

Rejecting the Grain Is Not the Cheapest Way to Prevent the Cancer: Aflatoxin Control in Maize Weighed Against Supply

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Abstract

Background. Aflatoxin B₁ in maize is a group 1 human carcinogen and a cause of hepatocellular carcinoma, and its potency is far higher in people chronically infected with hepatitis B. Control is usually framed as enforcement of a regulatory limit, which removes contaminated lots from the food supply. In settings where maize is the staple and supply is tight, rejecting grain is not a costless intervention.

Objective. To quantify population aflatoxin exposure and the resulting liver cancer risk from a realistic contamination distribution, to examine how hepatitis B prevalence modifies that risk, and to compare agricultural prevention against regulatory enforcement on the two axes that matter: risk reduction and maize supply rejected.

Methods. Five hundred thousand maize lots were simulated with a log-normal aflatoxin B₁ distribution of median 8 µg/kg and log standard deviation 1.5, combined with log-normal maize intake around 300 g per day and a body weight distribution, giving individual exposure in ng per kg body weight per day. Liver cancer risk was computed with potency factors of 0.30 cases per 100,000 per year per unit exposure in hepatitis B surface antigen positive individuals and 0.01 in negative individuals, across population prevalences from 2 % to 15 %. Eight scenarios were evaluated: improved drying, improved storage, their combination, hand sorting, enforcement of 20 and 10 µg/kg limits, and prevention combined with enforcement.

Results. Mean contamination was 24.6 µg/kg against a median of 8.0, with 27.1 % of lots above 20 µg/kg, and the most contaminated tenth of lots carried 58.4 % of total population exposure. Mean exposure was 145.2 ng/kg body weight per day. Risk rose from 2.29 to 7.77 cases per 100,000 per year as hepatitis B prevalence rose from 2 % to 15 %, with 84.1 % of the burden falling on the infected minority at the higher prevalence. Enforcing a 20 µg/kg limit reduced risk by 74.2 % but rejected 27.1 % of the maize supply; a 10 µg/kg limit reduced risk by 84.3 % and rejected 44.1 %. Improved drying and storage together reduced risk by 55.1 % with no supply rejected, and prevention followed by the 20 µg/kg limit achieved 81.5 % risk reduction while rejecting only 12.7 %.

Conclusions. Enforcement alone buys risk reduction with food supply at a rate of 2.7 percentage points of risk per percentage point of maize rejected; prevention first raises that to 6.4. Where hepatitis B prevalence is high, vaccination coverage is a determinant of aflatoxin-attributable cancer comparable in magnitude to the contamination itself.

Keywords: aflatoxin; maize; food safety; hepatocellular carcinoma; hepatitis B; risk assessment.

1. Introduction

Aflatoxins are produced by *Aspergillus* species growing on crops in the field and, more importantly, during storage when moisture and temperature permit. Aflatoxin B₁ is among the most potent naturally occurring carcinogens known, is classified as carcinogenic to humans, and causes hepatocellular carcinoma through a characteristic mutational signature in the TP53 gene. It also has non-cancer effects, with growing evidence linking chronic exposure to impaired child growth.

The contamination is an agricultural phenomenon with a medical consequence, and the two ends of that chain are usually managed by different ministries. Agriculture manages drying, storage and handling; health and standards bodies manage a maximum permitted concentration, typically 20 µg/kg for total aflatoxins in many jurisdictions and 4 µg/kg in others. Enforcement of the limit means that lots exceeding it are diverted from human food.

Where maize is a traded commodity that is one intervention among many. Where maize is the staple, eaten daily by a population with limited alternatives, rejecting a quarter of the harvest is a food security event. Contaminated maize that is refused by a formal market does not disappear; it moves into informal channels, into the household's own consumption, or into animal feed from which aflatoxin M₁ returns in milk. Enforcement in that setting is not obviously the dominant strategy, and the comparison against prevention has rarely been made on a common scale.

This study makes that comparison. Three questions are addressed: how population exposure is distributed and how concentrated it is in the worst lots; how far hepatitis B prevalence modifies the resulting cancer burden; and what each control strategy achieves per unit of maize removed from the food supply.

2. Methods

2.1 Exposure model

Individual exposure was computed as

$$E = C \times I / BW \quad (1)$$

where *C* is the aflatoxin B₁ concentration in the maize consumed (µg/kg), *I* the daily maize intake (g/day) and *BW* body weight (kg), giving exposure in ng per kg body weight per day. Five hundred thousand individuals were simulated, each drawing independently from the three distributions.

