Prevention of suicide with regulations aimed at restricting access to highly hazardous pesticides: a systematic review of the international evidence

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Summary

Background Pesticide self-poisoning accounts for 14–20% of suicides worldwide. Regulation aimed at restricting access to pesticides or banning highly hazardous pesticides is one approach to reducing these deaths. We systematically reviewed the evidence of the effectiveness of pesticide regulation in reducing the incidence of pesticide suicides and overall suicides.

Methods We did a systematic review of the international evidence. We searched MEDLINE, PsycINFO, and Embase for studies published between Jan 1, 1960, and Dec 31, 2016, which investigated the effect of national or regional bans, and sales or import restrictions, on the availability of one or more pesticides and the incidence of suicide in different countries. We excluded other interventions aimed at limiting community access to pesticides. We extracted data from studies presenting pesticide suicide data and overall suicide data from before and after national sales restrictions. Two reviewers independently assessed papers for inclusion, extracted data, and assessed risk of bias. We undertook a narrative synthesis of the data in each report, and where data were available for the years before and after a ban, we pooled data for the 3 years before and the 3 years after to obtain a crude estimate of the effect of the ban. This study is registered through PROSPERO, number CRD42017053329.

Findings We identified 27 studies undertaken in 16 countries—five low-income or middle-income countries (Bangladesh, Colombia, India, Jordan and Sri Lanka), and 11 high-income countries (Denmark, Finland, Germany, Greece, Hungary, Ireland, Japan, South Korea, Taiwan, UK, and USA). Assessments largely focused on national bans of specific pesticides (12 studies of bans in six countries—Jordan, Sri Lanka, Bangladesh, Greece [Crete], South Korea, and Taiwan) or sales restrictions (eight studies of restrictions in five countries— India, Denmark, Ireland, the UK and the USA). Only five studies used optimum analytical methods. National bans on commonly ingested pesticides in five of the six countries studied, including four studies using optimum analytical methods, were followed by reductions in pesticide suicides and, in three of these countries, falls in overall suicide mortality. Greece was the only country studied that did not show a decrease in pesticide suicide following a ban. There were no high-quality studies of restricting sales to people for occupational uses; four of the seven studies (in three of the five countries studied—India, Denmark, and the USA) showed sales restrictions were followed by decreases in pesticide suicides; one of the two studies investigating trends in overall suicide mortality reported a fall in deaths in Denmark, but there were also decreases in suicide deaths from other methods.

Interpretation National bans on highly hazardous pesticides, which are commonly ingested in acts of self-poisoning, seem to be effective in reducing pesticide-specific and overall suicide rates. Evidence is less consistent for sales restrictions. A worldwide ban on the use of highly hazardous pesticides is likely to prevent tens of thousands of deaths every year.

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Introduction

Pesticide self-poisoning accounts for 110 000 to 168 000 deaths globally every year, and up to 20% of global suicides.[1] Many of these deaths occur among people living in rural areas of low-income and middle-income countries (LMIC) who ingest pesticides impulsively in a moment of crisis.[2–4] There is strong evidence that restricting access to frequently used, high-lethality methods is an effective suicide-prevention strategy.[5,6] Several factors contribute to the success of methods restriction. First, if a means of suicide is not immediately accessible at the moment of suicidal crisis, suicidal feelings might subside before alternative means can be accessed. Second, people deterred from using one method of suicide might instead use a less lethal alternative, thereby increasing the chances of survival. Less than 10% of people who survive a suicide attempt go on to take their lives at a later date.[7] Third, if a method is less frequently used, it might be less likely to be reported in the media, thereby reducing the cognitive availability of the method.[8]

Research in context

Evidence before this study

Self-poisoning with pesticides is one of the leading methods of suicide worldwide, accounting for 14–20% of all deaths by suicide annually (110 000–168 000 fatalities). Regulation aimed at restricting access to highly hazardous pesticides is one approach suggested by WHO to reduce these deaths. To identify whether any systematic reviews had assessed the evidence concerning the effectiveness of pesticide regulations, we searched MEDLINE for reports published between January, 1960, and December, 2016, using the search terms pesticide? or insecticide? or rodenticide? or fungicide? or herbicide? or paraquat or organophosphate? Or organophosphorus.af or agricultural.af or agrochemical?).af and (suicid??.af or (self and harm).af or parasuicide. af or (Self-Injurious and Behavior).af or ([self?.af or deliberate.af and poison???.af)). We also searched our personal collections of relevant papers. We identified papers assessing the effect of bans in single countries as well as opinion pieces and commentaries, but no systematic reviews.
Our subsequent (more detailed) searches for empirical data confirmed that no previous systematic reviews had been done.

Added value of this study

Ours is the first systematic review of evidence concerning the effect of regulatory action to restrict access to pesticides on pesticide and all-cause suicide mortality. We identified assessments of regulatory activity in 16 countries. National bans on commonly ingested pesticides in five of the six countries where these were studied were followed by reductions in pesticide suicides and, in three of the countries, reductions in overall suicide mortality. There were no high-quality studies of restricting sales to people for occupational uses; four of the seven studies (three of the five countries) showed sales restrictions were followed by reductions in pesticide suicides; one of the two studies investigating trends in overall suicide mortality reported a fall in deaths, but there were also decreases in suicide deaths from other methods.

Implications of all the available evidence

A worldwide ban on the use of highly hazardous pesticides is likely to prevent tens of thousands of deaths every year. More research is required concerning the effectiveness of sales restrictions and other approaches for restricting access to pesticides. The effect of regulations on crop yields and other aspects of health requires further study.

Agricultural pesticides—defined in this review as insecticides, herbicides, fungicides, and rodenticides—are readily available in rural areas of LMIC because a high proportion of their population are engaged in farming. Pesticides are used as a means of increasing crop yield and are heavily marketed by agricultural companies. By contrast, in high-income countries (HIC), a much smaller proportion of the population is involved in agriculture, so agricultural-strength pesticides are less accessible.

