlife, and the environment from the harmful effects of pesticide cocktails.

> Particularly concerning is the way multiple chemical exposures can combine and interact with each other to impact health. Yet the few risk assessments that have been completed focus on the risk of exposure to individual substances, and don't consider the human rights of the child.
>
> Interview with UN Special Rapporteur on Toxics, Baskut Tuncak, June 2019.[27]

Key findings – Pesticide cocktails in our food

The UK Government monitors the amount of pesticide residues in food consumed in the UK. This includes both food grown domestically and imports. In addition to testing fruit and vegetables, the programme also covers animal products (dairy products, fish and meat) and starchy food and grains (bread, rice, rye flour and rye grain).[28]

The authors of this report have analysed the results of the government's monitoring programme for 2017[29] and 2018[30] (the most recent years for which data is available) in order to ascertain how much of the food we eat contains potentially harmful pesticide cocktails. It should be noted that the monitoring scheme, which is run by the Expert Committee on Pesticide Residues in Food (PRiF), is extremely limited. Of all the food consumed in the UK in 2017, PRiF tested just 3,357 samples (a 'sample' must be a minimum number of twelve items weighing at least 1.2kg).[31] In 2018, they tested 3,385 samples.[32] This is the only food residue monitoring carried out by the Government. The approximately 40 different food items chosen for testing vary from year-to-year making it difficult to identify trends.

Unless otherwise stated, all of the analysis presented in this section is based on UK government monitoring data which can be found in the 2017[33] and 2018[34] annual reports of the Expert Committee on Pesticide Residues in Food (PRiF). Our overall findings are presented below.

2017 findings [35]

- Of the 3,357 total number of samples tested by the government in 2017, more than a quarter (26%) contained residues of multiple pesticides.

- Of the 1,883 samples of fruit and vegetables tested, 40% contained residues of multiple pesticides.

- Every single type of fruit and vegetable and all four types of starchy food and grain tested included at least one sample that contained multiple pesticide residues.

- A deeper look at just under half of the samples tested in 2017 (1,467 samples, or roughly 43% of the total number of samples tested by the government in 2017), revealed that they contained the residues of 110 different active ingredients (Note: an 'active ingredient' or 'active substance' is the chemically active part of a manufactured pesticide product. For example, glyphosate is the active substance in the weedkiller product RoundUp). The active ingredients detected included;
  - 39 'known', 'probable' or 'possible' human carcinogens.
  - 24 suspected Endocrine Disrupting Chemicals (EDCs) which interfere with hormone systems and can cause cancerous tumours, birth defects, and other developmental disorders.
  - 16 developmental, reproductive or neurotoxins. Developmental and reproductive toxins have adverse effects on sexual function and fertility in children and adults while neurotoxins have negative impacts on brain development, the nervous system and nerve tissue.
  - 11 cholinesterase inhibitors which affect the nervous system.[36]

In terms of specific food items tested, the results of all testing conducted in 2017 revealed that:

- 92% of oranges contained multiple residues. 39% had five or more residues present. 8% had eight or more residues present.

- 87.5% of pears contained multiple residues. 37.5% have five or more. 10% have seven or more. 4% have nine or more.

- 64% of apples contained multiple residues. 15% had five or more. 4% had seven or more residues present. 1% had nine or more residues present.

- 53% of rice contained multiple residues. 28% contain five or more. 4% continued nine or more.

- 25% of bread contained multiple residues, 4% had three or more residues present and one sample contained residues of six pesticides.

Looking at some specific food items in more detail revealed the following:

Raspberries

- Of the 72 samples tested, 40 contained multiple residues.
- In total 24 different active ingredients were found on the samples of raspberries tested in 2017, including herbicides, fungicides and insecticides.
- The samples tested contained a total of nine known, possible or probable human carcinogens and five potential endocrine disrupting chemicals (EDCs).
- One sample of raspberries contained;
  1 known carcinogen, 1 probable carcinogen, 2 possible carcinogens
  2 EDCs
  1 developmental toxin
  1 neurotoxin

Pears

- Of the 96 samples tested, 84 contained multiple residues.
- In total 33 different active ingredients were found on the pears sampled in 2017, including herbicides, fungicides and insecticides.
- The samples tested contained a total of 14 possible, probable or known carcinogens and eight potential endocrine disrupting chemicals (EDCs).
- One sample of pears contained;
  7 known, probable or possible carcinogens
  5 EDCs

Rice

- Of the 96 samples tested, 51 contained multiple residues.
- In total 23 different active ingredients were found on the rice sampled in 2017.
- The samples tested contained a total of six possible carcinogens and seven potential endocrine disrupting chemicals (EDCs).
- One sample of rice contained;
  3 known, possible or probable carcinogens
  2 EDCs
  1 developmental toxin

2018 findings [37]

- Of the 3,385 total number of samples tested by the government in 2018, nearly a quarter (23.5%) contained residues of multiple pesticides.

- Of the 1,962 samples of fruit and vegetables, more than a third (36%), contained residues of multiple pesticides.

- Of the 288 samples of bread and wheat that were tested (listed as 'starchy goods'), just under a fifth (18.75%) contained multiple residues.

- A deeper look at all 3,385 of the samples tested revealed that they contained the residues of 157 different active ingredients, including:
  - 63 'known', 'probable' or 'possible' human carcinogens (40% of the total).
  - 41 suspected Endocrine Disrupting Chemicals (EDCs) which interfere with hormone systems and can cause cancerous tumours, birth defects, and other developmental disorders (26% of the total).
  - 22 developmental, reproductive or neurotoxins. Developmental and reproductive toxins have adverse effects on sexual function and fertility in children and adults while neurotoxins have negative impacts on brain development, the nervous system and nerve tissue (14% of the total).
  - 19 cholinesterase inhibitors which affect the nervous system (12% of the total).[38]

In terms of specific food items tested, the results of all testing conducted in 2018 revealed that:

- 27% of aubergines contained multiple residues. 14.5% had three or more residues present.

- 99% of grapefruits contained multiple residues. 79% contained residues of three or more different pesticides. 21% contained six or more.

- 77.5% of grapes contained multiple residues. 51% contained residues of three or more. 20% contained five or more. One sample of grapes contained residues of 14 different pesticides.

- 19% of wheat contained multiple residues.

Looking at some specific food items in more detail revealed the following:

Grapefruit

- Of the 96 samples tested, 95 contained multiple residues (99% of the total).
- In total, 26 different active ingredients were found on the samples of grapefruits tested in 2018, including herbicides, fungicides and insecticides.
- The samples contained a total of 11 known, possible or probable human carcinogens, 11 suspected endocrine disruptors and ten reproductive, developmental or neurotoxins.
- One sample of grapefruits contained;
  5 known, possible or probable human carcinogens
  5 suspected endocrine disruptors
  4 developmental toxins

Apples

- Of the 96 samples tested, 42 contained multiple residues (43% of the total).
- In total, 22 different active ingredients were found on the samples of apples tested in 2018, including fungicides and insecticides.
- The samples contained a total of eight known, possible or probable human carcinogens, four suspected endocrine disruptors and four reproductive, developmental or neurotoxins.
- One sample of apples contained;
  3 known, possible or probable human carcinogens
  2 suspected endocrine disruptors

Lentils

- Of the 48 samples tested, 14 contained multiple residues (29% of the total).
- In total, nine different active ingredients were found on the samples of lentils tested in 2018, including herbicides, insecticides and fungicides.
- The samples contained a total of three known, possible or probable human carcinogens, two suspected endocrine disruptors and one reproductive, developmental or neurotoxin.
- One sample of lentils contained;
  2 known, possible or probable human carcinogens
  1 suspected endocrine disruptor

Peppers

- Of the 96 samples tested, 35 contained multiple residues (36% of the total).
- In total, 24 different active ingredients were found on the samples of peppers tested in 2018, including fungicides and insecticides.
- The samples contained a total of six known, possible or probable human carcinogens, one suspected endocrine disruptor and two reproductive, developmental or neurotoxins.
- One sample of peppers contained;
  2 known, possible or probable human carcinogens
  1 developmental toxin

Multiple pesticides are found in our food and environment forming **chemical "cocktails"**

43% of bumblebees had detectable levels of two or more pesticides, with up to **seven pesticides found in one bumblebee**

Two thirds of **river** samples contained over 10 pesticides

Flowers, **soil** and **river water**, can contain 10 or more different pesticides in a single sample

67% of **soil samples** contained multiple pesticides

25% of samples had more than 6 pesticides

4% had more than 10 pesticides

1/4 In 2017 and 2018, roughly a quarter of all the **food items** tested by the UK government contained pesticide cocktails

In 2017, 40% of all **fruit** and **vegetables** tested contained pesticide cocktails

14 The number of different **pesticides** found in some produce

64% of **apples** contained multiple pesticides

87% of **pears** contained multiple pesticides

25% of **bread** contained multiple pesticides

The UK Government urgently needs to support farmers to reduce pesticide use. Tell the government to protect us from the **#cocktaileffect**

Key findings – Pesticide cocktails in our environment

In contrast to the testing conducted on UK food, there is virtually no government monitoring of pesticide residues in our environment. The monitoring that does take place – the majority of which looks at water – tends to focus on individual pesticides, largely ignoring pesticide cocktails.

