TITLE: FACTORS ASSOCIATED WITH THE DECLINE IN SUICIDE BY PESTICIDE POISONING IN TAIWAN: A TIME TREND ANALYSIS, 1987-2010

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DECLARATION OF INTEREST STATEMENT

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ABSTRACT

Objective. Pesticide self-poisoning accounts for one third of suicides worldwide, but few studies have investigated the national epidemiology of pesticide suicide in countries where it is a commonly used method. We investigated trends in pesticide suicide, and factors associated with such trends, in Taiwan, a rapidly developing East Asian country.

Methods. We conducted an ecological study using graphical approaches and Spearman's correlation coefficients to examine trends in pesticide suicide (1987-2010) in Taiwan in relation to pesticide sales, bans on selected pesticides, the proportion of the workforce involved in agriculture and unemployment. We compared pesticide products banned by the Taiwanese government with products that remained on the market and pesticides that accounted for the most poisoning deaths in Taiwan.

Results. Age-standardised rates of pesticide suicide showed a 67% reduction from 7.7 per 100 000 (42% of all suicides) in 1987 to 2.5 per 100 000 (12% of all suicides) in 2010, in contrast to a 69% increase in suicide rates by other methods. Pesticide poisoning was the most commonly used method of suicide in 1987 but had become the third most common method by 2010. The reduction was paralleled by a 66% fall in workforce involved in agriculture but there was no strong evidence for its association with trends in pesticide sales, bans on selected pesticide products or unemployment. The bans mostly post-dated the decline in pesticide suicides; furthermore, they did not include products (e.g. paraquat) that accounted for most deaths and were mainly restricted to selected high-strength formulated products whilst their equivalent low-strength products were not banned.

Conclusions. Access to pesticides, indicated by the size of agricultural workforce, appears to influence trends in pesticide suicide in Taiwan. Targeted bans on pesticides should focus on those products that account for most deaths.

INTRODUCTION

The World Health Organization (WHO) acknowledges that pesticide self-poisoning is amongst the most frequently used methods of suicide worldwide,[1] and many of these deaths occur in rural areas of South and East Asia.[2] Pesticide ingestion causes 250 000-370 000 deaths every year - around one third of the world's suicides.[2] Many of these deaths are preventable by simple measures such as legislative bans on the import and sale of the most toxic pesticides.[3] It has been shown that the incidence of suicide by pesticide poisoning declined in Finland[4] and Sri Lanka[5] following restricting pesticides that were the most toxic or most harmful to human health. Furthermore, such pesticide restrictions do not appear to have adverse effects on agricultural output.[6] However, with some exceptions[4, 5, 7-11] there have been few studies investigating trends in pesticide suicide in countries where pesticide poisoning is a commonly used method.

In Taiwan, pesticides are amongst the most commonly used agents involved in poisoning suicide.[12] Since the Agro-pesticides Management Act was passed in 1972 the Taiwanese government had banned 112 pesticide products by the end of 2010.[13] Early bans in the 1970s and 1980s were mainly targeted on carcinogenic or teratogenic pesticides, e.g. organochlorine pesticides.[14] The Taiwanese government only began banning pesticide products due to concerns of their human toxicity and use in self-harm in the 1990s.[13] The effect of these bans on reducing pesticide suicides has not been investigated.

Few studies have investigated long-term trends in suicide by pesticide poisoning in countries with rapid economic development such as Taiwan. As countries industrialise, a decreasing proportion of the population will work in agriculture; it is possible that this may reduce day-to-day access to pesticides and lead to declines in their use for suicide. However, evidence from South Korea suggests that the incidence of pesticide suicide increased between 1991 and 2005.[10, 11] In Japan pesticide suicides doubled between 1979 and 1985,[8] although more recent data showed that the proportion of overall suicides attributable to pesticide poisoning decreased between 1995 and 2006.[15]

In this study we have examined secular trends in the incidence of suicide by pesticide poisoning in Taiwan, an island country with a population of 23 million people that has experienced rapid economic growth over the last few decades.[16] We have also investigated the possible impact on trends in pesticide suicide of changes in pesticide exposure, indicated by the size of exposed population, pesticide sales and bans on pesticides. Data from Taiwan provide an ideal opportunity to study trends in pesticide suicide in relation to both changes in exposure and pesticide regulations aimed at reducing their toxicity in a rapidly developing economy. Throughout the paper the term "pesticide" was used as a general term for a range of different products including insecticides, herbicides, fungicides and rodenticides.