Unlike the substances commonly ingested in suicide attempts in HIC such as analgesics, tranquilisers, and antidepressants,[2] pesticides are highly toxic even when ingested in small amounts (eg, one mouthful or 20 mL of 20% paraquat). The case fatality of poisoning by paraquat (a herbicide) and aluminium phosphide (a fumigant) is often in excess of 60%,[9,10] similar to that for other high-lethality suicide methods such as firearms and hanging.[11]

In recent years, considerable attention has been given to the method-restriction strategy of providing farmers or villages with lockable boxes or stores for the safekeeping of pesticides.[12] This approach seems to be favoured by the pesticide industry, which has sponsored work in this area by the International Association of Suicide Prevention and WHO, as well as funding pilot studies.[12,13] Adoption of this approach implies that farmers need to take the responsibility for inadequate storage of their pesticides, rather than the manufacturer or regulatory authorities needing to increase their safety.[14] To date, there is no robust evidence indicating effectiveness of this approach in reducing pesticide poisonings or suicides. Furthermore, a large-cluster randomised trial by Melissa Pearson and colleagues[15] published in *The Lancet* involving 223 000 people in the North-Central Province of Sri Lanka did not show any effectiveness of improved household pesticide storage.

Prevention strategies involving sales restrictions or outright bans on specific pesticides have not received widespread attention. Such restrictions have, however, been favoured by the suicide-prevention community for medicines commonly ingested in fatal overdoses such as paracetamol and co-proxamol.[16,17] Suggested strategies for restricting pesticides include the adoption of a minimum-pesticides list of low-toxicity products[18] and outright bans of more toxic products such as the European Union's (EU) 2007 ban of paraquat.[19] To inform national and international policy formulation concerning pesticide regulations, we have systematically reviewed the literature on targeted pesticide sales restrictions. We aimed to address two linked questions: first, do pesticide bans, sales restrictions, or regulations lead to fewer suicides by pesticide ingestion? And second, do reductions in suicides from pesticide poisoning following sale bans or restrictions lead to reductions in the overall incidence of suicide?

Methods

Search strategy and selection criteria

We did a systematic review of international evidence. We searched MEDLINE, PsycINFO, and Embase databases for

English-language reports and abstracts published between Jan 1, 1960, and Dec 31, 2016, documenting the effects of pesticide sales or import regulations, or both, on the incidence of suicide by pesticide poisoning. We also reviewed all papers identified from our two previous systematic reviews of studies investigating the country-specific incidence of pesticide self-poisoning for relevant articles.[1,20] We searched the reference lists of eligible papers and carried out citation searches of key publications using Google Scholar to identify additional articles. We identified additional relevant papers from our personal collections. Papers in English or with English language abstracts were eligible to be included. For our searches of the databases, we used the following search terms coded in all fields (af): (Pesticide? or insecticide? or rodenticide? or fungicide? or herbicide? or paraquat or organophosphate? or organophosphorus.af or agricultural.af or agrochemical?). af and (suicid??.af or (self and harm).af or parasuicide. af or (Self-Injurious and Behavior).af or ([self?.af or deliberate. af) and poison???.af]). We extracted data from studies presenting pesticide suicide and overall suicide data before and after national sales restrictions. Where no data were presented on trends in overall suicides, we used the databases to identify publications giving suicide trend data. Where data were only presented graphically, we estimated incidence from the graphs.

The interventions we investigated were national or small-area bans, and sales or import restrictions on the availability of one or more specific pesticides. We included required or regulated changes in the concentration of particular products (eg, the requirement in Japan to market 5% paraquat from 1986 onwards),[21] and regulations such as those limiting sales to authorised users only.[22] We excluded other interventions aimed at limiting community access to pesticides—eg, lockable boxes or village pesticide stores; manufacturer initiatives to make the product safer—eg, the inclusion of emetics; and training initiatives for pesticide vendors.

We included natural experimental and controlled intervention designs (randomised and non-randomised) reporting data on overall incidence of suicide and suicides by pesticide self-poisoning either before and after the introduction of bans or sales restrictions or in intervention (pesticide ban/restriction) versus control areas (in this context, control areas are geographical districts within the same country where the regulations were not applied). We excluded reviews (except as a potential source of relevant papers). We included studies regardless of whether they presented a statistical comparison of trends before and after pesticide regulations.

Our focus was on studies of general population samples—either whole countries or districts within countries. Studies of selected population groups—eg, hospital admissions and specific sex or age groups (eg, young people) were excluded because our intention was to identify the effect of regulations on overall national or district-level suicide rates. DG and DK screened the titles and abstracts and read full-text reports of all potentially relevant articles independently and in duplicate. They discussed discordant decisions until consensus was reached. DG and DK also extracted data and assessed risk of bias in duplicate; again, they discussed discordances and resolved uncertainties regarding eligibility through discussion with co-authors and email contacts with study authors. To investigate bias, we used a modified version of the risk of bias criteria for interrupted time series studies suggested by the Cochrane Effective Practice and Organisation of Care.[23] Rather than excluding studies that ignored secular trends in the preintervention period as recommended in these guidelines, we included all studies but added this as a separate item on the risk of bias scale as follows: "Did the study ignore secular (trend) changes and perform a simple *t*-test of the pre-intervention period versus the post-intervention period without further justification?" The other measures of potential for bias were whether the intervention was independent of other changes, whether the shape of the intervention was prespecified, whether the intervention was likely to affect data collection, whether knowledge of the allocated interventions was adequately prevented, whether incomplete data were adequately assessed, whether the study was free from selective reporting, and whether the study was free from other risks of bias. We classified studies as being at high, low, or unclear risk in these domains (appendix p 1).

See Online for appendix

Data analysis

Because of the range of different interventions, settings, and differences in the incidence of suicide by pesticide poisoning and the contribution of pesticide self-poisoning to overall suicide rates in different countries, we undertook a narrative synthesis of the data presented in each paper. We presented results separately for bans versus other regulations, and also separately for LMIC and HIC because the proportion of suicide deaths due to pesticide poisoning is generally higher in LMIC and therefore interventions in such countries might be more likely to have an effect on overall suicide rates.

Where several papers assessed the effect of the same set of regulations in one country, we focused on the paper with the most detailed assessment of effect but included relevant data from other papers investigating the same issue in that country. Where data about suicide rates or suicide numbers are presented for the years before and after a ban, we pooled data for the 3 years before the regulation and the 3 years after to obtain a crude estimate of the ban effect, but noted where there was evidence that decreases in rates were simply part of a pre-existing downward trend.