The research conducted for this report has focussed on the small number of independent scientific studies that have been conducted. Many of these have only looked for traces of a limited list of particular pesticides and therefore may have missed the presence of others. From this limited selection, pesticide cocktails in the environment are of evident concern and warrant further research. A summary of the evidence follows.

Flowers and plants

Flowers and plants are important because they are at the bottom of the food chain and provide sustenance for countless insects and animals. As a result, there is a high likelihood that residues of pesticides cocktails found in flora will be passed on to a wide range of wildlife. We found only one study[39] testing flowers in the UK for a broad range of pesticides. This tested pollen from wildflowers around wheat and oil seed rape fields and found between two and five pesticides in all samples (out of 20 tested for). This result is in line with a US study[40] which found a high proportion of pesticide and pharmaceutical mixtures in the wildflowers around crops. Another study screened for eight insecticides and 16 fungicides within plants marketed as 'bee friendly' in UK garden centres[41], and found that plants contained traces of up to 10 different pesticides, suggesting that pesticide cocktails could be an issue for gardeners as well as farmers.

Pollinators

Pesticide cocktails are also of concern for insect pollinators and products (such as pollen or honey) from hives or colonies. We found only one UK study[42] concerning bumblebees, which looked for evidence of five neonicotinoid insecticides, thirteen fungicides and a pesticide synergist. The study found that 67% of bumblebees had detectable levels of at least one pesticide. 43% had two or more pesticides, with up to seven pesticides found in one bumblebee. Higher detection frequencies were found in bumblebees in agricultural areas, but multiple residues were also found in bees in urban areas. Several studies from other countries have consistently found multiple pesticides in bees, bee collected pollen, honey and other bee products. Examples where studies have been conducted include Italy[43], France[44], Belgium[45], Poland[46], the USA[47,48,49] and in a meta-analysis on honey bees and bumble bees[50].

Birds and mammals

Research on birds and mammals has focussed on individual pesticides or a particular pesticide class such as neonicotinoids; there are no UK studies that we know of which look at the impact of pesticide mixtures on birds or mammals. Two French studies have looked at pesticide cocktails in grey partridges. One used information on farm habitats combined with detailed pesticide use data and suggests that clutches (groups of eggs) and coveys (small flocks of birds) were exposed to around 33 pesticide actives[51]. Another study tested partridge eggs directly and found 14 different pesticides, including many that have persisted in the environment following bans several years earlier[52].

Earthworms

No UK studies were found for earthworms. A study in France recently established a methodology for assessing pesticide cocktails in earthworms and whilst the sample size was small (only eight worms) they nonetheless found 10 pesticides out of 27 looked for, with as many as five different pesticides in one earthworm individual[53].

Soil

Only two studies testing for pesticide mixtures were found for soils. A study[54] of 11 European countries found UK sites had the second highest diversity of pesticide residues. Around 67% of the UK samples had multiple residues, 25% of samples had more than six and around four percent had more than 10 residues. Soil taken from an area around Derbyshire/Nottinghamshire was revealed to be one of the worst of all soils sampled in the EU-wide study, with half of samples containing residues of more than ten different pesticides. Overall, glyphosate and its metabolite AMPA, as well as DDT (which was banned in Europe in the 1980s but still persists) and broad-spectrum fungicides, were the most frequently detected. Another study[55] of note from the Netherlands tested the soils, manure and animal feed of 24 livestock farms. No sample was free from pesticide residues and 134 pesticides were found at 'ecologically relevant concentrations'. The report states that "the effects of all substances taken together, their synergistic interactions and their cumulative effects on the ecosystem are unknown".

Surface water & Aquatic life (Macroinvertebrates)

Several scientific studies have looked at pesticides in surface water. Most of these have looked at one or two pesticides of known interest, but a handful have looked at broader contamination and have attempted to identify the presence of pesticide mixtures, evaluating the additive effects of these mixtures but not synergistic effects, therefore only taking a partial look at the cocktail effect (see definition of 'additive' vs. 'synergistic' on page 25). A summary of four such studies is given here:

- A long-term UK study[56] over two years across seven river catchments: found 66% of samples contained over 10 pesticides. Around 3% of samples were found to have combined toxicities high enough to cause short-term extinction of Daphnia (Water Flea) populations. The researchers concluded that due to limitations in data and modelling "despite all the effort that is put into chemical monitoring programs, it remains a challenge to make statements on whether or not the environment is protected."

- A recent study[57] testing freshwater shrimps in Suffolk: found 50 different chemicals in the bodies of freshwater shrimps, including illicit drugs and pharmaceuticals as well as pesticides. Of the pesticides detected, seven are banned in the EU, including Oxycarboxine and Fenuron, which were found in nearly all shrimp tested (100% and 86% respectively). Using a model that compared known toxicity levels for the shrimp with the concentrations of individual pesticides found in their bodies, the authors concluded that the mixtures posed low risk to the health of the shrimp.

- Sampling of 29 waterways in 10 European countries: found 21 veterinary drugs and 100 pesticides[58]. A quarter of the pesticides found are banned, and nearly half of the streams analysed had at least one pesticide above permitted levels – most often neonicotinoids. Two of the small rivers were in the UK, in East Devon, where up to 24 pesticides and six veterinary drugs were found. Nearly half of the streams, including both UK sites, were considered to have worryingly high levels of pesticides.

- A meta-analysis[59] reviewing studies looking at pesticides in watercourses across the EU: found 135 different pesticides (66 insecticides; 42 herbicides; 27 fungicides). Around 90% of samples had mixtures of pesticides, containing up to 13 different pesticides. The study was the first EU-wide study to test whether pesticide levels are exceeding 'regulatory acceptable levels'. These levels are defined in the environmental risk assessment conducted as part of the EU process for authorising pesticides. They are based on ecotoxicological tests of individual pesticides on model organisms. The study found that these levels were exceeded in 45% of sites overall, including 78% of UK sites.

No bees were harmed in the making of this report

Should we be concerned about the cocktail effect?

Given the wide variety of different active ingredients used in food production, pesticides almost always occur in mixtures. However, not all mixtures of pesticides interact in the same way, and the precise extent of combined effects is unpredictable[60].

Nonetheless it has been possible to understand some of the interactions among different groups of pesticides, such as organophosphates, organochlorines, pyrethroids and carbamates[61]. The following sections provide examples of studies which have found pesticide mixtures to have combinatory effects. They are the result of a non-exhaustive literature review. They illustrate that there is sufficient evidence to indicate that pesticide mixtures and the cocktail effect should be of major concern with respect to their effects on human health and the environment.

Effects on human cells and tissues

Several pieces of research conducted on human cells and tissues have highlighted that combined actions of chemical mixtures can lead to disruption of the endocrine system and the transformation of normal cells into cancer cells[62]. A 2001 study assessed the combined effects of four organochlorine pesticides on human breast cancer cell proliferation and reported that the cancer cell proliferation was induced even when each individual chemical was present at levels at or below its no-observed-effect-concentration.[63] Mixtures of pesticides with endocrine activity have also been shown to have deleterious effects on human estrogenic receptors, meaning that they can affect the hormonal system more than the individual pesticides they contain[64]. Recently it has been shown that the composition of a mixture of organochlorine pesticides could play a role in the initiation processes of breast cancer[65]. A study on neuronal cells showed that chlorpyrifos and carbofuran have a synergistic action, which means the joint toxicity of the two pesticides is greater than when either is used alone and that the two pesticides together can inhibit cell proliferation and have other harmful effects on cellular activity[66]. Another study investigated the potential cellular toxicity and genotoxicity of the seven most common pesticide mixtures to which the French population is exposed through food consumption. One of the mixtures showed both cellular and genotoxic effects in vitro at low concentrations, with a significantly higher effect than would be expected from the response to the individual compounds[67].