METHODS

Suicide and population data

Suicide data for people aged 15+ years were extracted from Taiwan's national cause-of-death data file, coded using the International Classification of Diseases, Tenth Revision (ICD-10), for years 2002-2010. ICD-10 coded data were also available for years 1987, 1992 and 1997; the Department of Health provided data for these years for academic research use.[17] Whilst ICD-9 coded suicide data were available for all study years prior to 2002, as Taiwan used only the 3-digit ICD-9 codes suicides by pesticides poisoning could not be distinguished from non-pesticide poisoning suicides (the fourth digit of the ICD-9 code is necessary to make this distinction for suicide and undetermined deaths).

Suicide by pesticide poisoning was identified using codes X68 (suicide by pesticide poisoning), Y18 (death of undetermined intent by pesticide poisoning) and X48 (accident by pesticide poisoning), as a previous study showed that, in keeping with findings from Western countries, a high proportion of deaths in the latter two cause-of-death categories are likely to be misclassified suicides in Taiwan as they have similar socio-demographic characteristics to suicides by self-poisoning.[18] We conducted sensitivity analyses based on data for certified suicides only (excluding undetermined deaths and accidents by pesticide poisoning) to investigate whether our assumption about the miscoding of suicide had an impact on our findings. Total suicides (all methods) were identified using the following ICD-10 codes: X60-X84 (suicide), Y10-Y34 (undetermined death), W75-W76 (accidental suffocation) and X48 (accidental pesticide poisoning).[18] “Non-pesticide” suicides were suicides by methods other than pesticide poisoning. As previous research indicated that suicides from carbon monoxide poisoning by burning barbecue charcoal contributed to the recent rises in suicide in Taiwan[19] in a sensitivity analysis we investigated trends in non-pesticide suicide excluding charcoal-burning suicide (ICD-10 X67 and Y17).[20]

As described above, data for pesticide suicide were available for selected years in 1987, 1992 and 1997 before annual data become available from 2002. To examine whether estimated year-on-year trends in pesticide suicide in 1987-2002 were influenced by data availability for the selected years, we used the ICD-9 coded data to extract i) suicides or undetermined deaths by poisoning using solid or liquid substances (ICD-9 E950 and E980) and ii) accidental pesticide poisonings (E863). Year-on-year ICD-9 coded data were available in 1987-2008; in 1987, 1992, 1997 and 2002-2008 Taiwan’s national cause-of-death data were coded using both the ICD-9 and ICD-10 when the Department of Health trained coders in preparation for a smooth transition from the ICD-9 to ICD-10.[17] Previous studies from Taiwan showed that the majority (62%) of suicides and undetermined deaths from solids/liquids poisoning were due to pesticides.[12] Past research also showed that accidental pesticide poisoning mortality rates were unusually high in Taiwan and, as mentioned above, these deaths had very similar socio-demographic characteristics to those for suicides from self-poisoning, indicating that a high proportion of these deaths are possible misclassified suicides.[18] Therefore these deaths could provide an indication of the underlying year-on-year trend in pesticide suicide.

Population data were obtained from the Demographic Fact Books (1987-2010) published by the Ministry of the Interior.

Data on factors that may influence rates of pesticide suicide

We used i) the proportion of agricultural workers in the labour force aged 15+, ii) the proportion of households involved in farming, and iii) the pesticide sales (in volume and monetary values) as proxy indicators of exposure to pesticides; these variables have been used in previous ecological analyses of population pesticide suicide rates as markers of access to pesticides.[5, 11, 21] Annual data on these variables for the period 1987-2010 were extracted from official statistics published by the Taiwanese Council of Agriculture.[22, 23] As previous studies have shown strong associations between secular trends in unemployment and overall suicide rates in Taiwan[24] we also collected data for unemployment between 1987-2010.[25]

To assess whether bans on selected pesticide products may have influenced trends in pesticide suicide in Taiwan we obtained online available data for these bans (1972-2010).[13] We used the WHO Recommended Classification of Pesticides by Hazard when classifying these pesticide products according to their toxicity.[26] Data were also obtained for available pesticides on Taiwan's market (by the end of 2010)[27] and the sale statistics of the top ten best-selling pesticide products (2002-2010)[28] to examine the extent to which these bans have influenced pesticide sales.

We investigated whether Taiwan's bans included the pesticides that accounted for most poisoning deaths by conducting a systematic literature review to identify Taiwanese studies of pesticide-specific poisoning mortality, published in English or Chinese. We searched databases including Medline (1950-2010), PsycInfo (1806-2010), EMBASE (1980-2010) and three Citation Indices of ISI Web of Science: Science (1899-2010), Social Sciences (1956-2010) and Arts & Humanities (1975-2010), using the following terms coded in all fields (af) including title, abstract and text: ((suicid$ or (pesticide$ and poisoning$) or (((self and harm$) or parasuicide$ or (self-injur$ and behavio$) or (self and injur$) or (self and poisoning$)) and (lethal or fatal))) and Taiwan). Relevant references in Chinese were identified by searching two large Taiwanese databases using the keywords “pesticide” and “suicide” in Chinese: the Index to Taiwan Periodical Literature (1970-2010; http://readopac.ncl.edu.tw/nclJournal/) and the Electronic Theses and Dissertations System (1956-2010; http://ndltd.ncl.edu.tw/cgi-bin/gs32/gsweb.cgi/ccd=5LtFgC/webmge?switchlang=en.).