Where the month and year of the regulation was recorded, we assumed when summarising data that for regulations introduced before July of any year, the year of the intervention was a post-regulation year because the

	Secular trends accounted for in analysis?*	Intervention independent of other changes?	Shape of the intervention prespecified?†	Likelihood of intervention affecting data collection?	Was knowledge of the allocated interventions adequately prevented?	Incomplete data adequately assessed?	Study free from selective reporting?	Study free from other risks of bias?
Al-Ragheb[48]	No formal comparison	Unclear	Low	Low	Low	Low	Low	Low
Gunnell[26]	Graphical analysis	Low	Low	Low	Low	Low	Low	Unclear
De Silva[28]	Graphical analysis	High	Low	Low	Low	Low	Low	Unclear
Knipe (2014)[27]	Graphical analysis	Low	Low	Low	Low	Low	Low	Unclear
Knipe (2017)[40]	Low	Low	Low	Low	Low	Low	Low	Low
Knipe (2017)[46]	Low	High	Low	Low	Low	Low	Low	Unclear
Chowdhury[44]	Low	Low	Low	Low	Low	Low	Low	Low
Kastanaki[24]	No formal comparison	Unclear	Low	Low	Low	Low	Low	Low
Myung[33]	High	Low	Low	Low	Low	Low	Low	Low
Cha[34]	Low	Low	Low	Low	Low	Low	Low	Low
Chang[35]	Graphical analysis	Unclear	Unclear	Low	Low	Low	Low	Low
Lin[42]	No formal comparison	High	Unclear	Low	Low	Low	Low	Low
Chaparro-Narvaez[45]	Low	Unclear	Unclear	Low	Low	Low	Low	Low
Berecz[29,43]	No formal comparison	Unclear	Unclear	Low	Low	Low	Low	Low
Nandi[38]	High	Unclear	Low	Low	Low	Low	Low	Low
Frost[30]	Graphical analysis	High	Unclear	Low	Low	Low	Low	Low
Casey[47]	Graphical analysis	Unclear	Low	Low	Low	Low	Low	Low
Onyon[41]	Graphical analysis	Unclear	Low	Low	Low	Low	Low	Low
Ohberg[25]	No formal comparison	Unclear	Low	Low	Low	Low	Low	Low
Moebus[31]	No formal comparison	Unclear	Unclear	Low	Low	Low	Low	Low
Fitzgerald[22]	No formal comparison	Unclear	Low	Low	Unclear	Unclear	Low	Low
Ito[21]	Graphical analysis	Unclear	Low	Low	Low	Low	Low	Low
Nagami[32]	Graphical analysis	Unclear	Low	Low	Low	Low	Low	Low
Copeland[39]	No formal comparison	Unclear	Unclear	Low	High	Low	Low	Low
Langley[36]	Graphical analysis	Unclear	Low	Low	Low	Low	Low	Low
Sudakin[37]	High	Unclear	Low	Low	Low	High	Low	Low

*Where graphical approaches were used to assess trends, or graphs provided reassurance that the incidence of suicide was not decreasing before the regulations, we identified these as graphical analyses. If there was no formal comparison of the incidence of suicide before and after regulations—eg, the paper presented numbers of suicides per year, but no statistical testing was undertaken—we rated this as no formal comparison. †Where a graphical assessment was used and the date of the regulation was specified—coded as low; where multiple interventions occurred over a short period (<5 years) or the date of the intervention was not specified—coded as unclear. For information on the Cochrane Effective Practice and Organisation of Care assessment, see appendix (p 1).

Table 1: **Risk of bias assessments for the reviewed studies**

regulation was in place for at least half the year. Where the regulation came into effect from July onwards of any year, we included that year as a pre-regulation year. Where no month was recorded we excluded the year of the intervention from our assessment of pre-regulation and post-regulation suicides. In two papers, data about pesticide suicides and overall suicide rates by year for at least 3 years before and after any regulation were presented.[24,25] We used negative binomial regression to quantify changes in the number of pesticide suicides and overall suicides reported in these papers—this method takes account of pre-intervention trends in incidence. We used Stata v.14 for all analyses. This review is reported according to the PRISMA guidelines for systematic reviews and is registered through PROSPERO (protocol number CRD42017053329).

Role of the funding source

There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

We identified 27 relevant studies[21,22,24–48] describing the effect of pesticide regulations in five LMIC (Bangladesh, Colombia, India, Jordan and Sri Lanka) and 11 HIC (Denmark, Finland, Germany, Greece, Hungary, Ireland, Japan, South Korea, Taiwan, UK, and USA; table 1, figure). The two studies from Hungary presented similar data.[29,43]

Quality ratings for each study are in table 1. Only eight studies[33,34,37,38,40,44–46] did a formal analysis of the effect of pesticide regulations; of these, only five[34,40,44–46] used methods that took account of pre-regulation trends in suicide rates. Few studies assessed whether observed changes in suicide rates could have been affected by contemporaneous changes in other risk factors for suicide.

The regulations assessed in the identified papers were import or sales bans (in Jordan, Sri Lanka, Bangladesh, Greece, South Korea, and Taiwan);[24,26–28,33–35,40,42,44,46,48] restriction of sales to, for example, occupations that use pesticides such as farmers and forestry workers (in Denmark, India, Ireland, UK, and USA);[22,30,36–38,41,47] non-specific restrictions (in Colombia, Finland, Germany, Hungary, India, and USA);[25,29,31,38,39,43,45] a ban on the sale of small containers (in Denmark);[30] and reductions in the concentration of pesticide in liquid formulations (in Taiwan and Japan).[21,32,35] In Sri Lanka, a reduction in the concentration of paraquat was introduced in the same year as the phased import bans (in 2008).[40] Some of the regulations appeared to include several elements.[37,38] We identified a number of other studies examining aspects of pesticide regulation that were outside our review criteria (eg, assessments based on in-hospital deaths,[49,50] or poison centre referrals or notifications,[19,51] or natural experiments where access to pesticides was restricted).[52–54]

National bans on commonly ingested pesticides were assessed in six countries (one study focused on the Greek island of Crete; table 2). Data for Sri Lanka relate to two series of bans: the first in the 1990s, the second during 2008–10. Four of these studies used appropriate analytical methods.[34,40,44,46] In all areas where bans had been assessed, pesticide self-poisoning accounted for a high proportion of total suicides (>15%).