Effects on mammals

A range of studies have been conducted on the effect of pesticide mixtures on mammals. A piece of research on rats assessed the effects of long-term, low-dose exposure to chemical mixtures (including pesticides) simulating complex real-life human exposures. The results revealed that liver function may be adversely affected and body weight can be significantly increased, even when the doses of individual chemicals are below the safety levels set by regulators[68]. A study on mice exposed in vivo to a common mixture of pesticides at Tolerable Daily Intake (TDI) levels reported obesogenic and diabetogenic effects resulting from chronic dietary exposure, especially in males[69]. While exposure to chemical mixtures in both young and mature adults seems to lead to a weight increase, exposure during foetal life can lead to low birth weight and is commonly observed in reproductive toxicology studies. A mixture of six different pesticides tested on rats resulted in significantly lower birth weights. Each of the six compounds was present at individual doses below their no-observed adverse effect levels (NOAELs) and therefore wouldn't have had any effect alone[70].

Effects on other wildlife

Non-target organisms are susceptible to deleterious effects of pesticide mixtures in their environment. A study recently demonstrated effects on the hormonal system of red avadavat birds due to both interactions between the components of pesticide mixtures and the cumulative toxicity of the mixture itself[71]. A recent study has shown synergistic effects of flupyradifurone (a new neurotoxic insecticide touted as a replacement for neonicotinoids) and propiconazole (a common fungicide) on honeybees, with the effects of the two pesticides together on bee survival and behaviour evident at lower doses than when acting alone[72]. Pesticide mixtures tested on earthworms have also shown synergistic effects[73]. A study found that the simultaneous presence of several pesticides in the terrestrial environment may lead to increased toxicity, causing more disturbing effects on the soil ecosystem than expected. Fish are also affected by pesticide mixtures.

A piece of research revealed that environmental cocktails of herbicides and fungicides can induce important changes in the metabolism of goldfish, with possible detrimental outcomes at both physiological and behavioural levels. The study also reports that increasing temperature could further affect the response of fish to exposure to pesticide mixtures[74]. The effects of mixtures of organophosphate pesticides have been studied in vivo on Pacific Salmon and been shown to induce neurotoxicity as well as mortality at concentrations that are sublethal for the individual pesticides[75]. In the aquatic environment, fish are not the only species endangered by pesticide cocktails. Several common fungicides have been tested on the crustacean Daphnia magna in different combinations with the insecticide alpha cypermethrin. The researchers concluded that almost all the fungicides tested can substantially enhance the effect of the insecticide on Daphnia magna[76]. Molluscs also appear to be adversely affected by pesticide mixtures, particularly when combined with other pollutants found in the natural environment. The Plymouth Marine Laboratory investigated the toxicity of chemical mixtures in molluscan blood cells and found significant synergistic interactions between chemicals deriving from various kinds of pollution (such as polycyclic aromatic hydrocarbons which are produced by burning oil or wood), pesticides and a pesticide additive[77].

Variety of pesticides used in UK farming

Around 400 different pesticides are permitted for use in the UK[78], and farmers are advised to use combinations of pesticides.

This is because using a variety of chemicals with different modes of action has been a strategy to slow the development of resistance (see page 28 for more detail). There are no government figures readily available for the diversity of pesticides used on various crops, though we do know that the average number of treatments is going up in the UK[79].

Three-years of pesticide use: A case study from a UK farm

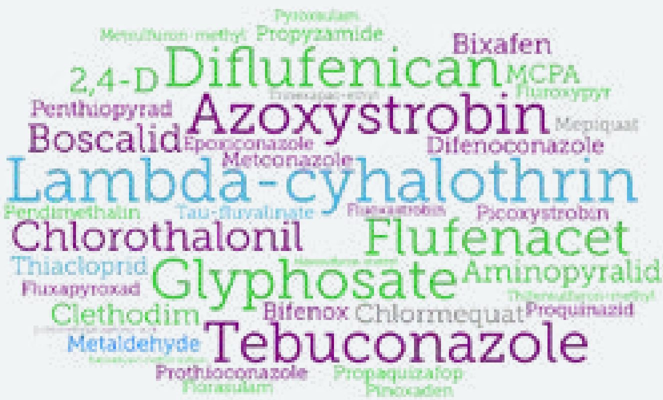
One farmer has shared three years of data with us. As this data is from one farm, it cannot be taken to be nationally representative or an indicator of numbers in the overall farm landscape, but it does provide insight into the variety of pesticides used in UK arable farming.

The farm: 530 hectares of wheat, barley, oil seed rape and peas farmed using a no tillage (no ploughing) approach to minimise soil disturbance. Data from 2015-2018.

Chemicals used:

- Between 32 and 40 different pesticide active ingredients were applied each year.
- At the field level, crops such as wheat received treatments of as many as a dozen different active ingredients. (Note: an 'active ingredient' or 'active substance' is the chemically active part of a manufactured pesticide product. For example, glyphosate is the active substance in the weedkiller product RoundUp).
- Over the three years, almost 70 different chemicals and compounds contained in roughly 90 products were applied. Three quarters of these were pesticide active ingredients (mostly herbicides & fungicides).

A year of chemicals on a 530ha arable farm in the year 2017/18



Fungicide
Herbicide
Molluscicide
Insecticide
Growth regulator

Key:
Font size corresponds to the size of the treated area

Is the current system failing to protect us from the cocktail effect?

There is clear evidence that pesticide cocktails are not well understood, occur widely, and can have significant impacts on health and the wider environment. How well do existing regulatory mechanisms address the potential impacts of the cocktail effect?

Our health

Our current regulatory system focusses solely on assessing the risk posed to human health by individual pesticides, failing to account for interactions between multiple chemicals. Pesticides are tested in isolation for harmful effects and are not looked at in combination. This system not only fails to protect us from the cocktail effect, it completely ignores the issue.

This is a serious shortcoming in the regulatory system. We are being exposed to cocktails of multiple pesticides via dietary intake and yet almost nothing is known about how these chemicals are interacting or the potential health effects of this repeated exposure.

This is not an insignificant problem. As this report has revealed, in both 2017 and 2018 roughly a quarter of all the samples tested by the UK government (and more than a third of all fruit and vegetables) contained pesticide cocktails, with some produce containing traces of up to 14 different active ingredients.[80,81] Safety levels set for residues of individual chemicals not only ignore the potential risks associated with pesticide mixtures found on one item (an apple, for example) but also those found in one dish (such as a fruit salad) let alone an entire day's worth of food. Add to this the likelihood that both rural and urban residents are exposed to other pesticides which are directly applied in their locality (be it for agriculture in the countryside or weed control in towns and cities), and the widely-held belief that our system is fit-for-purpose in terms of protecting our health from pesticides begins to sound highly questionable.

The main piece of legislation governing what is permissible in food is the Maximum Residue Level (MRL) (Regulation (EC) No 396/2005).[82] The Expert Committee on Pesticide Residues in Food (PRiF) – a small committee which meets just four times per year[83] and has an extremely limited budget – reports annually on the presence of residues in produce available to consume in the UK with a focus on how many samples have exceeded the MRL.[84] The implication is that any pesticide residue below the MRL doesn't pose a threat to human health. However, MRLs are set to ensure that food is grown according to 'good agricultural practice'.[85] They do not guarantee that the quantity of pesticide found in food is safe.

According to the UK Health and Safety Executive, under EU regulations MRLs are always set below levels that would present a risk to consumers.[86] However, MRLs are

The combined effects of mixtures of agents are commonly assessed in terms of synergism, additivity, or antagonism. Such evaluations critically rely on quantitative estimations of what the expected effect of a mixture should be. If the combined effects total the sum of their individual components – then the mixture effect is considered 'additive' and as expected. If the observed responses are stronger or weaker than expected, the combined effect can be called 'synergistic' or 'antagonistic' respectively.

only set for individual pesticides. They do not take account of multiple residues of different pesticides which can interact with each other, despite the increasing body of evidence showing that chemicals can be more toxic when combined than alone.