This study was approved by the Institutional Research Board of National Cheng Kung University, Taiwan.

Analysis

Age-standardised rates of pesticide suicide for males, females and both sexes combined and sex-age-specific rates (15-24, 25-44, 45-64 and 65+ years old) were calculated for each year, based on the WHO world standard population.[29] Non-pesticide and overall suicide rates were also calculated. We used graphical approaches to compare trends in pesticide and non-pesticide suicide and related these trends to those in the proportion of workforce in agriculture, pesticide sales, unemployment rates and the timing of bans on selected pesticides. We also used Spearman’s correlation coefficients to investigate the relationship between pesticide suicide rates and these factors. Trends in sex- and age-specific pesticide suicide rates were also examined graphically.

RESULTS

Pesticide bans

Amongst the 112 pesticide products banned by the Taiwanese government between 1972-2010, 64 were banned due to potential carcinogenic or teratogenic effects, 14 were due to no sales (i.e. use) for many years and a lack of human safety information and one were due to its effect on the ozone layer (Methyl Bromide). Thirty-six products were banned because of the concern of human toxicity (Table 1). The first ban on these toxic pesticide products was implemented in 1978 but others were between 1988-2010, mostly after 1997. Most of the bans shown in Table 1 were restricted to formulated products of specific forms and concentrations (e.g. 35% emulsifiable concentrates of endosulfan) rather than wide-ranging bans on all formulated products containing the same pesticides. The majority of these banned products were high-strength formulations of organophosphates (OPs) or carbamates classified by the WHO as “extremely” (Class Ia) or “highly” (Ib) hazardous pesticides. By the end of 2010 there were still 4994 pesticide products, containing 522 different pesticides, available in Taiwan; 23 of these products were classified as ‘highly toxic’ by the Taiwan’s government.

For some pesticides lower strength products were still widely available on the market despite the bans on their equivalent high-strength products (Table 1). For example, the 90% wettable powder and soluble granule of methomyl (a carbamate) were banned in 2006 but there were still 67 products containing different forms of methomyl available in 2010; its 24% soluble concentrate liquid was a popular product in Taiwan, with its sale ranking 4th amongst all insecticide products available on the market in 2010. In contrast, the bans placed on parathion (1997), EPN (1998) and monocrotophos (2000) were more complete; only one product of 8% granule monocrotophos was still available after the ban of its 50% soluble concentrate formulation in 2000.

Our literature search identified four studies that provided nation-wide poisoning data by pesticide or pesticide category.[30-33] Three of them were based on the National Poison Control Centre data[30-32] and one extracted data from the national mortality database based on all death certificates.[33] The main causes of fatal and non-fatal pesticide poisoning in Taiwan were paraquat (55.4%), OPs (23.3%), glyphosate (6.1%) and carbamates (4.8%) in 1985-1993,[30, 31] whilst major causes of fatal self-poisoning were paraquat (53.2%), OPs (14.7%) and methomyl (11.0%) in 2006-2008.[33] In 1985-2006 OPs that accounted for the most mortality included mevinphos (26.3%), methamidophos (13.0%), dimethoate (6.3%), chlorpyrifos (5.7%), parathion (4.8%), monocrotophos (4.8%) and EPN (3.8%).[32] However, Taiwan’s bans on pesticide products did not include the pesticides that caused the most deaths, e.g. paraquat and some OPs (e.g. methamidophos and dimethoate), or were only restricted to selected high-strength formulated products, e.g. mevinphos and methomyl (Table 1). Paraquat, a herbicide associated with a >60% case fatality in acts of self-poisoning,[34] is widely available in Taiwan; in 2010, the sale of one paraquat product (24% soluble concentrate liquid) ranked 3rd amongst all herbicide products available on the market.