In all countries except Greece, the bans were followed by reductions in pesticide suicides. In Bangladesh, Sri Lanka, and South Korea, where the timing of the bans on specific pesticides was reported and where investigators assessed the effect of regulations on overall suicides, there were simultaneous declines in overall suicide rates. The cumulative effect of Sri Lanka's pesticide regulations was estimated to have prevented 93 000 suicide deaths in 20 years up to 2015.[46] In Bangladesh, overall injury rates including suicides decreased by 24% (separate data for suicides were not reported).[44] In the 3 years after a ban on paraquat in South Korea, the decline in pesticide suicides following the ban contributed to more than half of the decrease in overall suicides that occurred after the ban.[34]

In Taiwan, overall suicide rates decreased at the same time as the country had its greatest fall in deaths from pesticide self-poisoning between 1987 and 1992;[35] formal analysis of the effect of the bans was not undertaken and would be challenging because of the multiplicity of bans and the fact that the product accounting for most self-inflicted deaths (paraquat) was not banned, making a step-change in incidence unlikely. In Crete, the withdrawal of parathion and monocrotophos in 2003 had little effect on the number of pesticide or overall suicides;

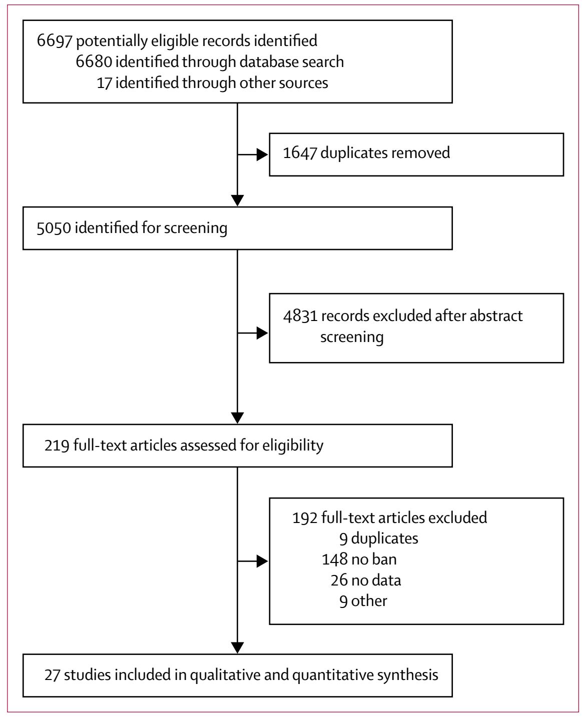

Figure: **Study selection**

however, the banned products accounted for only 14% of all pesticide suicides over the study period.[24]

Other regulations aimed at reducing the availability of pesticides have been studied in ten countries or districts (table 3). In these countries, pesticides accounted for between less than 1% (in the USA) and 20–30% (in India) of all suicides. Sales restrictions were adopted in India, Denmark, Ireland, the UK, and the USA, although additional interventions were also instituted in Denmark (restrictions on bottle sizes),[30] India (restricted storage),[38] and the USA (phase-out of organophosphates from domestic environments during 2000–05).[37] A requirement to dilute paraquat, followed by a ban of the actual product in 1999, was the approach used in Japan.[21,32] The precise scope of the regulations was unclear in Hungary, Colombia, Finland, Germany, India, and the USA. The only study that used appropriate analytical methods was of Colombian pesticide suicide trends, although the timing of the pesticide regulations was unclear.[45]

In all countries, except Ireland and the UK (England, Wales, and Scotland),[22,41,47] product-specific or overall pesticide mortality were reduced following regulatory actions. Four of the seven studies (in three of the five countries) where sales restrictions were studied showed that restrictions were followed by falls in pesticide suicides. Such reductions occurred in Denmark, India, and the USA, but none of these studies used appropriate analytical methods taking account of pre-ban trends in suicide.[30,36–38] The regulations in India targeted