The 'cocktail effect' has in fact long-been recognised as an area of concern in the UK. A 2002 report from the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (a group of independent experts which advises the UK government) concluded that the UK did not have the tools necessary to investigate whether interactions may occur at the low levels of residues to which consumers are exposed, or sufficient scientific understanding of the toxicology of mixtures to allow such risk assessment. The report also noted that certain groups in the population, notably pregnant women and young children, may be at higher risk from possible interactions than other adults.[87] Despite this concern, in the 17 years since these findings were published, little has been done to progress the UK's understanding of the human health impacts of food containing multiple residues. At the European Level, the European Commission has launched a programme to assess cumulative risk associated with multiple pesticide residues in food.[88] However, this is still in development and therefore not at present able to address the issue.

Our wildlife and environment

The current regulatory system does not consider the cocktail effect, and fails to assess, monitor or limit the sum total of pesticide residues to which the environment and wildlife is exposed. As noted by Professor Ian Boyd (Defra Chief Scientific Advisor from 2012 to October 2019): "[There is] no systematic monitoring of pesticide residues in the environment, and no equivalent to Maximum Residue Levels in foods exists for the environment...Without knowledge of safe environmental limits, the total pesticides used — and therefore the total environmental dose — is governed by market demand rather than by a limit on what the environment can endure."[89]

Thanks to the EU Water Framework Directive, the best monitoring of pesticide residues is in our rivers and streams where progress has been made in reducing pollution from pesticides. This monitoring has tended to focus on individual pesticides of known concern and fails to adequately assess the total pesticide pollution that persists across freshwater habitats. The presence of diverse pesticide cocktails may be having subtle but deleterious effects on aquatic wildlife communities, as highlighted in the handful of independent studies, outlined above, that have looked at this issue.

There is no government monitoring for pesticide mixtures in pollinators or other wildlife. With strong evidence linking pesticide use to declines in insect populations, including pollinators,[90] there is an urgent need for a monitoring system which can assess the total pesticide exposure of insects and wildlife, and the potential harm caused by the cocktail effect. Independent research has not been able to make up for the lack of government testing in this respect. As described in one research paper: "For the most part, pesticide research remains a scattered assemblage of data recorded at the molecular, cellular, physiological, or individual levels for different species on the one hand, and records of population declines or altered community structure in areas with high pesticide input or persistence on the other hand. Evidence for causal links across the levels is still scarce." [91]

Despite the exposure of farmland to multiple applications of pesticides, there is no government monitoring of pesticide residues in agricultural soils, or of their effect on soil life. Soil contains communities vital to soil health and the food chain including microorganisms, mycorrhizal fungi, insect larvae and earthworms. Unhealthy soil communities affect the functioning of soil, with long term implications for plant disease, nutrients and climate change resilience, which may take time to become evident. There is widespread concern that arable soils are declining in health. Whilst this is largely seen to be due to failure to replace lost soil organic matter, the potentially harmful impact of pesticides has not been adequately assessed let alone mitigated against.

Pesticide usage statistics are gathered for weight, spray hectares, and numbers of treatments. No national figures exist on the number of different pesticides used on crops. Equally there is no national monitoring of total pesticide usage across a given landscape. The Centre of Ecology and Hydrology is looking to address this with maps of use for individual pesticides based on an analysis of the national statistics collected by FERA.[92] However, while these maps provide a clearer picture of the total usage of individual pesticides, they will not reveal the extent to which pesticide cocktails appear. According to Professor Ian Boyd "There is little information about where, when, and why pesticides have been used, making it very difficult to quantify potential environmental effects."[93]

There is also a growing realisation that it isn't just pesticides that are of concern – wildlife is being exposed to cocktails of other chemicals in branded pesticide products along with other unnamed ingredients in pharmaceuticals, chemicals leaching from plastics, and even illicit drugs. The failure to consider cocktail effects is a widespread problem in chemical regulations in general, though pesticides are of particular concern given that they are the only chemicals intentionally placed into our natural environment.

Can the system be improved to protect us from the cocktail effect?

"The number of different combinations of chemicals in mixtures is infinite and an efficient test strategy for mixtures is lacking." [94]

Description taken from website of 'Euromix', an EU project designed to create a strategy for risk assessment of mixtures of multiple chemicals

The risk assessment of chemicals for regulatory purposes does not generally take into account the "real life" exposure to multiple substances, but almost exclusively relies on the assessment of individual active ingredients.[95]

Assessment of toxicity and risks of combined exposure to multiple chemicals is a concept that has been evolving over decades, driven in part by the rising numbers of chemicals in use. Over the last decade in particular, there have been significant advances in the field of combined exposure assessment internationally, accompanied by the publication of various guidance documents[96,97].

There are a number of different possible approaches for assessing the hazard presented by chemical mixtures. The mixture itself can be tested as a whole (referred to as a 'whole-mixture approach'). Acknowledging that it is not feasible to test all possible combinations of chemicals, testing can also be carried out based on data generated with a mixture of similar composition (a similar mode of action or chemical structure of components in similar concentrations). The hazard of chemical mixtures can also be assessed by taking into account information concerning the concentration and effect of the individual components of the mixture. However, component-based approaches can potentially lead to underestimations of risk when the composition of a mixture is not fully known. This is usually the case with the exception of pesticide products designed to contain more than one active ingredient, for which the manufacturer must specify in what proportion each one is present.

One of the main challenges in the toxicological assessment of mixtures is the need to address data gaps: data concerning the effects induced by mixtures are available for a very limited number of mixtures only, and single chemical hazard, dose–response, and Mode of Action information needed in component-based approaches is often lacking for many chemical classes[98].

Another major challenge concerns the unpredictability of possible interactions between chemicals and their impact on the overall hazard of a chemical mixture. Individual chemicals may influence the combined activity of the mixture in very different ways and can modify the magnitude and sometimes also the nature of the toxic effect. This means that when mixed, chemicals do not simply lead to a sum of the single effects expected by each chemical (additive effects), but their interactions can cause effects that are more than additive (synergistic) or less than additive (antagonistic). As a result, we currently, have very little idea of what impact the cocktail effect has on human health or the environment at real-life exposure levels[99].

Several new approach methodologies are currently being tested and compared, and efforts are underway to integrate all these different approaches.[100] The EU in particular has been undertaking work to assess the health risks associated to pesticide cocktails. Its Euromix project aims to "...provide information for future risk management decisions on the safety of chemicals in mixtures..." and there is also a separate initiative looking specifically at the effects of mixtures of endocrine disruptive chemicals on children.[101,102]

Despite these efforts, we remain a long way from being able to precisely assess the risk of pesticide cocktails. In fact, it is hard to envision that it will ever be possible to devise a model sufficiently sophisticated to accurately assess the effect of pesticide mixtures, which can appear in millions of different specific combinations both in the natural environment and in our food.

The one thing we do know for certain, however, is that mixtures do present a substantial hazard to human health and the environment. Given that it is impossible to lessen the level of hazard associated with pesticides currently in use, the only realistic way to limit the risk presented by mixtures is to take action to reduce exposure to them by decreasing or eliminating the use of pesticides.

Mitigating the cocktail effect by using a smaller range of pesticides

Over time plants, pests and diseases can develop resistance to the pesticides used to control them – meaning that these pesticides are no longer effective at dealing with the particular problem. This is a serious issue for famers and growers as they seek to control pests and diseases that adversely affect their crops.

One of the main drivers of resistance is the overuse or over-reliance on a limited number of active ingredients to control a particular problem. As an example, the huge increase in the use of glyphosate to control weeds on GM crops in the USA has led to the development of 'super weeds' that are resistant to the herbicide and render it ineffective. We are now beginning to see the development of glyphosate resistance in the UK, with the first case reported in October 2018.[103]

In order to deal with the loss of efficacy, and when no approved substitute is available, farmers may resort to using greater quantities of a substance to try and cope with a problem. This increased use then leads to further resistance and things can begin to spiral out of control (a phenomenon known as 'the pesticide treadmill').