Trends in pesticide suicide

In Taiwan, the annual number of pesticide suicides declined from 989 (42.0% of all suicides) in 1987 to 546 (12.3% of all suicides) in 2010 (Table 2). Pesticide poisoning was the most commonly used method of suicide in Taiwan in 1987 but had become the third most common method by 2010, following hanging (27.9%) and non-domestic gas poisoning (27.8%). Age-standardised rates of pesticide suicide decreased 67% from 7.7 (95% Confidence Interval [CI] 7.2-8.2) per 100 000 in 1987 to 2.5 (95% CI 2.3-2.7) per 100 000 in 2010 (Table 2). Trends were similar for males and females; male rates decreased 60% from 9.3 (95% CI 8.5-10.1) per 100 000 to 3.7 (95% CI 3.4-4.1) per 100 000 in 1987-2010 and female rates decreased 78% from 5.9 (95% CI 5.3-6.6) per 100 000 to 1.3 (95% CI 1.1-1.6) per 100 000. Trends were similar (although absolute rates were lower) when data were restricted to certified suicide only (i.e. excluding undetermined deaths and accidental pesticide poisonings) – pesticide suicide rates declined 53% from 4.7 (95% CI 4.3-5.1) per 100 000 to 2.2 (95% CI 2.0-2.4) per 100 000 in 1987-2010 (detailed data not shown).

Fig 1 shows trends in pesticide and non-pesticide suicide, the workforce involved in agriculture, pesticide sales and unemployment; years are highlighted with arrows when the Taiwanese government banned selected toxic pesticide products (bans were numbered as shown in Table 1). Most of the fall in rates of pesticide suicide occurred between 1987 and 1992, followed by relatively stable rates in 1997 and 2002 and a slight downward trend in 2002-2010. In contrast, rates of non-pesticide suicide decreased slightly from 1987 to 1992 but subsequently rose markedly; rate was 69% higher in 2010 than that in 1987. When charcoal burning suicides were excluded the increase from 1992 onwards became less dramatic, although non-pesticide non-charcoal-burning rate in 2010 was still 14% higher than that in 1987 (supplementary material 1).

The overall reduction in pesticide suicide paralleled a downward trend in the agricultural workforce in 1987-2010 (Fig 1); workers involved in agriculture accounted for 13.8% of the labour force in 1987 but only 4.7% by 2010, a 66% reduction. The proportion of households involved in farming also fell 37% (from 20.7% to 13.0%) over the period 1987-2009 (detailed data not shown). Trends in pesticide suicide did not appear to be associated with trends in pesticide sales (in tonnes) (Fig 1), which changed little over the study period; results for pesticide sales in monetary values were similar (data not shown). Overall, unemployment rates increased over the study period, in contrast to the downward trend in pesticide suicide. These observed associations in trends were in keeping with the results of correlation analyses, with the exception that there was some weak evidence for a positive association of trends in pesticide suicide rates with pesticide sales – Spearman's correlation coefficients were 0.93 (95% CI 0.76 to 0.98), 0.52 (95% CI -0.07 to 0.84) and -0.24 (95% CI -0.87 to -0.04) for the correlations of pesticide suicide rates with agricultural workforce, pesticide sale and unemployment respectively, using data for years when pesticide suicide rates were available.

There was limited evidence for an association of the bans on toxic pesticides with reductions in pesticide suicide in 1987-2010. There were only five bans in 1987-1992 (Table 1) when pesticide suicide rates declined by nearly half (48%); three of these bans (No. 2-4 in Table 1) were placed on one single carcinogenic fungicide, Captafol. Fifteen bans were implemented between 1997 and 2000 when pesticide suicide rates decreased slightly (10%) in 2002 compared to 1997, whilst non-pesticide suicide rates increased 40%. The remaining 15 bans became effective in 2006-2010, postdating the main period of reduction in pesticide suicide.

Overall, sex- and age-specific trends in pesticide suicide were similar (Fig 2) –

there were marked reductions in 1987-1992 followed by gradual declines up to 2010. The only exceptions to the general pattern were some increases in males aged 45-64 years in 1992-1997 and a 4% rise for males aged 65+ in 2002-2010. Throughout the study period rates of pesticide suicide were highest in the older age groups. In 2010, rates were 51 times higher for males aged 65+ than males aged 15-24 (12.16 [95% CI 11.94-12.40] versus 0.24 [95% CI 0.19-0.32] per 100 000) and 38 times higher for females aged 65+ than females aged 15-24 (4.94 [95% CI 4.81-5.09] versus 0.13 [95% CI 0.09-0.20] per 100 000); pesticide self-poisoning was the second most common method of suicide (after hanging) in people aged 65+ and accounted for 20.4% (210/1029) of all suicides in this age group.

Year-on-year data for ICD-9 coded suicides and undetermined deaths by solids/liquids poisoning and accidental pesticide poisonings showed similar trends to those for ICD-10 coded pesticide suicides (supplementary material 1).