	Proportion of suicides due to pesticide ingestion	Type of regulation	Effect on pesticide suicides*	Effect on overall suicides*
Low-income and middle-income countries				
Jordan[48]	>20% from 1980–85[55]	Ban on parathion and other toxic pesticide imports from January 1981	Decrease—48% fewer pesticide deaths from 1981–83 *vs* 1978–80. Before 1981, the number of deaths due to pesticides was increasing.	Not investigated
Sri Lanka[26–28,46]	Estimates vary depending on assumptions about coding of pesticide deaths: >60% in 1980s to 16–48% by 2008–12.	Series of bans of most toxic pesticides between 1984 and 2011. 1984: parathion banned 1984–95: gradual phase out of class I organophosphates, culminating in a ban on monocrotophos and methamidophos in 1995 1998: endosulfan banned 2008–11: phased bans of dimethoate, fenthion, and paraquat (see below)	No change—previously rising rates of suicide by poisoning and other methods levelled off between 1984 and 1995 Decrease—around 50% fewer poisoning suicides by 2003 compared to rates in 1995 Case fatality for pesticide poisoning decreased from 11% in 1997 to 5% in 2008	No change between 1984 and 1995, previously rising rates of suicide levelled off Decrease for 2005 *vs* 1995—suicide rates decreased by around 50% An estimated 93 000 suicide deaths have been prevented because of the cumulative effect of all of Sri Lanka's pesticide bans
Sri Lanka[40]	50% in 2007 (unpublished data)	3-year phased bans of the pesticides dimethoate and fenthion in 2008–10. In 2008 all paraquat formulations were reduced to 6·5% followed by a 3-year phased ban of paraquat in 2009–11	Decrease—the rate ratios between observed and expected pesticide suicide rates for 2011, 2012, and 2013 were 0·90 (95% CI 0·83–0·97), 0·72 (0·65–0·80), and 0·59 (0·51–0·68), respectively. An estimated 1500 fewer pesticide suicides occurred in this period than expected, based on pre-ban trends in suicide rates.	Decrease—the rate ratios between observed and expected pesticide suicide rates for 2011, 2012, and 2013 were 0·97 (95% CI 0·92–1·02), 0·93 (0·88–0·98) and 0·92 (0·86–0·98), respectively. An estimated 700 fewer suicides occurred than expected, based on pre-ban suicide rates.
Bangladesh[44]	Approximately 40% of all deaths deemed unnatural in 2000	Between 1996 and 2007, 21 pesticides were partly or completely banned. In 2000, all WHO Class I (highly hazardous) pesticides were banned	Decrease—rate ratios between observed and expected pesticide suicide rates for 2000, 2001, and 2002 were 1·00 (95% CI 0·98–1·03), 0·88 (0·85–0·91), and 0·76 (0·72–0·79), respectively. An estimated 2800 fewer pesticide suicides occurred in this period than expected based on pre-ban trends in suicide rates.	Decrease in unnatural deaths (most of which were suicides). The rate ratios between the observed and expected suicide rates for 2000, 2001, and 2002 were 1·00 (95% CI 0·98–1·02), 0·87 (0·85–0·90), and 0·76 (0·73–0·79), respectively. An estimated 7200 fewer unnatural deaths (mainly pesticide suicides) occurred in this period than expected based on pre-ban trends in suicide rates.
High-income countries				
Greece (Crete)[24]	24% of suicides in Crete in 1999–2007	Parathion and monocrotophos withdrawn in late 2003. Paraquat banned in July, 2007 (following a European-wide ban), but no post-ban data presented	No change—29 pesticide suicides in 2001–03 versus 29 in 2004–06. No change—based on reanalysis of data presented in the paper, the rate ratios between observed and expected pesticide suicide rates for 2004, 2005, and 2006 were 0·77 (95% CI 0·43–1·36), 0·81 (0·36–1·84), and 0·75 (0·25–2·23), respectively. An estimated eight fewer pesticide suicides than expected occurred in 2004–06, based on pre-ban trends in suicide rates Pesticides accounted for 25% of suicides in 2001–03 and 23% in 2004–06	Increase—10% rise in overall suicides: 115 in 2001–03 versus 127 in 2004–06 No change—based on reanalysis of data presented in the paper, the rate ratios between the observed and expected overall suicide rates for 2004, 2005, and 2006 were 0·68 (95% CI 0·44–1·06), 1·02 (0·51–2·03), and 0·83 (0·32–2·12), respectively. An estimated 21 fewer suicides than expected occurred in 2004–06, based on pre-ban trends in suicide rates
South Korea[33,34]	16% in 2011	Paraquat implementation plan (PIP) introduced in 1999. PIP revised in 2005. Re-registration of paraquat cancelled in November, 2011. Paraquat sale and use banned in October, 2012	Decrease—49% fall in the incidence of pesticide suicide from 5·26 per 100 000 in 2011 to 2·67 per 100 000 in 2013. Decrease in pesticide suicides as a proportion of all suicides, from 16·3% in 2011 to 10·0% in 2013. Decrease of 37% (rate ratio 0·63, 95% CI 0·55–0·73) in pesticide suicide rates compared with expected rates in 2013·	Decrease—the fall in pesticide-related suicides contributed to 56% of the decline in total suicides in South Korea in 2013 versus 2011
Taiwan[35,42]	42% in 1987	1972: Pesticides regulation Act. 112 pesticide products were banned by Taiwan during 1972–2010. Among them, 36 products—mostly WHO Class I pesticides—were banned because of the concern of human toxicity (most bans occurred after 1997). Products banned did not include paraquat, which accounted for most pesticide suicides, and were mainly restricted to selected high-strength formulated products; their equivalent low-strength products were not banned.	Decrease—pesticide suicide (including accidental deaths) rates fell from 7·7 per 100 000 in 1987 to 2·5 per 100 000 in 2010. Pesticide suicides accounted for 42·0% of total suicides in 1987 and 12·3% in 2010. The greatest reduction in pesticide suicide occurred between 1987 and 1992 before most of the bans on WHO Class I pesticides occurred (ie, after 1997).	Overall suicides decreased over the period of the greatest reduction in pesticide suicides (from 1987–1992); there were also decreases in hanging and non-pesticide poisoning in this period. However, overall suicide rates increased between 1992 and 2006.

*Where data are available, we have estimated the reduction in suicides for the 3 years after the regulation (s) compared with the 3 years before, and commented on the direction of trends before the regulation (s).