Table 1. Model inputs

Input	Distribution	Basis
Aflatoxin B ₁ concentration	Log-normal, median 8 µg/kg, log SD 1.5	Reproduces the strong right skew characteristic of mycotoxin survey data
Maize intake	Log-normal, median 300 g/day, log SD 0.45, truncated 20–1,200 g	A maize-staple diet
Body weight	Normal, mean 58 kg, SD 11, truncated 35–110 kg	Adult population
Cancer potency, HBsAg positive	0.30 cases per 100,000 per year per ng/kg bw/day	Higher-potency group
Cancer potency, HBsAg negative	0.01 cases per 100,000 per year per ng/kg bw/day	Lower-potency group
Hepatitis B prevalence	2 %, 5 %, 10 %, 15 %	Spans low to high endemicity

Input	Distribution	Basis
Individuals simulated	500,000	Monte Carlo error negligible

Note. The thirtyfold difference in potency between hepatitis B positive and negative individuals is the central feature of the dose–response relationship for this carcinogen and is the reason the same diet produces very different burdens in different populations. All values are representative assumptions for modelling and are not estimates for any country or survey.

2.2 Scenarios

Two families of control were modelled. Preventive measures reduce the concentration in all lots without removing any: improved drying to safe moisture before storage, modelled as a 40 % reduction, and improved storage conditions, modelled as 25 %. Removal measures reject lots above a threshold, retaining the rest: hand sorting of visibly mouldy and damaged kernels, modelled as rejection above 50 µg/kg, and enforcement of a 20 or 10 µg/kg regulatory limit.

The distinction matters for the outcome measured. Preventive measures shift the whole distribution and cost no supply; removal measures truncate it and cost the rejected fraction. A combined scenario applies prevention first and then the 20 µg/kg limit, which is how the two would be deployed in practice.

3. Results

3.1 Contamination and exposure

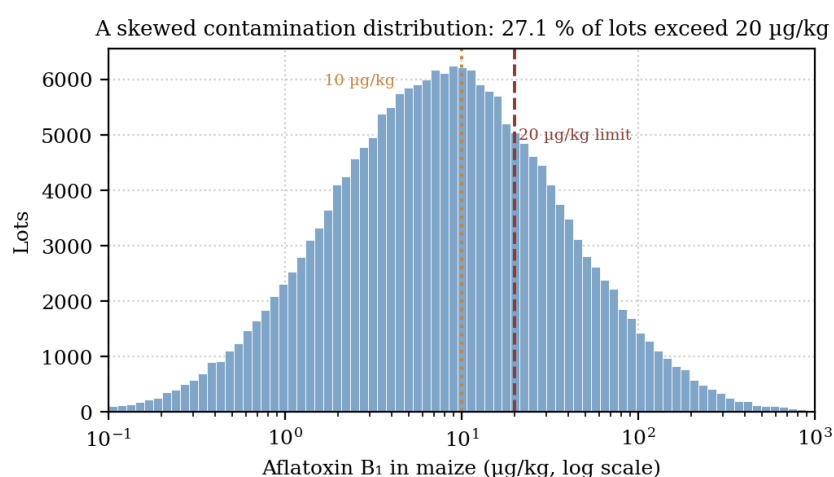


Figure 1. Simulated distribution of aflatoxin B₁ in maize lots, on a logarithmic scale.

Table 2. Baseline contamination and exposure

Quantity	Value
Median concentration	8.0 µg/kg
Mean concentration	24.6 µg/kg
95th percentile concentration	94.4 µg/kg
Lots above 10 µg/kg	44.1 %
Lots above 20 µg/kg	27.1 %
Mean maize intake	332 g/day
Mean exposure	145.2 ng/kg bw/day
95th percentile exposure	563.0 ng/kg bw/day

The mean concentration is three times the median, which is the signature of the log-normal form and the reason mean-based reporting of mycotoxin surveys is misleading in both directions: it overstates what a typical household eats and understates the range of what some do.