DISCUSSION

Main findings

There was a marked reduction (67%) in pesticide suicide rates in Taiwan over the period 1987-2010, mostly occurring between 1987 and 1992. Pesticide poisoning was the most commonly used method of suicide in 1987 but had become the third most common method by 2010. However, there were still 546 pesticide-related deaths in Taiwan in 2010, accounting for 12% of all suicides in that year. The downward trend in pesticide suicide was in contrast to a 69% increase in suicide by other methods over the same period. The reduction in pesticide suicide was paralleled by a 66% fall in agricultural workforce but there was no strong evidence for an association of pesticide suicide rates with trends in unemployment, pesticide sales or bans on selected pesticide products. These bans mostly post-dated the main period of the reduction in pesticide suicide. Furthermore, Taiwan's bans on pesticide products did not include pesticides that accounted for the most poisoning deaths, e.g. paraquat, and were restricted to selected high-strength formulated products whilst their equivalent low-strength products were not banned.

Strengths and limitations

The availability of long-term Taiwanese data on pesticide suicide, pesticide sales and bans, and the size of agricultural population allowed us to investigate their associations. The study has several limitations. First, data for pesticide suicide were available only in selected years before 2002; this limits our assessment of year-on-year trends prior to 2002 and prevents any in-depth statistical trend analyses. However, the simple graphical approach adopted here is appropriate to address the research question given this limitation. Meanwhile, year-on-year data for ICD-9 coded suicides and possible suicides (i.e. undetermined deaths by solids/liquids poisoning and accidental pesticide poisonings) for 1987-2002 showed consistent trends. Second, data for non-fatal pesticide self-poisoning were unavailable; we were unable to determine whether the reduction in pesticide suicide was due to declines in the incidence of pesticide self-poisoning or in case-fatality. Finally, when investigating which pesticides accounted for the most deaths in Taiwan three out of the four studies identified from our literature review used data from the National Poison Control Centre;[30-32] such data may be unrepresentative of the overall pattern of pesticide poisoning in the community although the fourth study[33] was based on all death certificates in 2006-2008 and was less likely to be biased.

Trends in pesticide suicide

Our study showed a marked reduction in pesticide suicide in Taiwan over the last two decades, whilst rates of suicides using other methods increased. Research from other countries showed different trends in pesticide suicide. Studies from South Korea and Japan have reported marked rises in pesticide suicide; rates increased nearly four times in South Korea in 1991-2005[10, 11] and the numbers of deaths doubled in Japan in 1979-1985,[8] although in Japan more recent data suggested a downward trend.[15] The increase in Japan in 1979-1985 was mostly due to paraquat ingestion,[8] and herbicides (e.g. paraquat) and fungicides were the most common agents involved in pesticide poisoning deaths in South Korea.[11, 35] In contrast, studies from the US[9] and Finland[4] demonstrated declines in pesticide suicides over the course of the 20th century. In Finland this was due to restrictions on the use of parathion.

We found that pesticide suicide rates increased with increasing age and were higher in men than women in Taiwan. Similarly, in South Korea the elderly showed the highest mortality rates of pesticide poisoning and rates were higher for males than females.[11] One possible explanation for high risk in the older population is that the elderly account for the majority of residents living in some rural areas; this is particularly so in rapidly industrialising countries such as Taiwan and South Korea, where the younger generations have tended to move to urban areas working in the industrial and service sectors. This is in contrast to findings from countries where there is still a large younger population living in rural areas. For example, in China, fatal self-poisoning using pesticides is commonly carried out by young females in rural areas.[36] Studies in Sri Lanka also showed high risk of pesticide suicides in young people.[37]

Factors that influence trends in pesticide suicide

One possible contributor to the reduction in pesticide suicide is the marked decline in the exposed population. In industrialising countries like Taiwan the proportion of the population involved in agriculture declines with increases in the mechanisation of farming; thus the number of people with easy access to pesticides is likely to decrease and this may lead to reductions in pesticide suicides. We also found no marked changes in pesticide sales over the study period. This supports the possibility that it is the increase in mechanisation of farming and the decline in the agricultural population rather than the decrease in pesticide use that contributed to the reduction in pesticide suicide. A further contributor may be a move towards larger farms and more affluent farmers – high socioeconomic position is associated with a reduced risk of suicide. This possibility is not, however, supported by the available data which show that farmers' income relative to non-farmers' income has not changed over the study period (71% in 1987 versus 69% in 2009).[22] In contrast, South Korea, another emerging Asian economy, witnessed a marked rise in pesticide suicide between 1991 and 2005[10, 11] when its level of agricultural workforce declined nearly 50% over the same period.[38] Reasons for these differences require further investigations.