***Table 2*: Effect of national bans on sale or import of specific pesticides**

	Proportion of suicides due to pesticide ingestion	Type of regulation	Effect on pesticide suicides*	Effect on overall suicides*
Low-income countries				
Colombia[45]	10% in 2000	Legislative measures prohibiting the use of highly toxic pesticides, but no date specified. Colombian Agricultural Institute document cited in paper indicates endosulfan restrictions were introduced in 1999 and 2001	Joinpoint analysis shows pesticide suicides rose by 9·3% per year from 1998 to 2002 ($p<0·05$) and fell by 3·3% per year ($p<0·05$) between 2002–11	Not investigated, but other evidence shows the overall incidence of suicide in Colombia followed a similar pattern to the trends in pesticide suicides.[56,57]
India[38]	20%–30% in 2000s[20]	The local government restricted the sale, purchase, and storage of Endrin in October, 1976	In the two districts studied, there was a reduction in Endrin suicides from 64% of all suicides (n=38) during January to September, 1976, to 48% (n=28) during January to September, 1977.	No clear effect—there were 59 suicides during January to September, 1976, and 58 in January to September, 1977. Increases in suicides by hanging and other poisons compensated for the decline in Endrin suicides
High-income countries				
Denmark[30]	Around 5%	1950: parathion sales required a request signed by vendor and purchaser (repealed in 1954). 1957: bottles of liquid organophosphates <1 L were banned. 1961: sale of class A pesticides restricted to people with evidence of professional need and the number of retailers authorised to sell such products was restricted. Additionally, any remaining small bottles were collected and destroyed.	Decrease—80% reduction in suicides from organophosphate insecticides from 105 between 1959 and 1960 to 31 between 1961 and 1962. (Tables only record data for the two years following the regulation). Estimation from graphs that the number of suicides from organophosphate insecticides as a proportion of total suicides decreased from 6% during 1958 to 1960 to 1% during 1961 to 1963.	Total suicides decreased; however, the effect of the regulation is unclear as suicides by other methods decreased too. Estimation from graphs indicates that there was an 11% reduction from 2860 deaths from 1958–60 to 2550 from 1961–63.
England, Wales, and Scotland[41,47]	Around 1%. Paraquat accounted for 76% of pesticide deaths in 1989	1972 UK: (England, Wales and Scotland) Poisons Act with the 1982 Poisons rules: sale of concentrated paraquat restricted to agriculture, horticulture, or forestry-related occupations.	Increase—from graphs, during 1969–71 in England and Wales, there were 0·2 deaths per million population from paraquat poisoning; this increased to 0·6 per million in 1973–75. Equivalent figures for 1979–80 (only 2 years' data available) versus 1983–84 were 0·6 per million in both periods. During 1969–71 in Scotland, there were 0·5 deaths per million from paraquat poisoning, rising to 0·9 per million during 1972–74. Equivalent figures for 1979–80 (only 2 years' data available) versus 1983–84 were 1·6 per million versus 1·4 per million. In England, but not Scotland, paraquat (and total pesticide) deaths decreased from the late 1970s and early 1980s	Other published data indicate that overall suicides in England and Wales also rose during the 1970s and early 1980s.[58]
Finland[25]	Parathion accounted for 9% of all suicides during 1957–59	Parathion restrictions in 1960: precise nature unclear, although indications are that that licensing was involved.	Decrease—based on a reanalysis of data presented in the paper, rate ratios between observed and expected pesticide suicide rates for 1961, 1962, and 1963 were 0·16 (95% CI 0·03–0·86), 0·10 (0·01–0·74) and 0·06 (0·01–0·64), respectively. An estimated 1181 fewer pesticide suicides occurred in this period than expected, based on pre-ban trends in suicide rates– but this is likely to be an overestimate as rates were rising steeply in the pre-ban period The proportion of total suicides due to Parathion declined from 9% (during 1957–59) to 4% (during 1961–63)	No clear effect—based on a reanalysis of data presented in the paper, the rate ratios between observed and expected pesticide suicide rates for 1961, 1962, and 1963 were 0·81 (95% CI 0·70–0·94), 0·93 (0·77–1·11), and 0·72 (0·59–0·88), respectively. The overall number of suicides in Finland rose by 1% in 1961–63 compared with the number of suicides in 1957–59
Germany[31]	Approximately 3% during 1981–83	No clear date, although chlorinated hydrocarbons seem to have been restricted around 1984 (but no specific date or intervention given) The number of registered pesticide products decreased from 1130 in 2000 to 729 in 2012, but the number of active ingredients was unchanged	Decrease—suicides by pesticides decreased annually between 1980 and 2000· There was a small step change in the number (%) of suicides due to pesticides in 1984–86: 1568 (2·8%) during 1981–83 compared with 1180 (2·3%) in 1984–86—a 25% fall—following the apparent restrictions on chlorinated hydrocarbons	There was a steady fall in suicides throughout the study. Total suicides fell by 8% from 55 953 during 1981–83 to 51 517 during 1984–86

(Table 3 continues on next page)

	Proportion of suicides due to pesticide ingestion	Type of regulation	Effect on pesticide suicides*	Effect on overall suicides
(Continued from previous page)				
Hungary[29,43]	7·5% in 1990	The paper states that most toxic pesticides and chemicals were removed from every day use, but no date is given.	Decrease—pesticide suicides fell from 312 in 1990 to 75 in 2001 (a 76% reduction). Pesticide suicides fell from 7·5% of total suicides (in 1990) to 2·5% (in 2001).	Total suicides decreased by 28% between 1990 and 2001.
Ireland[22,41]	Around 3% from paraquat during 1975–77	1968: sale of paraquat restricted to licensed dealers. 1970: manufacturers reduced the number of retail outlets from 510 to 80 and wrote to farmers about dangers of decanting. 1975: sales restricted to agricultural, horticulture or forestry-related occupations. Additional safety labelling. None of these restrictions apply to granular paraquat products.	Increase—paraquat suicides increased year-on-year up to 1977, then subsequently fell (data up to 1984). During 1973–74 there were ten paraquat suicides and in 1975–76 there were around 23—a 130% rise.	Other published data indicate that overall suicide rates in Ireland doubled between 1970 and 1980 and between 1980 and 2000[59]
Japan[21,32]	10% in 1986	Products comprising 24% concentration of paraquat were suspended in 1986 and replaced with 5% products. Paraquat production ended in Japan in 1999.	Decrease of 6% in pesticide deaths from 5804 during 1983–85 to 5445 during 1987–89.† The proportion of total suicides due to pesticides declined from 10·3% of total suicides in 1986 to 2·1% in 2005. The fall was particularly marked (approximately 50%) between 1986 and 1989.	Although total suicides decreased during 1987–89 compared with the 3-year period from 1983–85 in Japan, the effect of regulation is unclear as the fall in suicides was greater than the reduction in pesticide deaths, and the timing of the marked fall in 1987 to 1989 corresponded with changes in economic conditions and a reduction in the incidence of suicide using other methods[60]
USA[39]	<1%	Laws to restrict the use of organophosphates introduced in the late 1960s and 1970s, but precise dates not given.	Decrease—81% reduction in pesticide suicide deaths, from 16 during 1961–65 to three during 1981-85.	Not investigated. Other published data[61] indicate that the overall incidence of suicide in the USA rose between the early 1960s and early 1980s·
USA[36,37] and personal communication (Langley R)	<1%	In 1972, certification was required for people wishing to purchase and use the most toxic pesticides. In 1994, the second round of certification training was completed. In 2000–05, the phase out began of organophosphates from residential environments.	Decrease in pesticide suicide deaths, from 128 between 1991 and 1994, to 87 between 1995 and 98. Graphical assessment (of all pesticide deaths, including accidents) indicates that there was a gradual fall between 1979 and 1998, with the steepest falls occurring between 1980 and 1983 and between 1992 and 1994. Organophosphate deaths (both suicides and accidents) decreased from 37 during 1995 to 1999 to 31 during 2000 to 2004.	Not investigated. Other published data[61] indicate that the overall incidence of suicide in the USA was stable in the 1980s, with gradual falls from the late 1980s and throughout the 1990s.