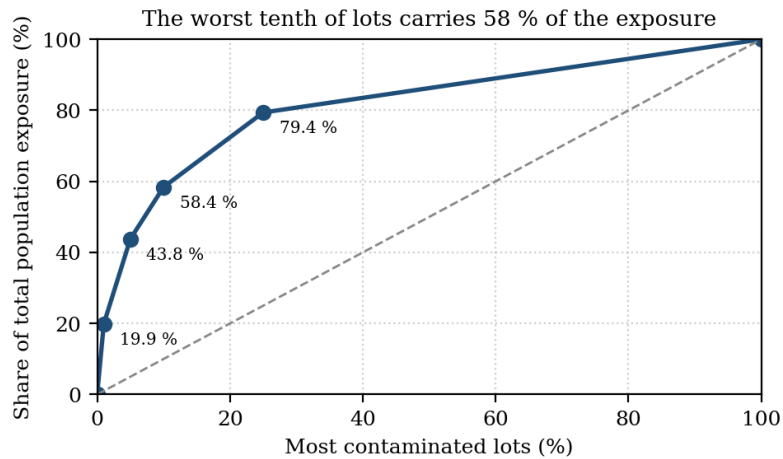


Figure 2. Share of total population exposure carried by the most contaminated lots.

The most contaminated 10 % of lots carry 58.4 % of total population exposure and the worst 1 % carry 19.9 %. This concentration is the single most useful property of the problem, because it means an intervention that identifies and removes a small fraction of the supply can remove a large fraction of the risk — which is the argument for sorting and for enforcement, and is quantified in Section 3.3.

3.2 Hepatitis B as the dominant effect modifier

Table 3. Liver cancer risk by population hepatitis B prevalence

HBsAg prevalence	Cases per 100,000 per year	Share of burden in HBsAg-positive individuals
2 %	2.29	38.0 %
5 %	3.56	61.2 %
10 %	5.66	76.9 %
15 %	7.77	84.1 %

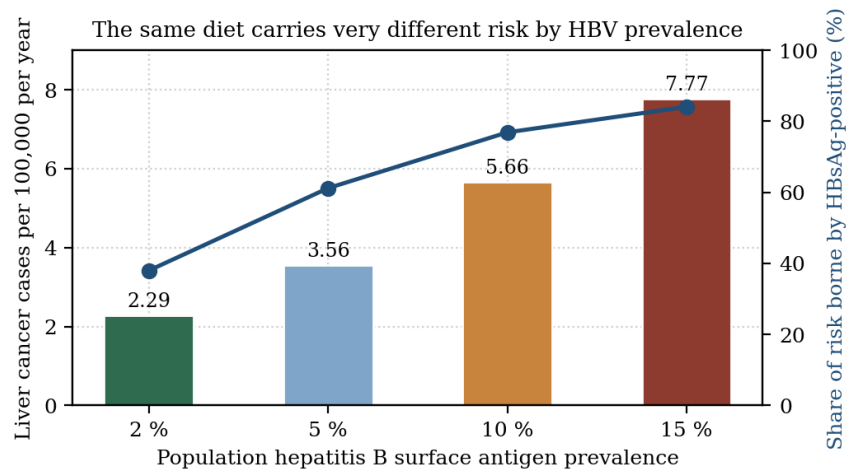


Figure 3. Aflatoxin-attributable liver cancer risk and the share borne by hepatitis B carriers.

The same maize, eaten in the same quantity, produces 2.29 cases per 100,000 per year in a population with 2 % hepatitis B prevalence and 7.77 in one with 15 % — a factor of 3.4 driven entirely by the host rather than by the food.

The second column is the more consequential observation. At 15 % prevalence, 84.1 % of the aflatoxin-attributable cancer falls on the 15 % of the population who are chronically infected. The burden is not

distributed across the population eating the maize; it is concentrated in a identifiable minority whose susceptibility is thirty times higher and who are, in most settings, already known to the health system or identifiable by a cheap test.

This has a consequence that does not follow from food safety reasoning at all. Hepatitis B vaccination reduces aflatoxin-attributable liver cancer by removing the high-potency group, and at high endemicity it addresses the larger share of the burden than a partial reduction in contamination would. Aflatoxin control and hepatitis B control are substitutes at the margin for this particular outcome, and neither ministry ordinarily evaluates them against each other.