There was no clear evidence for a beneficial effect of bans on selected pesticide products in Taiwan. The most likely explanation for the limited impact on pesticide suicide is that these bans have not included the pesticides accounting for the most deaths e.g. paraquat, which is still commonly used in Taiwan. In the 1990s Taiwan's Council of Agriculture required that paraquat should have emetics as well as stenching and colouring agents added to make it difficult to be ingested and absorbed,[39] aiming to reduce the incidence and fatality of paraquat poisoning. There have been no studies investigating the impact of these measures on trends in paraquat poisoning; however, they did not appear to impact on its high case-fatality. In studies conducted in Taiwan before 2000,[30, 40, 41] the case fatality of paraquat poisoning was reported to be 54-75%; this was comparable to the results (68-88%) of studies conducted after 2000.[42-44] A recent study in Sri Lanka also showed that changes in formulations for paraquat did not lead to clinically significant reductions in case fatality.[34] Furthermore, some toxic OPs such as methamidophos, dimethoate and fenthion that are highly toxic to humans[32, 45] have not been banned in Taiwan.

Another possible reason for the lack of impact of pesticide bans on suicide in Taiwan is that some bans were merely limited or partial – these bans were restricted to high-strength products but not their equivalent lower strength products; some of these lower strength products were still popular on the market. Although bans placed on parathion, EPN and monocrotophos were more complete, these three pesticides accounted for only a small proportion (13.4%) of deaths from OP poisoning.[32]

However, it is of note that the two-thirds reduction of pesticide suicide rates in Taiwan occurred against the background of a 69% increase in suicide by other methods – it is possible that the bans may have prevented a similar rise in pesticide suicide as factors influencing the rise in suicides, e.g. unemployment,[24] are unlikely to affect suicides by non-pesticide methods only.

Better accessibility to treatment and improved medical management of pesticide poisoning may have contributed to reductions in case fatality and thus pesticide suicide in Taiwan over the study period. However, it is unknown whether case fatality of pesticide poisoning has reduced in Taiwan. A study in Sri Lanka found a reduction in case fatality of pesticide poisoning in 1986-2000;[7] this was thought to be due to the ban on all WHO Class I pesticides in 1995 and endosulfan in 1998 when the availability of highly toxic pesticides was restricted. Taiwan has not banned all the Class I pesticides and some of the most toxic pesticides, such as paraquat, are still widely available; thus Taiwan's bans on selected pesticide products may have had limited impact on case fatality.

Finally, substitution of methods may have occurred over the study period, i.e. suicidal people who may have ingested pesticides shifted towards other emerging popular methods. An epidemic of suicide – carbon monoxide poisoning by burning barbecue charcoal – contributed to a marked rise in overall suicide rates in Taiwan after 2000.[19] However, charcoal-burning suicides showed little similarities in their age and geographic patterns to pesticide suicides – their rates were higher amongst middle-aged people than other age groups and were higher in urban than rural areas,[19,

[46] whilst our data showed that pesticide suicide rates were highest in the elderly and recent studies showed higher rates in rural than urban areas.[21, 46] Therefore method substitution between pesticide ingestion and charcoal burning is unlikely to account for the reduction in pesticide suicide in Taiwan, although a shift towards other methods such as hanging or drowning could not be ruled out.

Policy implications

Pesticides are readily available in rural areas of developing countries and self-poisoning using pesticides has caused many tragic deaths in these regions.[2, 47] Our study showed that in rapidly industrialising countries such as Taiwan pesticides also contributed to a substantial proportion of suicide deaths. Similar high rates of pesticide suicide have also been documented in South Korea.[15] Strategies to prevent deaths from pesticide self-poisoning may have a large impact on the global burden of suicide.

One strategy to reduce these deaths is to restrict the availability of toxic pesticides.[3-5] However, our data suggested limited benefit of Taiwan's pesticide bans, which were restricted to a selected number of mainly high-strength products and did not include toxic pesticides causing the most deaths. Therefore, when aiming to reduce pesticide self-poisoning deaths by regulating the availability of toxic pesticides, strategies should be applied to enforce restrictions on access to pesticides that are highly toxic to humans. One sensible approach is to withdraw all Class I pesticides, following the advice from the UN Food and Agriculture Organization,[48] as well as selected Class II pesticides that are known to be highly lethal for human subjects.[45] Another recommended approach is the introduction of a minimum pesticides list to restrict pesticide use to a small number of pesticides with the least human toxicity.[3] As a recent study showed that paraquat and methomyl accounted for nearly two thirds of all pesticide suicides in Taiwan,[33] it could be estimated that banning these two pesticides alone may result in a >50% reduction in pesticide suicides and a >5% reduction in overall suicides, based on our finding that pesticide poisoning accounted for 12% of all suicides in 2010.