One of the main strategies currently employed to deal with resistance is to use a wider range of active ingredients to avoid pests and diseases developing resistance. However, this leads to a greater number of actives being applied to food crops and subsequently released into the environment, exacerbating the cocktail effect.

However, radically different strategies are available that largely avoid the risks for farmers of getting stuck on the pesticide treadmill. Adopting the methods and principles used by organic growers, such as varied rotations, selection of pest and disease resistant varieties and increasing the numbers of beneficial insect predators can all help reduce both the quantity and variety of pesticides applied to deal with pests and diseases, reducing both the risk of exposure to pesticide cocktails and the build-up of resistance.

Recommendations

The findings of this report have highlighted that both the environment and UK citizens are potentially being put at risk by the combined impacts of cocktails of pesticides.

Threatening to exacerbate this situation is the imminent risk that the UK's pesticide regime could be weakened as a consequence of Brexit. Although there has been promising rhetoric of a "Green Brexit", there is undoubted pressure to weaken domestic standards and make trade deals with countries that have more lax approaches to pesticides. This could lead to a rise in the number of active ingredients authorised for use in the UK, as well as an increase in the level and variety of pesticides permitted to appear in UK food. Both of these outcomes would increase the exposure of the public and environment to unassessed and potentially dangerous pesticide cocktails.

Brexit also presents a range of opportunities to introduce new measures to drive a reduction in pesticide-related harms. Managing the risks and taking advantage of the opportunities presented by Brexit, to better protect human health and environment from pesticide cocktails, forms the focus of our recommendations to the UK Government.

1. Significantly reduce UK pesticide use

As outlined on page 27 of this report, no assessment model is sufficiently sophisticated to offer a guarantee of protection to human health and the environment from pesticide cocktails. The only realistic way to reduce the human health and environmental risks associated to pesticide cocktails, therefore, is to significantly decrease or phase out our overall pesticide use. As the UK leaves the EU regime, there are a number of measures which the UK Government should implement:

- Introduce a clear, quantitative target for significantly reducing the overall use of pesticides in agriculture with a focus on phasing out the pesticides which are most toxic to human health and environment.
- Introduce measures to support UK farmers to transition to whole farm agroecological systems that include genuine and holistic Integrated Pest Management (IPM). Most notably:
- Use future farmer payments under the Environmental Land Management Scheme (ELMS) to incentivise and reward farmers for transitioning to whole farm agroecological systems that incorporate genuine IPM, of which organic and agroforestry are well defined examples.
- Create a new, independent extension service for research, development and dissemination of IPM techniques.
- Facilitate farmer-to-farmer learning on agroecology and IPM, including opportunities for knowledge and information exchange between organic and nonorganic farmer.
- Introduce a pesticide tax or levy to drive significant reductions in pesticide use and fund research, development and innovation into IPM and agroecological systems.

- Increase support to the British organic sector to increase the area of land organically managed.

- Ensure that farmers have access to independent advice, breaking the link between the pesticide industry and the advice farmers receive on plant protection.

- Strengthen the UK National Action Plan with a particular focus on phasing out all non-agricultural uses of pesticides, and banning public authorities from spraying next to homes, schools and playgrounds.

2. Improve systems for monitoring the usage and impacts of pesticides

The UK's current monitoring systems for pesticides are woefully inadequate. In terms of both human health and the environment, the existing systems focus almost entirely on individual pesticides and therefore fail to take account of the cocktail effect. They also look at levels of usage rather than impact, resulting in a lack of clarity on the real world effects of pesticide use. The UK Government urgently needs to:

- Establish a robust environmental monitoring system for pesticide use which;
  - Takes account of the toxicity of the pesticides being used and their potential for harming the environment, including terrestrial and aquatic wildlife.
  - Assesses how toxicity, and combined toxic load, is impacting on the environment at a landscape-scale.
  - Includes monitoring for pesticide residues in both water and soil.
  - Looks specifically for post-approval impacts on bee and pollinator species.
  - Picks up issues around resistance and efficacy.

- Establish a robust human health monitoring system for pesticide related harms which includes;
  - A focus on those who routinely work with pesticides, including farmers, farmworkers and amenity operatives.
  - Establish a reporting system for others exposed to pesticides including the general public, farming families and rural residents.
  - Expand the government residue-testing scheme to cover a wider range of food and strengthen the capacity of the Expert Committee on Pesticide Residues in Food (PRiF).

- Conduct government-funded research into the effects of pesticide cocktails on the natural environment, wildlife and human health.

- Introduce total transparency for all monitoring results (including farmers' spray records) so that they are accessible to all stakeholders, including members of the public. End the current time lag and make monitoring data available in a timely manner, so that negative impacts can be identified and solutions found as soon as possible.

3. Ensure the UK pesticide regime is fit-for-purpose post-Brexit

Although far from perfect, the EU's pesticide regulatory regime is the strongest in the world in terms of protecting human health and the environment. The UK Government has committed to delivering a 'Green Brexit' including maintaining existing UK pesticide standards. In order to keep its promise, the Government should:

- At least in the short term, remain aligned with the EU pesticide regime including all decisions on active ingredient approvals and Maximum Residue Levels (MRLs), thereby ensuring that UK farmers are able to continue trading with EU Member

States and making sure that highly toxic active ingredients are not authorised for use while the UK is in the process of establishing its own, standalone system.

- Design and implement new UK systems, or strengthen existing systems, to carry out all functions pertaining to regulating pesticides previously performed by EU institutions in order to ensure that Brexit doesn't lead to a governance gap. In particular, before transitioning to a UK standalone system, the Government must ensure that the UK has a scientific body able to undertake the toxicological analysis currently carried out by Rapporteur Member States and by EFSA, and at least one body which is independent of industry or government influence and whose role it is to scrutinise the process through which active ingredients are authorised.

- Maintain the EU's hazard-based approach (rather than revert to a risk-based approach) to pesticide regulation in general, and active ingredient approvals in particular. This means that if an active substance is judged to be intrinsically dangerous then its use should be banned with no need for further assessment.

- Ensure that no weakening of UK pesticide regulations or standards occurs as a result of trade negotiations with non-EU countries and that in turn, food imports meet these same UK standards.

- Enshrine environmental principles, most notably the precautionary and polluter pays principles, into UK law.

- Use Brexit as an opportunity to create the world's most transparent regulatory system for pesticides, thereby breaking the undue influence of the pesticide industry and building public trust that decisions are the result of an unbiased process.

- Follow the EU's lead in moving towards making it mandatory that third-party scientific assessment is taken into account, both pre and post-approval of an active ingredient.

- Introduce strong penalties based on the 'polluter pays' principle and robust enforcement to ensure that contamination of the environment by pesticides is dealt with firmly and will act as a deterrent to misuse.

