

Tonnes Are the Wrong Unit: Post-Harvest Loss Measured in Micronutrients and Its Consequence for Dietary Adequacy

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Abstract

Background. Post-harvest loss is measured, reported and targeted in tonnes or in calories, and interventions are prioritised accordingly — which directs effort toward staple grains, where the tonnage is. Losses are not distributed evenly across food groups, and the groups that lose most are the perishable, micronutrient-dense ones. The nutritional consequence of that asymmetry has rarely been quantified.

Objective. To re-express post-harvest loss in nutrient units rather than mass, to identify which food groups dominate the loss of each nutrient, and to estimate the effect of targeted loss-reduction scenarios on the prevalence of inadequate intake.

Methods. A farm-gate-to-consumer supply model was constructed for seven food groups with stage-specific loss fractions at harvest, storage, transport, processing and retail. Nutrient densities were applied to compute supply at each stage for energy, protein, iron, zinc, vitamin A, vitamin C and folate. Prevalence of inadequate intake was estimated by comparing a log-normal intake distribution around the per-capita supply with the estimated average requirement for each nutrient. Seven single-group scenarios halving losses in one group at a time, and a cold-chain scenario halving storage and transport losses in perishables only, were evaluated.

Results. Total losses ranged from 18.5 % for cereals to 39.2 % for fruits and 37.8 % for vegetables. Expressed in nutrients, 21.3 % of energy was lost against 35.6 % of vitamin A and 36.7 % of vitamin C — the micronutrient loss exceeded the mass loss by two thirds. The food groups responsible differed sharply: cereals supplied 58.5 % of the energy lost but only 0.7 % of the vitamin A, while vegetables supplied 6.1 % of the energy lost and 81.1 % of the vitamin A. Halving vegetable losses reduced modelled vitamin A inadequacy by 12.2 percentage points and energy inadequacy by 0.9; halving cereal losses reduced energy inadequacy by 9.2 points and vitamin A inadequacy by 0.1. A cold-chain intervention confined to perishables reduced vitamin A inadequacy by 6.3 points and vitamin C inadequacy by 3.9.

Conclusions. Loss-reduction programmes prioritised by tonnage and those prioritised by nutritional benefit select almost disjoint interventions. Where the public health problem is micronutrient deficiency rather than energy shortfall, investment in perishable-chain storage and transport delivers benefits that grain-focused programmes cannot.

Keywords: post-harvest loss; micronutrient adequacy; food systems; cold chain; vitamin A deficiency; public health nutrition.

1. Introduction

A substantial fraction of what agriculture produces never reaches anybody's plate. Grain is eaten by insects in store, milk sours on the way to market, tomatoes are bruised in transport and discarded at retail, and roots rot in heaps. The aggregate is routinely described as a scandal and is measured, almost universally, in tonnes.

Tonnes are a natural unit for an agricultural statistic and they encode a particular view of what food is for. If the purpose of the food system is to deliver mass or calories, then a programme that saves a tonne of maize and a programme that saves a tonne of spinach are equivalent, and the first is far cheaper per tonne saved. Loss-reduction investment follows that logic: storage technology for grains, hermetic bags, drying, warehouse management.

The purpose of the food system is not to deliver mass. In populations where the burden of malnutrition is increasingly micronutrient deficiency rather than energy deficit, what matters is whether the diet supplies iron, zinc, vitamin A, folate and the rest, and those nutrients are concentrated in exactly the foods that are hardest to keep. A tonne of spinach and a tonne of maize are not interchangeable, and a loss statistic that treats them as such will misdirect the response.

This study re-expresses post-harvest loss in nutrient units and follows the consequence through to dietary adequacy. Three questions are addressed: how much of each nutrient is lost, compared with how much mass and energy; which food groups are responsible for the loss of each nutrient; and what different targeting strategies would achieve for the prevalence of inadequate intake.

2. Methods

2.1 Supply chain model

Seven food groups were modelled from farm gate to consumer through five sequential stages: harvest and handling, storage, transport and distribution, processing, and retail and market. Surviving supply is the product of the surviving fractions at each stage,

$$S = \prod_{\text{stages}} (1 - l_i) \quad (1)$$

so that a group losing 10 % at each of five stages retains 59 % rather than 50 %. Household-level waste is excluded, since the question posed concerns the agricultural and distribution system rather than consumer behaviour.