CONCLUSIONS

Our data showed a marked reduction in pesticide suicide in Taiwan over the last two decades. Secular trends in pesticide suicide were strongly associated with changes in exposures to pesticides, as indicated by the size of agricultural workforce. Bans on selected pesticide products that do not include toxic pesticides accounting for the most deaths will have only limited benefit in preventing pesticide suicide. Even with a reduced exposure due to reductions in farming population, in countries where pesticide self-poisoning is still a common method targeted prevention strategies may have considerable impact on overall suicide mortality if the most toxic pesticides could be removed completely from the market.

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TABLES WITH CAPTIONS

Table 1. Bans on 36 pesticide products classified as highly toxic in Taiwan, 1972-2010.

No	Banned pesticide product[a]	Banned formulation[b]	Date of sale and use banned	Chemical category	WHO classification[c]	Products containing the same pesticide(s) with different formulations available on the market by the end of 2010[d]	Deaths (%) caused due to single organophosphate exposure[e]
1	Leptophos	All formulations	01 June 1978	OP	O	Nil	0 (0%)
2	Captafol[f]	All formulations	01 October 1988	Sulfanilamide	Ia	Nil	NA
3	Captafol-Polyoxins[f]	All formulations	01 October 1988	Sulfanilamide	Ia	Nil	NA
4	Captafol-Zn,Cu[f]	All formulations	01 October 1988	Sulfanilamide	Ia	Nil	NA
5	Endosulfan	35% EC	15 January 1990	Organochlorine	II	14 brands of 3% DP	NA
6	Aldicarb	All formulations	01 January 1992	Carbamate	Ia	Nil	NA
7	Parathion	47% EC	01 January 1997	OP	Ia	Nil	25 (4.8%)
8	Parathion + malathion	50% EC	01 January 1997	OP	Ia-III	Nil	NA
9	Pirmiphosmethyl + mevinphos	50% EC	01 January 1997	OP	Ia-Ia	Nil	NA
10	Prothoate	40% EC	01 January 1997	OP	O	Nil	0 (0%)
11	EPN	All formulations	01 August 1998	OP	Ia	Nil	20 (3.8%)
12	EPN + methyl-parathion	All formulations	01 August 1998	OP	Ia-Ia	Nil	NA
13	Dichlorvos[f]	50% EC	01 August 1998	OP	Ib	Nil	4 (0.8%)
14	Fonofos	47.3% EC	01 January 1999	OP	O	Nil	0 (0%)
15	Carbofuran	75% and 85% of WP	01 January 1999	Carbamate	Ib	27 brands of 3% GR, 2 brands of 37.5% WPSB, 21 brands of 40.64% SC, 1 brand of 44% SC	NA
16	Mevinphos	25.3% EC	01 January 1999	OP	Ia	10 brands of 10% SL, 2 brands of 10% EC	138 (26.3%)
17	Ethoprop	70.6% EC	01 January 1999	OP	Ia	4 brands of 10% GR	0 (0%)
18	Prothiophos + mevinphos	45.3% EC	01 January 1999	OP	II-Ia	Nil	NA
19	Phosphamidon + mevinphos	70% SL	01 January 1999	OP	Ia-Ia	2 brands of 40% WP	NA
20	Phosphamidon	51% SL	01 January 1999	OP	Ia	Nil	0 (0%)
21	Monocrotophos	55% SL	01 September 2000	OP	Ib	1 brand of 8% GR	25 (4.8%)
22	Methomyl	90% WP and SG	01 June 2006	Carbamate	Ib	39 brands of 24% SL, 1 brand of 25% SP, 25 brands of 40% SP, 1 brand of 40% SG, 1 brand of 40% SPSB	NA
23	Dichlorvos[f]	30% FU	31 December 2008	OP	Ib	Nil	4 (0.8%)
24	Methyl-parathion	50% EC	31 December 2008	OP	Ia	1 brand of 40% CS	11 (2.1%)
25	Azinphos-methyl	20% EC	31 December 2008	OP	Ib	13 brands of 25% WP	1 (0.2%)
26	Carbofuran + phosmet	50% WP	31 December 2008	Carbamate + OP	Ib-II	5 brands of 4% GR	NA
27	Disulfoton + ethoprop	10% GR	31 December 2008	OP	Ia-Ia	Nil	NA
28	Ethoprop	45% EC	31 December 2008	OP	Ia	See above	See above
29	MIPC (isoprocarb) + ethoprophos	40% EC	31 December 2008	Carbamate + OP	II-Ia	Nil	NA
30	Phosphamidon + mevinphos	35% SL	31 December 2008	OP	Ia-Ia	2 brands of 10% WP	NA
31	Phosphamidon	25% SL and 50% WP	31 December 2008	OP	Ia	Nil	0 (0%)
32	Omethoate	50% SL	31 December 2008	OP	Ib	Nil	6 (1.1%)
33	Oxamyl	24% SL	31 December 2008	Carbamate	Ib	3 brands of 10% SL and 3 brands of 10% GR	NA
34	Formetanate	50% SP	31 December 2008	Carbamate	Ib	3 brands of 20% SP	NA
35	Dicrotophos	27.4% SL	31 December 2008	OP	Ib	Nil	0 (0%)
36	Methidathion	40% EC	31 December 2010	OP	Ib	1 brand of 40% WPSB	4 (0.8%)

Abbreviation: organophosphate (OP).