*Where data are available, we have estimated the reduction in suicides for 3 years after the regulation compared with 3 years before, and commented on the direction of trends before the regulation.
†Suicide, accident, homicide, and unspecified deaths combined.

Table 3: **Effect of other or unspecified national pesticide regulations**

the organochlorine insecticide endrin, but it was still used frequently for suicide after the regulations, indicating that the intervention might not have been implemented effectively.

Despite the sales restrictions on paraquat in Ireland and the UK, the number of paraquat and total pesticide deaths increased.[22,41,47] These rises occurred at the same time as increases in overall national suicide rates in these countries[58] (overall suicide rates in Ireland doubled between 1970 and 1980 and again between 1980 and 2000);[59] there are insufficient data to determine whether pesticide poisoning fell as a proportion of total suicides. Two of seven studies of sales restriction assessed trends in overall suicide. In Denmark, overall suicide rates decreased around the time of the falls in pesticide suicide deaths, but the specific effect of the regulations was unclear because suicide deaths from other methods decreased at the same time.[30] No change occurred in overall suicide rates in the Indian study, although only a 9-month period was assessed.[38] Although the precise nature of the regulations in Colombia is unclear,[45] regulatory documents cited in the paper indicate that restrictions on endosulfan were introduced in 1999 and 2001; the incidence of suicide by pesticide poisoning increased from 1998 to reach a peak in 2002, then declined—following the same pattern as for overall suicide rates.[56,57] There was no evidence that the proportion of suicides due to pesticide poisoning in Colombia decreased over this period.

In Finland regulations targeting parathion were followed by a halving in its use for suicide; however, the overall incidence of suicide increased.[25] In Germany, decreases in pesticide suicides paralleled annual declines in overall suicides[31] with no clear effect of regulations. In

Hungary, the proportion of suicides due to pesticides decreased by more than 70% between 1990 and 2001; this was greater than the 28% decrease in overall suicides, but the precise timing (and nature) of the regulations was unclear.[29] In Japan, pesticide poisoning deaths were lower in the 3 years after regulations requiring decreased concentrations of paraquat in products were introduced in 1986, compared with the 3 years preceding the regulations;[21] the precise month of the regulation was not specified.

Three studies examined the effect of pesticide regulation in the USA;[36,37,39] two of these included elements of sales restriction.[36,37] A small-scale county-level analysis of the effect of organophosphate insecticide regulations in Dade County (FL) reported a fall in pesticide suicides after the regulations, a period when overall suicide rates were rising in the USA.[39] Langley and colleagues[36] reported on trends in pesticide suicide mortality over a period when regulations were introduced and showed a decline without evidence of a specific step-change in incidence. Sudakin[37] showed that the staged phase-out of organophosphate insecticides in residential environments between 2000 and 2005 was associated with a reduction in organophosphate-incident reports (including intentional exposures) and a reduction in the incidence of suicide; these effects might have been underestimated, however, because population coverage of the system used to identify incidents increased from 83% to 96% over the study period. None of the three US studies reported on overall suicide mortality trends.

Discussion

27 studies in 16 countries have investigated the effect of pesticide regulations on method-specific suicides and overall suicide mortality. Most studies adopted potentially biased assessments of their effectiveness or made no formal assessment. The exceptions were studies from South Korea,[34] Sri Lanka,[40,46] and Bangladesh.[44] The findings suggest that the number of pesticide-specific and overall suicides can be reduced by national bans of highly hazardous pesticides.

Regulatory action to ban highly hazardous pesticides, particularly organophosphate insecticides and paraquat, was followed by falls in pesticide suicides and overall suicides in Sri Lanka, Bangladesh, and South Korea.[26,33,34,40,44,46] These case-studies indicate that for a ban to result in a demonstrable fall in overall suicide rates, a high proportion of pesticide suicide deaths need to have been caused by the specific products, and pesticides should be shown to have contributed to a high proportion of suicides. In the three countries that showed reductions in overall suicides following a ban, pesticide poisoning accounted for more than 15% of all suicides before the ban. Pesticide bans in other countries have either not targeted the pesticides that account for most deaths (eg, paraquat in Taiwan),[35] or have occurred in contexts where pesticides account for only a small proportion of total suicide deaths, making it difficult to detect changes in incidence. Additionally, only a complete ban of paraquat in South Korea in 2012 seemed to decrease paraquat-related mortality; other regulatory actions in this country in 1999 and 2005 had no effect on the incidence.[34]

Although little information is available about the precise nature of the regulations, bans appear to be more effective than sales restrictions, such as regulations restricting sales to individuals with a legitimate occupational need to use pesticides. Sales restrictions in three countries of five studied (Denmark, India, and the USA)[30,36–39] were associated with decreases in pesticide suicides, but their effects on overall suicide rates were uncertain. There is some evidence from Japan that regulations requiring the dilution of paraquat resulted in falls in pesticide suicide,[21,32] but there was no clear evidence for an effect on overall suicide rates.

Clearer reporting of the precise nature of the regulation and contextual factors surrounding their introduction is required. The effectiveness of any ban or restriction will not only be affected by the nature of the intervention, but will also be influenced by the effectiveness of enforcement, trade across borders, and residual stocks of the product.

We found several other relevant papers that were outside the inclusion criteria for this review but are informative. A ban on the import, distribution and use of aluminium phosphide in Iran in 2007 had no effect on deaths recorded in two hospitals in Tehran during 2008–10[49] and 2005–10.[62] The authors speculated that an effect was absent because aluminum phosphide could still be bought easily on the black market. In two countries — Western Samoa and Suriname—the effects of reductions in imports of paraquat as a result of economic problems within the countries have been assessed.[52,53] Although these were not bans, their effect—ie, the reduced availability of a highly toxic pesticide, was similar to that occurring following a ban. The effect was most striking in Samoa where, in 1980–82, paraquat accounted for 72% of suicides; decreases in imports were followed by a 65% fall in paraquat suicides (1983–85 *vs* 1980–82) and a 45% reduction in total suicides in the same period. In Suriname, paraquat imports fell by 23% from 1985 to 1986; this fall was accompanied by a three-fold reduction in admissions for paraquat poisoning (from 211 per million to 68 per million population) in the hospital serving most of the population.[53] In a non-randomised controlled experiment in India,[54] pesticide use was discontinued in four villages and replaced by organic alternatives. Suicides fell from 14 (during 1998–2002) before the intervention to three in the following years (2003–06); by contrast, in four control villages, suicides fell from 15 to eight. 92% of the suicide deaths in this study (intervention and control areas combined) resulted from ingestion of pesticides.