3.3 What each control strategy achieves

Table 4. Control scenarios: exposure, risk and supply

Scenario	Mean concentration (µg/kg)	Mean exposure (ng/kg bw/day)	95th percentile exposure	Supply retained	Risk at 5 % HBsAg	Risk reduction
Baseline	24.6	145.2	563.0	100 %	3.56	—
Improved storage (–25 %)	18.4	108.9	422.2	100 %	2.67	25.0 %
Improved drying (–40 %)	14.7	87.1	337.8	100 %	2.13	40.2 %
Drying + storage (–55 %)	11.1	65.4	253.3	100 %	1.60	55.1 %
Hand sorting above 50 µg/kg	10.8	64.1	228.1	88.9 %	1.57	55.9 %
Enforce 20 µg/kg	6.3	37.4	115.4	72.9 %	0.92	74.2 %
Enforce 10 µg/kg	3.9	23.1	65.3	55.9 %	0.56	84.3 %
Drying + storage + 20 µg/kg	4.6	27.1	94.8	87.3 %	0.66	81.5 %

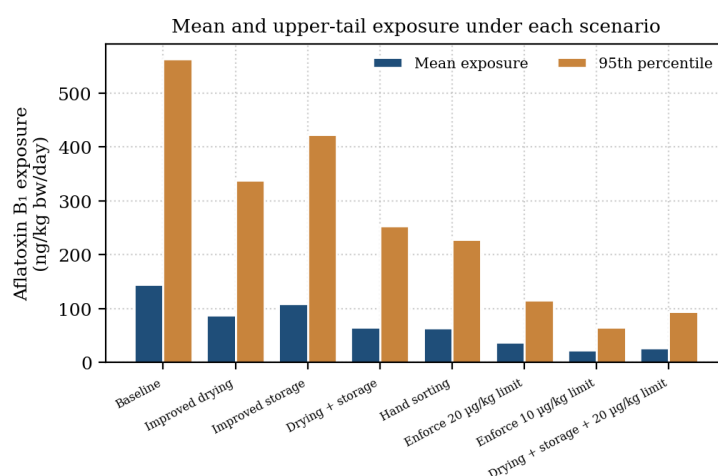


Figure 4. Mean and 95th-percentile exposure under each control scenario.

Read down the risk reduction column alone, the strictest limit wins: enforcing 10 µg/kg removes 84.3 % of the risk, more than any other single measure. Read the supply column alongside it and the picture changes, because that reduction is bought by rejecting 44.1 % of the maize.

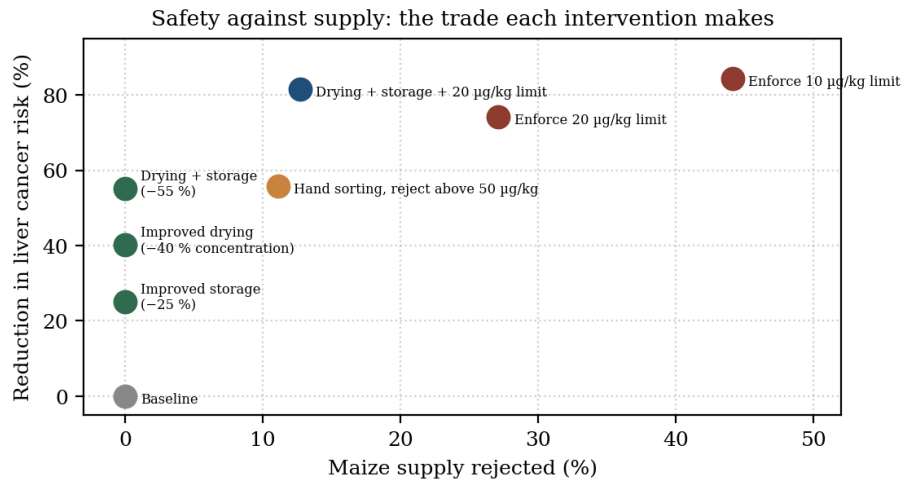


Figure 5. Risk reduction against maize supply rejected for each scenario.

Figure 5 separates the scenarios into three groups. The preventive measures sit on the vertical axis: they deliver up to 55.1 % risk reduction at zero supply cost, because they lower contamination rather than removing food. The enforcement measures sit along a diagonal, buying risk reduction with supply. The combined scenario sits above the diagonal, which is the finding of this study.