References

1 PAN UK. (March 2018). The Hidden Rise of UK Pesticide Use: Fact-checking an Industry Claim, https://issuu.com/pan-uk/docs/the_hidden_rise_of_uk_pesticide_use?e=28041656/59634015
2 Farmers Guardian. (31st January 2018). New poll finds public uneasy about pesticide use. https://www.fginsight.com/news/news/new-poll-finds-public-uneasy-about-pesticide-use-51422
3 Pesticide Usage Survey Statistics (PUS STATS) are hosted on the website of Fera Science Ltd (Fera) on behalf of the UK government's Department of Environment Food and Rural Affairs (DEFRA) and can be accessed at: https://secure.fera.defra.gov.uk/pusstats/
4 Area treated refers to the active substance treated area. This is the basic area treated by each active substance, multiplied by the number of times the area was treated e.g. A field of 3 ha is treated 4 times with active X. Therefore, the area treated is 12 ha (3x4).
5 Pesticide Usage Survey Statistics (PUS STATS).'Total Area Treated'. https://secure.fera.defra.gov.uk/pusstats/index.cfm
6 Pesticide Usage Survey Statistics (PUS STATS). 'Total Area Treated'. https://secure.fera.defra.gov.uk/pusstats/index.cfm
7 Pesticide Usage Survey Statistics (PUS STATS). 'Times Treated'. https://secure.fera.defra.gov.uk/pusstats/mytreatindex.cfm
8 Goulson, D., (2013). An overview of the environmental risks posed by neonicotinoid insecticides, Journal of Applied Ecology 2013, 1. https://www.sussex.ac.uk/webteam/gateway/file.php?name=goulson-2013-jae.pdf&site=411
9 DDT contact acute LD50 for honeybees is 0.54 micrograms, https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/204.htm. Deltamethrin contact acute LD50 for honeybees is 0.0015 micrograms, (360 times more toxic than for DDT) https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/205.htm. Therefore 1 microgram of deltamethrin has the same toxic effect as 360 micrograms of DDT.
10 Pesticide Usage Survey Statistics (PUS STATS), https://secure.fera.defra.gov.uk/pusstats/myindex.cfm
11 PAN UK. (March 2018). The Hidden Rise of UK Pesticide Use: Fact-checking an Industry Claim, 3-4, https://issuu.com/pan-uk/docs/the_hidden_rise_of_uk_pesticide_use?e=28041656/59634015
12 Sánchez-Bayo, F. & Wyckhuys, K., (April, 2019) Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation, Volume 232, 8-27, https://www.sciencedirect.com/science/article/pii/S0006320718313636
13 IPBES. 29 May 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/system/tdf/ipbes_7_10_add-1-_advance_0.pdf?file=1&type=node&id=35245
14 Powney, G. G., Carvell C., Edwards, M., Morris, R. K. A., Roy, H. E., Woodcock, B. A & Isaac, N. J. B. (2019). Widespread losses of pollinating insects in Britain. Nature Communications. 10(1018) https://www.nature.com/articles/s41467-019-08974-9
15 DEFRA. (July 2018). Species in the wider countryside: farmland, 1, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726447/5_Farmland_Species_2018.pdf
16 RSPB. (November 2016), State of Nature 2016, 16, https://www.rspb.org.uk/globalassets/downloads/documents/conservation-projects/state-of-nature/state-of-nature-uk-report-2016.pdf
17 Wilson, E., & Wembridge, D., People's Trust for Endangered Species (PTES) & the British Hedgehog Preservation Society (BHPS). (February 2018). The State of Britain's Hedgehogs 2018, 2-3, https://www.hedgehogstreet.org/wp-content/uploads/2018/02/SoBH-2018_final-1.pdf
18 Wembridge, D., People's Trust for Endangered Species (PTES) & the British Hedgehogs Preservation Society (BHPS). (2011). The state of Britain's hedgehogs 2011, 2, https://www.britishhedgehogs.org.uk/leaflets/sobh.pdf
19 Cohen, J., Mole, N., & Tyrell, K., Food Research Collaboration, Centre for Food Policy, City University. (November 2018). Brexit and pesticides: UK food and agriculture at a crossroads, https://foodresearch.org.uk/publications/brexit-pesticides-crossroads/
20 HM Government. (2018). A Green Future: Our 25 Year Plan to Improve the Environment, 40, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf
21 CropLife International. (April 2014). Integrated Pest Management, 4, https://croplife.org/wp-content/uploads/pdf_files/Integrated-pest-management.pdf
22 The Voluntary Initiative. (2018). Annual Report 2017-2018. 3. https://voluntaryinitiative.org.uk/media/2223/draft-annual-report-2018.pdf
23 Pesticide Usage Survey Statistics (PUS STATS). (2017-2018). 2016 surveys, https://secure.fera.defra.gov.uk/pusstats/surveys/2016surveys.cfm
24 Lundgren, P., Friends of the Earth. (November 2018). Cutting Pesticide Use & Promoting Integrated Pest Managemnt in UK Agriculture – A Farmer's Perspective, 1, https://cdn.friendsoftheearth.uk/sites/default/files/downloads/cutting-pesticide-use-farmers-perspective_1.pdf
25 Food and Agriculture Organization of the United Nations, Integrated Pest Management (webpage), http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/
26 Polling commissioned by PAN UK and SumOfUs and conducted by GQR Research. (September 2017). https://gqrr.app.box.com/s/0ddbifc853j9k1t1sbjvuc1crvxw8zbc
27 Swiss Broadcasting Corporation, SWI swissinfo.ch. (June 2019). Pesticide companies 'seriously deficient' on human rights, says UN toxics expert, https://www.swissinfo.ch/eng/health-and-environment_un-expert-urges-phase-out-of-hazardous-pesticides/45040316
28 Expert Committee on Pesticide Residues in Food (PRiF), Pesticide residues in food: results of monitoring programme. https://www.gov.uk/government/collections/pesticide-residues-in-food-results-of-monitoring-programme
29 Expert Committee on Pesticide Residues in Food (PRiF). (2018). Annual Report 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf
30 Expert Committee on Pesticide Residues in Food (PRiF). (2019). Annual Report 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf
31 Expert Committee on Pesticide Residues in Food (PRiF). (2018). Annual Report 2017. 5. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf
32 Expert Committee on Pesticide Residues in Food (PRiF). (2019). Annual Report 2018. 5. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf

33 Expert Committee on Pesticide Residues in Food (PRiF). (2018). Annual Report 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf
34 Expert Committee on Pesticide Residues in Food (PRiF). (2019). Annual Report 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf
35 Expert Committee on Pesticide Residues in Food (PRiF). (2018). Annual Report 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf
36 Active ingredients listed in 2017 Annual Report of Expert Committee on Pesticide Residues in Food (PRiF) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf. Active ingredients then cross-checked with following databases in order to establish associated health issues: University of Hertfordshire, Pesticide Properties DataBase (PPDB), https://sitem.herts.ac.uk/aeru/ppdb/en/index.htm; PAN North America (PANNA), PAN Pesticide Database, http://www.pesticideinfo.org/.
37 Expert Committee on Pesticide Residues in Food (PRiF). (2019). Annual Report 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf
38 Active ingredients listed in 2018 Annual Report of Expert Committee on Pesticide Residues in Food (PRiF) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf. Active ingredients then cross-checked with following databases in order to establish associated health issues: University of Hertfordshire, Pesticide Properties DataBase (PPDB), https://sitem.herts.ac.uk/aeru/ppdb/en/index.htm; PAN North America (PANNA), PAN Pesticide Database, http://www.pesticideinfo.org/.
39 David, A., Botias, C., Abdul-Sada, A., Nicholls, E., Rotheray, E. L., Hill, M. E. & Goulson, D. (2016). Widespread contamination of wildflower and bee-collected pollen with complex mixtures of neonicotinoids and fungicides commonly applied to crops. Environmental International,. 88, 169-178. https://www.sciencedirect.com/science/article/pii/S0160412015301161
40 Peterson, E.M., Wooten, K.J., Subbiah, S., Anderson, T.A., Longing, S. & Smith, P.N. (2017). Agrochemical Mixtures Detected on Wildflowers near Cattle Feed Yards. Environmental Science & Technology Letters, 4:(6) 216-220. https://pubs.acs.org/doi/10.1021/acs.estlett.7b00123
41 Lentola, A., David, A., Abdul-Sada, A., Tapparo, A., Goulson, D. and Hill, E.M. (2017). Ornamental plants on sale to the public are a significant source of pesticide residues with implications for the health of pollinating insects. Environmental Pollution, 228, 297-304. https://www.sciencedirect.com/science/article/pii/S0269749117305158
42 C. Botías, A. David, E.M. Hill, D. Goulson, (2017). Quantifying exposure of wild bumblebees to mixtures of agrochemicals in agricultural and urban landscapes. Environ. Pollut., 222, 73-82. https://doi.org/10.1016/j.envpol.2017.01.001
43 Tosi, S., Costa, C., Vesco, U., Quaglia, G. & Guido, G. (2018). A 3-year survey of Italian honey bee-collected pollen reveals widespread contamination by agricultural pesticides. Sci. Total Environ. 615, 208–218
44 Lambert O, Piroux M, Puyo S, Thorin C, L'Hostis M, Wiest L, et al. (2013). Widespread Occurrence of Chemical Residues in Beehive Matrices from Apiaries Located in Different Landscapes of Western France. PLOS ONE 8(6): e67007. https://doi.org/10.1371/journal.pone.0067007
45 Simon-Delson, N., Martin, G. S., Bruneau, E., Minsart, L., Mouret, C and Hautier, L. (2014). Honeybee Colony Disorder in crop Areas: The Role of Pesticides and Viruses. PLOS ONE, https://doi.org/10.1371/journal.pone.0103073
46 Kiljanek T, Niewiadowska A, Gaweł M, Semeniuk S, Borzęcka M, Posyniak A & Pohorecka K. (2017), Multiple pesticide residues in live and poisoned honeybees - Preliminary exposure assessment. Chemosphere. 175:36-44. doi: 10.1016/j.chemosphere.2017.02.028. https://www.ncbi.nlm.nih.gov/pubmed/28211333
47 Ostiguy, N.; Drummond, F.A.; Aronstein, K.; Eitzer, B.; Ellis, J.D.; Spivak, M.; Shepherd, W.S. (2019) Honey bee exposure to pesticides: A four-year nationwide study. Insects, 10, 13. https://www.mdpi.com/2075-4450/10/1/13
48 Pettis JS, Lichtenberg EM, Andree M, Stitzinger J & Rose R, vanEngelsdorp D. (2013). Crop Pollination Exposes Honey Bees to Pesticides Which Alters Their Susceptibility to the Gut Pathogen Nosema ceranae. PLoS ONE 8(7). e70182. https://doi.org/10.1371/journal.pone.0070182
49 Hladik ML, Vandever M, Smalling KL (2016) Exposure of native bees foraging in an agricultural landscape to current-use pesticides. Sci Total Environ. 542:469–477 https://www.ncbi.nlm.nih.gov/pubmed/26520270
50 Sanchez-Bayo, F. and Goka, K. (2014). Pesticide residues and Bees – A Risk Assessment. PLOS ONE, 9(4), e94482. https://doi.org/10.1371/journal.pone.0094482
51 Bro, E., Milliot., F., Decors, A.and Devillers, J. (2015), Quantification of potential exposure of gray partridge (Perdix perdix) to pesticide active substances in farmlands. Science of The Total Environment, (521–522), 315-325 https://www.sciencedirect.com/science/article/pii/S0048969715003484
52 Bro, E., Devilliers, J., Millot, F. and Decors, A. (2016). Residues of plant protection products in grey partridge eggs in French cereal ecosystems. Environmental Science and Pollution research, 23(10), 9559-9573 https://link.springer.com/article/10.1007/s11356-016-6093-7
53 Daniele, G., Lafay, F., Pelosi, C., Fritsch, C. and Vulliet, E. (2018). Development of a method for the simultaneous determination of multi-class pesticides in earthworms by liquid chromatography coupled to tandem electrospray mass spectrometry. Analytical and Bioanalytical Chemistry, 410:5009–5018 https://doi.org/10.1007/s00216-018-1151-2
54 Silva, V., Mol, H., Zomer, P., Tienstra, M., Ritsema, C. and Geissen, V. (2019). Pesticide residues in European agricultural soils – A hidden reality unfolded. Science of the Total Environment 653: 1532–1545. https://doi.org/10.1016/j.scitotenv.2018.10.441
55 WECF International, Provincie Gelderland & BUIJS Agro-Services. (2019). An examination of possible relationships between the reduction of meadow birds and the presence of pesticides on livestock farmers in Gelderland (The Netherlands). Summary only in English. http://www.wecf.eu/download/2019/onderzoeksrapport_JB_10_051.pdf
56 Baas J., vijver, M., Rambohul, J., van 't Zelfde, M., Svendsen, C. and Surgeon, D. (2016). Comparison and evaluation of pesticide monitoring programs using a process-based mixture model. Environ. Toxicol. Chem., 35(12), 3113-3123. https://www.ncbi.nlm.nih.gov/pubmed/27183059
57 Miller, T. H., Tiong Ng, K., Bury, S. T., Bury, S. E., Bury, N., R., & Barron, L. P. (2019). Biomonitoring of pesticides, pharmaceuticals and illicit drugs in a freshwater invertebrate to estimate toxic or effect pressure. Environment International, 129, 595-606. https://doi.org/10.1016/j.envint.2019.04.038
58 Casado, J., Brigden, K., Santillo, D. and Johnston, P. (2019). Screening of pesticides and veterinary drugs in small streams in the European Union by liquid chromatography high resolution mass spectrometry. Science of the Total Environment, 670, 1204-1225
https://doi.org/10.1016/j.scitotenv.2019.03.207

59 Stehle, A. & Schulz, R. Pesticide authorization in the EU—environment unprotected? Envrion. Sci. Pollut. Res. https://link.springer.com/article/10.1007/s11356-015-5148-5
60 Rizzati, V., Briand, O., Guillou, H., Gamet Payrastre, L. (2016). Effects of pesticide mixtures in human and animal models: an update of the recent literature. Chemico Biological Interactions, 254, 231-246. DOI : 10.1016/j.cbi.2016.06.003. https://www.ncbi.nlm.nih.gov/pubmed/27312199
61 Hernández, A.F., Parrón, T., Tsatsakis, A.M., Requena, M.E., Alarcón, R.I., & López-Guarnido, O. (2013). Toxic effects of pesticide mixtures at a molecular level: their relevance to human health. Toxicology, 307, 136-45.
62 Silins, I., & Högberg, J. (2011). Combined toxic exposures and human health: biomarkers of exposure and effect. International journal of environmental research and public health, 8(3), 629 647. https://doi.org/10.3390/ijerph8030629
63 Payne, J., Scholze, M., & Kortenkamp, A. (2001). Mixtures of Four Organochlorines Enhance Human Breast Cancer Cell Proliferation. Environmental Health Perspectives, 109(4), 391-397. doi:10.2307/3454899
64 Seeger B, Klawonn F, Nguema Bekale B, Steinberg P (2016) Mixture Effects of Estrogenic Pesticides at the Human Estrogen Receptor α and β. PLoS ONE 11(1): e0147490. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0147490
65 Rivero J., Henríquez-Hernández L.A., Luzardo O.P., Pestano J., Zumbado M., Boada L.D., Valerón P.F. (2016). Differential gene expression pattern in human mammary epithelial cells induced by realistic organochlorine mixtures described in healthy women and in women diagnosed with breast cancer. Toxicology Letters. 246. 10.1016/j.toxlet.2016.02.003. https://www.ncbi.nlm.nih.gov/pubmed/26853153
66 Dongjun, Fu & Li, Ping & Song, Jian & Zhang, Saiyang & Xie, Han-Zhong. (2018). Mechanisms of synergistic neurotoxicity induced by two high risk pesticide residues – Chlorpyrifos and Carbofuran via oxidative stress. Toxicology in Vitro. 54. 10.1016/j.tiv.2018.10.016. https://www.ncbi.nlm.nih.gov/pubmed/30385350
67 Graillot, V., Takakura, N., Hegarat, L.L., Fessard, V., Audebert, M., Cravedi, JP. (2012) Genotoxicity of pesticide mixtures present in the diet of the French population. Environ Mol Mutagen. Apr;53(3):173-84. doi: 10.1002/em.21676. https://onlinelibrary.wiley.com/doi/abs/10.1002/em.21676
68 Docea, A.O., Gofiţă, E., Goumenou, M., Calina, D., Rogoveanu, O.C., Varut, M., Olaru, C., Kerasioti, E., Fountoucidou, P., Taitzoglou, I.A., Zlatian, O.M., Rakitskii, V.N., Hernandez, A.F., Kouretas, D., & Tsatsakis, A.M. (2018). Six months exposure to a real life mixture of 13 chemicals' below individual NOAELs induced non monotonic sex-dependent biochemical and redox status changes in rats. Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association, 115, 470-481 .
69 Lukowicz, C., Ellero - Simatos, S., Regnier, M., Polizzi, A., Lasserre, F., Montagner, A., Lippi, Y., Jamin, E., Martin, J.-F., Naylies, C., Canlet, C., Debrauwer, L., Bertrand-Michel, J., Al Saati, T., Théodorou, V., Loiseau, N., Lakhal, L., Guillou, H., Payrastre, L. (2018). Metabolic effects of a chronic dietary exposure to a low-dose oesticide cocktail in mice: Sexual dimorphism and role of the constitutive androstane receptor. Environmental Health Perspectives, 126 (6), 18 p. , DOI : 10.1289/EHP2877. https://ehp.niehs.nih.gov/doi/full/10.1289/EHP2877
70 Hass, U., Christiansen, S., Petersen, M. A., Scholze, M., & Boberg, J. (2017). Combined exposure to low doses of pesticides causes decreased birth weights in rats. Reproductive Toxicology, 72, 97-105. https://doi.org/10.1016/j.reprotox.2017.05.004
71 Pandey S.P., Mohanty B. (2017) Disruption of the hypothalamic-pituitary-thyroid axis on co-exposures to dithiocarbamate and neonicotinoid pesticides: Study in a wildlife bird, Amandava amandava. Neurotoxicology. May;60:16-22. doi: 10.1016/j.neuro.2017.02.010. https://www.ncbi.nlm.nih.gov/pubmed/28237669
72 Tosi S., Nieh J.C. (2019) Lethal and sublethal synergistic effects of a new systemic pesticide, flupyradifurone (SivantoÒ), on honeybees. Proc. R. Soc. B 286: 20190433. http://dx.doi.org/10.1098/rspb.2019.0433
73 Yang G., Chen C., Wang Y., Peng Q., Zhao H., Guo D., Wang Q., Qian Y. (2017) Mixture toxicity of four commonly used pesticides at different effect levels to the epigeic earthworm, Eisenia fetida. Ecotoxicol Environ Saf. Aug;142:29-39. doi: 10.1016/j.ecoenv.2017.03.037. https://www.ncbi.nlm.nih.gov/pubmed/28384501
74 Gandar, A., Laffaille, Marty Gasset, N., Viala, D., Molette, C., Jean (2017). Proteome response of fish under multiple stress exposure: Effects of pesticide mixtures and temperature increase. Aquatic Toxicology, 184, 61-77. , DOI : 10.1016/j.aquatox.2017.01.004. https://www.ncbi.nlm.nih.gov/pubmed/28109940
75 Laetz, C.A., Baldwin, D.H., Collier, T.K., Hebert, V.R., Stark, J.D., & Scholz, N.L. (2009). The Synergistic Toxicity of Pesticide Mixtures: Implications for Risk Assessment and the Conservation of Endangered Pacific Salmon. Environmental health perspectives. https://www.ncbi.nlm.nih.gov/pubmed/19337507
76 Banke Nørgaard, Katrine & Cedergreen, Nina. (2010). Pesticide Cocktails Can Interact Synergistically on Aquatic Crustaceans. Environmental science and pollution research international. 17. 957-67. 10.1007/s11356-009-0284-4. https://www.ncbi.nlm.nih.gov/pubmed/20077025
77 Moore, M.N., Wedderburn, R.J., Clarke, K.R., McFadzen, I.R., Lowe, D.M., & Readman, J.W. (2018). Emergent synergistic lysosomal toxicity of chemical mixtures in molluscan blood cells (hemocytes). Environmental pollution, 235, 1006-1014. https://www.ncbi.nlm.nih.gov/pubmed/29751396
78 Goulson, D., Thompson, J. & Croombs, A. (2018) 'Rapid rise in the toxic load for bees revealed by analysis of pesticide use in Great Bitain', PeerJ 6:e5255 https://doi.org/10.7717/peerj.5255
79 Changes in number of treatments between most recent and historic FERA Pesticide Usage Survey Reports https://secure.fera.defra.gov.uk/pusstats/surveys/
80 Expert Committee on Pesticide Residues in Food (PRiF). (2018). Annual Report 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726926/expert-committee-pesticide-residues-food-annual-report-2017.pdf
81 Expert Committee on Pesticide Residues in Food (PRiF). (2019). Annual Report 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824814/expert-committee-pesticide-residues-food-annual-report-2018.pdf
82 Regulation (EC) No 396/2005 of the European Parliament and of the Council on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC. (23rd February 2005). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32005R0396&from=EN
83 Expert Committee on Pesticide Residues in Food (PRiF). https://www.gov.uk/government/groups/expert-committee-on-pesticide-residues-in-food-prif#results-of-monitoring-programme
84 Expert Committee on Pesticide Residues in Food (PRiF). Pesticide residues in food: results of monitoring programme. https://www.gov.uk/government/collections/pesticide-residues-in-food-results-of-monitoring-programme
85 European Commission website. Maximum Residue Levels. https://ec.europa.eu/food/plant/pesticides/max_residue_levels_en