Ours is the first systematic review of the effect of regulatory activity on pesticide-specific suicide and overall suicide mortality. We identified studies assessing the effect of pesticide regulations in several HIC and LMIC and a range of regulatory approaches in different settings. However, there are several limitations to our assessment. First, with the exception of one study from a region of rural India,[38] there was no substantial evidence from the two countries contributing most to the global burden of pesticide suicides—India and China.[1,20] Second, with some exceptions,[33,34,40,44–46] few investigators of studies undertook a formal time-trend analysis. Third, studies showing gradual reductions in pesticide suicides might have been confounded either by improvements over time in the management of pesticide poisoning[28] or by decreases in the number of people who have easy access to pesticides.[35] With mechanisation of farming practices, the actual use of pesticides might not decrease, but the size of the agricultural workforce decreases.[63] Studies showing step-changes in rates while accounting for previous trends in incidence provide more robust evidence of an effect. Last, some studies investigated effects on overall pesticide-related poisoning deaths (accidental, homicide, and undetermined intent, as well as suicide),[21,47,48] rather than suicides only; such studies provide a more complete assessment of the overall public health effect of regulatory activity, although most deaths in these studies were from suicide.

The appropriate date to begin assessing the effect of a ban is sometimes uncertain—the ban might be staggered over several years,[40] or there might be a lag-period before an effect is evident while existing supplies of the banned product are depleted, or because of purchasing behaviour. For example, in South Korea, the registration of paraquat was cancelled in November, 2011, but its sale was not banned until October, 2012;[34] however, a decrease in pesticide suicides began soon after November, 2011.[33] These early decreases might have occurred either because manufacturers stopped producing paraquat in November, 2011, or because farmers began stockpiling paraquat as soon as they knew it was to be withdrawn, thereby reducing supplies and overall availability.[33] Sensitivity analyses, such as those used in other studies,[34,40] using different start dates for the intervention, is one approach to assess the robustness of findings.

Restricting access to high-lethality, commonly used methods for suicide leads not only to a reduction in method-specific suicide rates, but also to the overall incidence of suicide.[5] Specific examples of this effect include the falls in the incidence of suicide in England and Wales following the detoxification of the domestic gas supply[64] and in Australia after restrictions on the prescribing of barbiturates.[65] Our review builds on this evidence in relation to pesticide poisoning. The other favoured approach for restricting access to pesticides is the provision of lockable storage devices or facilities to farmers.[15] There is some evidence from a non-randomised controlled study in China[12] that this approach might lead to reductions in suicide deaths, but the apparent effect might have resulted from baseline differences between the control and intervention groups. Concerns have been raised that lockable storage devices could lead to farmers storing hazardous pesticides close to their household, rather than in their fields, thereby increasing accessibility to family members and neighbours.[14] Furthermore, it has been shown that despite good intentions and public education campaigns, most farmers stop locking the storage devices shortly after they have been installed.[12,66] A recent cluster-randomised trial showed no effect of providing household lockable pesticide storage on the incidence of pesticide self-poisonings.[15]

An important concern with banning pesticides is that this might decrease crop yield and increase the labour costs involved in keeping crops free from pests. The few studies[34,40,67] that have examined this issue in relation to pesticide bans in Sri Lanka and South Korea showed no evidence of such an effect, although small effects were unlikely to be detected. Bans of specific pesticides might lead to alternative, possibly more toxic agents replacing them; eg, unpublished data indicate that bans on the herbicide arsenite in Malaysia were followed by an rise in paraquat poisoning.[41] However, for the most hazardous pesticides such as paraquat and aluminium phosphide (for which case fatalities are often >60%), this is not a concern.

In conclusion, our systematic review indicates that bans on the sale of highly hazardous pesticides could also result in falls in method-specific and overall suicide rates in countries where pesticide self-poisoning is a frequently used method of suicide and the bans target the products most commonly ingested. Bans in countries where pesticides account for a small proportion of suicides are likely to be equally effective, but detecting their effect on overall suicide rates is statistically challenging.[60]

Our findings indicate that rather than focusing on safe storage, as is currently the case, policy focus should shift towards bans on the pesticides most frequently used for suicide, as encouraged by the UN Food and Agriculture Organisation, or supporting effective implementation of alternatives to the use of pesticides for pest control. Bans should be based on local epidemiological assessments of pesticide usage and misuse. Initiatives such as integrated pest management programmes and the replacement of pesticides with safer, less toxic alternatives[54] leading to reduced use of pesticides, are likely to have similar effects. Thousands of deaths could be prevented by a widespread ban of the use of highly hazardous pesticides.

Contributors

ME and DG developed the idea for the research. All authors contributed to the design of the study. DK and DG did the literature searches and reviewed all papers. S-SC reviewed Chinese language papers. DG, ME, and DK wrote the first draft of the manuscript. All authors contributed to the final version of the manuscript. DG is the study guarantor.

Declaration of interests

All authors are co-authors on one or more papers included in this review. Between 2003 and 2011, DG was a member of the scientific advisory group for a Syngenta-funded study to assess the toxicity of a new paraquat formulation and the scientific advisory group for a pesticide self-storage project funded by Syngenta; chaired a data monitoring and ethics committee for a Syngenta-funded trial of the medical management of paraquat poisoning; and received travel costs to attend research meetings, but no other fees. DG was an expert adviser to WHO's first consultation on best practices on community action for safer access to pesticides (Geneva, 2006). FK is a member of the UN expert committee on dichlorodiphenyltrichloroethane. ME received travel fees from Syngenta up to 2006. ME has been a member of the WHO/UN Food and Agriculture Organization joint meeting on pesticide management (as a WHO expert) since 2015.

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