3.4 The efficiency of each trade

Table 5. Risk reduction per unit of maize rejected

Scenario	Risk reduction	Supply rejected	Risk reduction per 1 % of supply rejected
Drying + storage	55.1 %	0 %	No supply cost
Hand sorting above 50 µg/kg	55.9 %	11.1 %	5.04
Enforce 20 µg/kg	74.2 %	27.1 %	2.74
Enforce 10 µg/kg	84.3 %	44.1 %	1.91
Drying + storage + 20 µg/kg	81.5 %	12.7 %	6.42

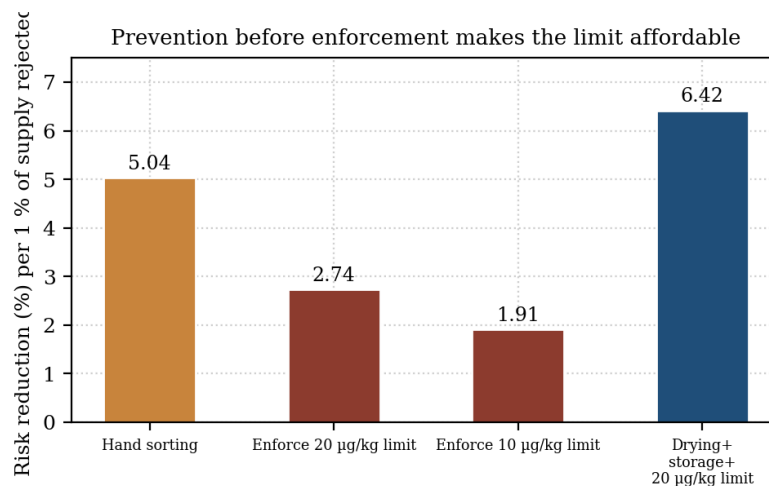


Figure 6. Risk reduction achieved per percentage point of maize supply rejected.

Enforcement alone becomes progressively less efficient as the limit tightens: 5.04 percentage points of risk per point of supply at a sorting threshold of 50 µg/kg, 2.74 at 20 µg/kg and 1.91 at 10 µg/kg. The reason is the shape of the distribution. The first lots rejected are the extreme ones carrying

disproportionate exposure; as the threshold falls, each additional rejected lot carries progressively less of the remaining risk while costing the same amount of food.

Prevention before enforcement reverses that decline. Applying drying and storage improvements first shifts the whole distribution downward, so that far fewer lots exceed 20 µg/kg when the limit is then applied: 12.7 % rejected instead of 27.1 %, for 81.5 % risk reduction instead of 74.2 %. The efficiency rises to 6.42, better than any enforcement-only option and better than sorting.

The practical reading is that a regulatory limit is not an alternative to agricultural improvement but a complement whose cost depends on it. The same limit, applied to a better-dried harvest, rejects less than half as much food and prevents more disease. Sequencing matters, and a food safety programme that begins with enforcement in a system that has not addressed drying is choosing the expensive order.

4. Discussion

4.1 Principal findings

Four results follow. Exposure is highly concentrated, with the worst tenth of lots carrying 58.4 % of the total, which is what makes removal-based control effective at all. Hepatitis B prevalence changes the resulting cancer burden by a factor of 3.4 across the range examined and concentrates 84.1 % of it in the infected minority at high endemicity. Enforcement of a 20 µg/kg limit removes 74.2 % of the risk and 27.1 % of the maize supply. And prevention applied before enforcement achieves 81.5 % risk reduction while rejecting 12.7 %, raising the efficiency of the trade from 2.74 to 6.42.

4.2 Implications for policy

Table 6. Implications

Finding	Implication	Recommendation
Worst 10 % of lots carry 58 % of exposure	Targeted removal is disproportionately effective	Prioritise identifying the extreme tail, not average compliance
Mean concentration is 3× the median	Survey means misdescribe typical exposure	Report distributions, not mean contamination
Risk varies 3.4-fold with HBV prevalence	The same food is not equally dangerous everywhere	Set control intensity against local hepatitis B burden
84 % of burden in the infected minority	Vaccination addresses the same cancer	Evaluate aflatoxin control alongside hepatitis B vaccination coverage
20 µg/kg limit rejects 27 % of supply	Enforcement has a food security cost	Account for rejected supply explicitly in limit-setting
Efficiency falls as the limit tightens	Each further reduction costs more food	Do not tighten limits without modelling the supply consequence
Prevention first raises efficiency 2.74 → 6.42	Sequencing determines the cost of a limit	Invest in drying and storage before enforcing, not after

The fourth row is the cross-sector point and is the one least likely to be acted on, because it requires two ministries to compare interventions they each own. At a hepatitis B prevalence of 15 %, the infected sixth of the population carries five sixths of the aflatoxin-attributable cancer, so expanding vaccination and expanding aflatoxin control address substantially the same disease burden through different mechanisms. Whichever is cheaper per case prevented should be done first, and neither sector currently computes that comparison.