[a]Data source: Bureau of Animal and Plant Health Inspection and Quarantine, Council of Agriculture, Taiwan (1972-2010).[13] The first ban was placed on an organic pollutant in 1972 but the first ban on pesticides due to the concern of human toxicity was implemented in 1978 (Leptophos).

[b]Abbreviations of formulations: capsule suspension (CS); dustable powder (DP); dustable powder (DP); emulsifiable concentrate (EC); emulsion, oil in water (EW); smoke generator (FU); granule (GR); suspension concentrate (SC); water soluble granules (SG); soluble concentrate (SL); water soluble powder (SP); water soluble powder in water soluble bag (SPSB); ultra-low volume liquid (UL); wettable powder (WP); wettable powder in water soluble bag (WPSB).

[c]WHO classification: Ia = Extremely hazardous; Ib = Highly hazardous; II = Moderately hazardous; III = slightly hazardous; U = Unlikely to present acute hazard in normal use; O = Obsolete as pesticide, not classified.

[d]Data source: Bureau of Animal and Plant Health Inspection and Quarantine, Council of Agriculture, Taiwan.[27]

[e]Of 524 deaths reported to the Taiwanese National Poison Control Centre between 1985-2006;[30] 103 (19.7%) were caused by unknown OPs.

[f]Banned due to their carcinogenic effects. Captafol is a fungicide.

Table 2. Numbers, proportions and age-standardised rates suicides by pesticide poisoning and overall suicide rates in Taiwan, 1987, 1992, 1997 and 2002-2010

	Pesticide suicide						
	Suicide	Undetermined	Accident	Suicide, undetermined death and accident combined			Overall suicide rate per 100 000[a]
Year	N	N	N	N	(% of all suicides[a])	Rate per 100 000	
1987	611	8	370	989	(42.0)	7.7	18.8
1992	268	24	281	573	(28.0)	4.0	14.3
1997	443	99	156	698	(24.8)	4.4	17.5
2002	505	144	59	708	(17.6)	4.0	22.3
2003	479	85	50	614	(15.2)	3.4	22.0
2004	484	85	48	617	(14.7)	3.3	22.4
2005	537	98	55	690	(13.8)	3.6	26.2
2006	493	65	39	597	(11.8)	3.1	26.1
2007	475	72	32	579	(12.7)	2.9	23.2
2008	494	49	15	558	(12.1)	2.7	23.1
2009	483	41	26	550	(11.9)	2.6	22.6
2010	478	49	19	546	(12.3)	2.5	21.3

[a]Including certified suicide, undetermined death, and accidental pesticide poisoning/suffocation.

FIGURE CAPTIONS

Fig. 1. Trends in pesticide[a] and non-pesticide[b] suicide, agricultural workers, pesticide sales and unemployment in Taiwan, 1987-2010[c].

[a]Including certified suicide, undetermined death and accident.

[b]Including certified suicide, undetermined death and accidental suffocation.

[c]Years are highlighted when bans became effective on pesticide products regarded as highly toxic in Taiwan, except the first ban implemented in 1978 (see Table 1 for numbered bans). Data for suicide were age-standardised rates in 1987, 1992, 1997 and 2002-2010; estimated rates were shown in dotted lines for other years in the period based on linear interpolation.

Fig. 2. Sex- and age-specific trends in pesticide suicide[a] in Taiwan, 1987-2010[b].

[a]Including certified suicide, undetermined death and accident.

[b]Data for pesticide suicide were age-standardised rates in 1987, 1992, 1997 and 2002-2010; estimated rates were shown in dotted lines for other years in the period based on linear interpolation.

Supplementary material 1

Trends in pesticide suicide[a], non-pesticide suicide (excluding charcoal-burning suicide)[b] and suicide/undetermined death by solids/liquids poisoning and accidental pesticide poisoning[c] in Taiwan.

[a]ICD-10 X48, X68 and Y18; data were for 1987, 1992, 1997 and 2002-2010.

[b]ICD-10 X60-X84 (excluding X67), Y10-Y34 (excluding Y17) and W75-W76; data were for 1987, 1992, 1997 and 2002-2010.

[c]ICD-9 E950, E980 and E863; data were for 1987-2008.