Table 1. Food groups, farm-gate availability and stage losses

Food group	Farm gate (g/capita/day)	Harvest	Storage	Transport	Processing	Retail	Total loss
Cereals	420	5 %	7 %	2 %	4 %	2 %	18.5 %
Roots & tubers	180	9 %	12 %	5 %	3 %	5 %	29.9 %
Pulses	60	6 %	8 %	2 %	3 %	2 %	19.4 %
Vegetables	250	10 %	14 %	8 %	3 %	10 %	37.8 %
Fruits	160	11 %	13 %	9 %	3 %	11 %	39.2 %
Dairy	120	2 %	8 %	5 %	2 %	4 %	19.4 %
Meat & fish	70	3 %	9 %	6 %	4 %	5 %	24.3 %

Note. Loss fractions and availabilities are representative assumptions for a food system with limited cold chain, chosen to reflect the well-documented pattern that perishable groups lose more and lose it later in the chain. They are not estimates for any country.

2.2 Nutrient densities and adequacy

Nutrient densities per 100 g of edible portion were applied to the surviving supply of each group and summed. Prevalence of inadequate intake was estimated by the cut-point method: usual intake was modelled as log-normal around the per-capita supply with a nutrient-specific coefficient of variation, and the proportion falling below the estimated average requirement was computed.

Table 2. Nutrient densities, requirements and assumed intake variability

Nutrient	Richest group modelled	Estimated average requirement	Intake CV assumed
Energy (kcal)	Cereals, 350 per 100 g	2,100 kcal/day	25 %
Protein (g)	Pulses, 22.0 per 100 g	46 g/day	30 %
Iron (mg)	Pulses, 6.5 per 100 g	8.1 mg/day	35 %
Zinc (mg)	Meat & fish, 3.5 per 100 g	8.6 mg/day	30 %
Vitamin A (µg RAE)	Vegetables, 180 per 100 g	500 µg/day	60 %
Vitamin C (mg)	Fruits, 40 per 100 g	60 mg/day	55 %
Folate (µg)	Pulses, 480 per 100 g	320 µg/day	40 %

Note. Requirements are representative adult values. Per-capita supply is used as a proxy for mean usual intake, which overstates intake because it ignores household waste and inedible fractions; the resulting prevalence estimates are therefore indicative of relative rather than absolute burden. Section 4.3 sets out the consequences, including for the energy column, which is distorted because oils, fats and sugars are not among the groups modelled.

2.3 Scenarios

Two families of scenario were evaluated. Seven single-group scenarios halved the total loss in one food group at a time, holding all others at baseline, which isolates the nutritional return on a loss-reduction investment targeted at that group. One cold-chain scenario halved storage and transport losses in the four perishable groups simultaneously, representing refrigerated storage and distribution, and left harvest, processing and retail losses unchanged. All computation was performed in Python and reproduces from the parameters in Tables 1 and 2.

3. Results

3.1 Loss by group and by nutrient

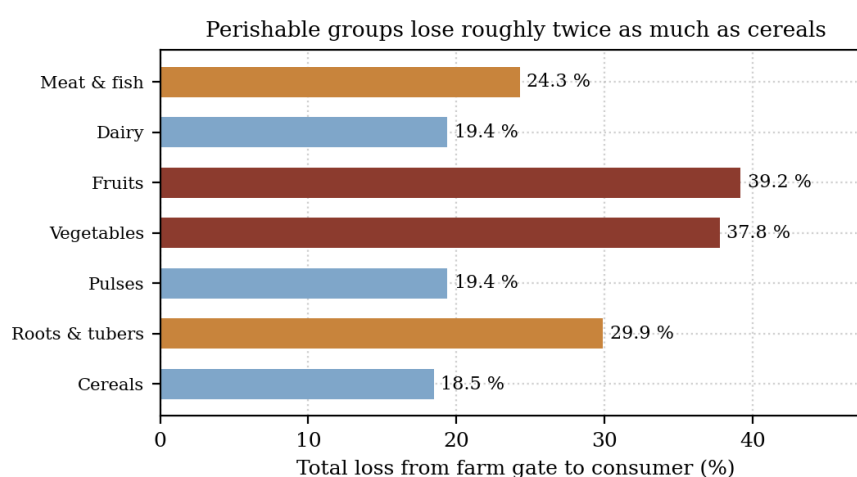


Figure 1. Total loss from farm gate to consumer by food group.

Losses range from 18.5 % for cereals and 19.4 % for pulses and dairy to 37.8 % for vegetables and 39.2 % for fruits. The perishable groups lose roughly twice as much as the storable ones, and they lose it

disproportionately in storage and transport rather than at harvest, which is where the chain lacks refrigeration.