The fifth and seventh rows together are the paper's main operational message. Rejected maize is not destroyed risk; it is displaced food, and in a maize-staple setting it frequently reappears in informal markets, in household consumption or in animal feed, from which aflatoxin M₁ returns through milk. A

limit enforced without a prevention programme therefore achieves less than the modelled 74.2 % and costs more than the modelled 27.1 %, and the direction of both errors favours doing the agricultural work first.

4.3 Limitations

The dose–response model is a linear potency applied to mean exposure, which is the convention for aflatoxin risk assessment and is a simplification of a process involving decades of latency, cumulative dose and interaction with other liver insults including alcohol and hepatitis C. It attributes cancer to current exposure rather than to a lifetime history, so the absolute rates reported should be read as comparative indices rather than as incidence predictions.

Rejected lots are treated as leaving the human food supply entirely. In practice they are frequently diverted rather than destroyed, so the risk reduction from enforcement is overstated here, possibly substantially, and the advantage of prevention over enforcement is correspondingly understated. Modelling the diversion pathway explicitly, including the feed-to-milk route for aflatoxin M₁, would be the most valuable extension of this analysis.

Only the cancer endpoint is modelled. Aflatoxin exposure is also associated with impaired child growth and with immune effects, which fall on a different age group and would be counted differently; a child-growth endpoint would weight exposure in young children rather than mean population exposure and could change the ranking of interventions. Concentration, intake and body weight are treated as independent, whereas households with poor storage may also be those with the highest maize dependence, and that correlation would increase exposure inequality beyond what is modelled.

All parameter values are representative assumptions rather than measurements. Contamination distributions vary enormously with season, rainfall at harvest, variety and region, the intervention effect sizes for drying and storage are illustrative, and the potency factors are subject to substantial uncertainty. Absolute figures should not be quoted for any population, and the analysis should be recomputed with local survey data before informing a decision.

5. Conclusion

Aflatoxin control is usually posed as a question about a limit. On this analysis the limit is the expensive part of the answer. Enforcing 20 µg/kg removed 74.2 % of the modelled liver cancer risk and 27.1 % of the maize supply; tightening to 10 µg/kg removed 84.3 % of the risk and 44.1 % of the food, at a falling rate of return because the extreme lots that carry most of the exposure have already been taken out.

Improved drying and storage removed 55.1 % of the risk with no supply cost at all, and applying them before the same 20 µg/kg limit produced 81.5 % risk reduction while rejecting 12.7 % rather than 27.1 %. The efficiency of the trade rose from 2.74 to 6.42 percentage points of risk per point of maize forgone. The limit is not an alternative to agricultural improvement; its affordability depends on it, and the sequence in which the two are deployed determines how much food a given level of safety costs.

One further result belongs to neither sector alone. Where hepatitis B prevalence is 15 %, the infected sixth of the population carries 84 % of the aflatoxin-attributable cancer, so vaccination and aflatoxin control are addressing the same disease from opposite ends. The comparison between them is a comparison worth making, and it will not be made by a food safety analysis or a hepatitis programme working separately.

Declarations

Ethical approval. Not applicable. This is a quantitative risk assessment using simulated exposures and published potency values; no human participants, biological samples or identifiable data were involved.

Funding. [To be completed by the authors.]

Conflicts of interest. [To be completed by the authors.]

Scope disclaimer. No country, region, commodity chain, regulatory authority or programme is evaluated. Contamination distributions, intervention effect sizes and potency factors are representative assumptions; absolute risk figures are comparative indices and must not be cited as incidence estimates for any population.

Public health disclaimer. Nothing here constitutes a recommendation to relax any statutory limit. The analysis compares control strategies on modelled outcomes and does not address legal obligations, trade requirements or the acceptability of residual risk, each of which is decided by the competent authority.

Data and code availability. No survey or surveillance data were used. All results were generated by the model described in Section 2; the code, run with a fixed random seed, reproduces every reported value and is available from the corresponding author.

Author contributions. [To be completed by the authors in accordance with ICMJE authorship criteria.]

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