86 UK Health and Safety Executive (HSE) website. EU Maximum Residue Levels Basic Guidance. http://www.hse.gov.uk/pesticides/topics/reducing-environmental-impact/maximum-residue-levels/mrls-basic-guidance.htm; European Commission website. EU legislation on MRLs. https://ec.europa.eu/food/plant/pesticides/max_residue_levels/eu_rules_en
87 Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment. (2002). Risk Assessment of Mixtures of Pesticides and Similar Substances. https://cot.food.gov.uk/sites/default/files/cot/reportindexed.pdf
88 European Commission. Cumulative Risk Assessment - State of play on the assessment of risks caused by the presence of multiple pesticide residues in food. https://ec.europa.eu/food/plant/pesticides/max_residue_levels/cumulative_risk_en
89 Milner, A., & Boyd, I., (September 2017). Science, Vol. 357, Issue 6357, pp. 1232-1234. Toward Pesticidovigilance - Can lessons from pharmaceutical monitoring help to improve pesticide regulation?. https://science.sciencemag.org/content/357/6357/1232
90 Sánchez-Bayo, F. & Wyckhuys, K., (April 2019). Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation, Volume 232, 8-27, https://www.sciencedirect.com/science/article/pii/S0006320718313636
91 Heinz - R. Köhler & Rita Triebskorn. (2013) Wildlife Ecotoxicology of Pesticides: Can We Track Effects to the Population Level and Beyond? Science 341, 759-765. https://pdfs.semanticscholar.org/d820/bf824c009336c6956ab6a47d31fe73a2b26d.pdf
92 Centre for Ecology and Hydrology. CEH Land Cover®plus Fertilisers and CEH Land Cover® plus Pesticides. https://www.ceh.ac.uk/services/ceh-land-cover-plus-products-fertilisers-pesticides
93 Milner, A., & Boyd, I., (September 2017). Science, Vol. 357, Issue 6357, pp. 1232-1234. Toward Pesticidovigilance - Can lessons from pharmaceutical monitoring help to improve pesticide regulation?. https://science.sciencemag.org/content/357/6357/1232
94 Euro Mix Project website. A tiered strategy for assessment of mixtures of various chemicals. https://www.euromixproject.eu/
95 European Commission, EU Science Hub. Assessment of Mixtures - Review of Regulatory Requirements and Guidance. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-mixtures-review-regulatory-requirements-and-guidance
96 OECD (2018), Considerations for Assessing the Risks of Combined Exposure to Multiple Chemicals, Series on Testing and Assessment No. 296, Environment, Health and Safety Division, Environment Directorate. http://www.oecd.org/chemicalsafety/risk-assessment/considerations-for-assessing-the-risks-of-combined-exposure-to-multiple-chemicals.pdf
97 Kienzler, A., Bopp, S.K., Linden, S.C., Berggren, E., & Worth, A.P. (2016). Regulatory assessment of chemical mixtures: Requirements, current approaches and future perspectives. Regulatory toxicology and pharmacology: RTP, 80, 321-34. https://www.sciencedirect.com/science/article/pii/S0273230016301337
98 European Commission. (2018). Something from nothing? Ensuring the safety of chemical mixtures. https://ec.europa.eu/jrc/en/publication/something-nothing-ensuring-safety-chemical-mixtures
99 Stephanie K. Bopp, Aude Kienzler, Andrea-Nicole Richarz, Sander C. van der Linden, Alicia Paini, Nikolaos Parissis & Andrew P. Worth (2019): Regulatory assessment and risk management of chemical mixtures: challenges and ways forward, Critical Reviews in Toxicology, https://www.tandfonline.com/doi/full/10.1080/10408444.2019.1579169
100 European Commission. (2015). Scientific methodologies for the assessment of combined effects of chemicals - a survey and literature review. https://ec.europa.eu/jrc/en/publication/scientific-methodologies-assessment-combined-effects-chemicals-survey-and-literature-review
101 Euro Mix Project. A tiered strategy for assessment of mixtures of various chemicals. https://www.euromixproject.eu/
102 European Commission Funded Research Project. EDC-MixRisk. https://edcmixrisk.ki.se/aboutedcmixrisk/
103 ADAS. (October 2018). First cases of evolving glyphosate resistance in UK sterile brome https://www.adas.uk/News/first-cases-of-evolving-glyphosate-resistance-in-uk-sterile-brome

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