Table 3. Supply and loss by nutrient

Nutrient	Farm-gate supply per capita per day	Consumer supply	Loss
Energy	1,914 kcal	1,506 kcal	21.3 %
Protein	73.4 g	57.5 g	21.6 %
Iron	15.2 mg	11.7 mg	23.2 %
Zinc	12.1 mg	9.4 mg	21.9 %
Vitamin A	624 µg RAE	402 µg RAE	35.6 %
Vitamin C	167 mg	106 mg	36.7 %
Folate	452 µg	338 µg	25.3 %

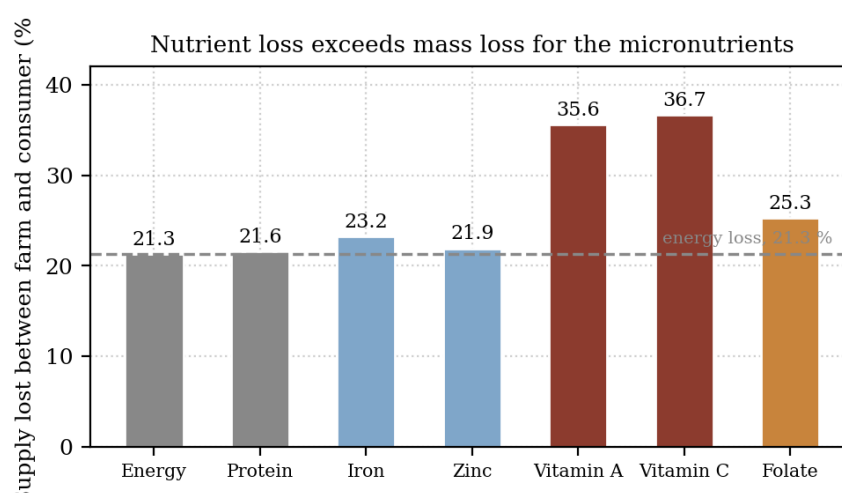


Figure 2. Proportion of each nutrient lost between farm gate and consumer, against the energy loss.

The headline comparison is between the first row and the fifth and sixth. Energy loss is 21.3 % and vitamin A loss is 35.6 %, two thirds higher; vitamin C loss is 36.7 %. Iron, zinc and protein track energy closely, because they are supplied largely by the storable groups, and folate sits between at 25.3 %.

A loss statistic expressed in tonnes or calories therefore understates the loss of the nutrients whose deficiency constitutes the public health problem, and understates it by the largest margin for vitamin A, which is among the deficiencies with the clearest clinical consequences.

3.2 Which groups lose which nutrients

Table 4. Share of each nutrient's total loss contributed by each food group (%)

Food group	Energy	Protein	Iron	Zinc	Vitamin A	Vitamin C	Folate
Cereals	58.5	46.8	39.3	46.1	0.7	0.0	15.1
Roots & tubers	10.4	5.8	5.8	5.3	1.3	13.7	8.4
Pulses	8.5	15.1	17.2	15.2	0.2	0.4	43.8
Vegetables	6.1	9.5	20.2	10.5	81.1	54.1	20.3
Fruits	7.4	2.4	3.8	2.6	10.5	31.3	3.9
Dairy	3.3	3.6	0.5	3.5	5.0	0.4	0.8
Meat & fish	5.8	16.8	13.2	16.8	1.2	0.0	0.7

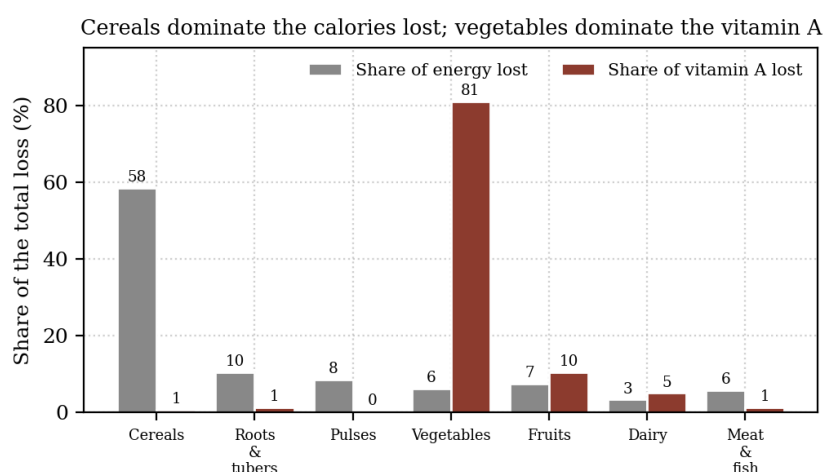


Figure 3. Share of the total energy lost and of the total vitamin A lost, by food group.

The first and fifth numeric columns describe two almost disjoint problems. Cereals account for 58.5 % of the energy lost and 0.7 % of the vitamin A. Vegetables account for 6.1 % of the energy and 81.1 % of the vitamin A. A programme that reduced cereal losses to zero would recover more than half the calories lost in the entire system and essentially none of the vitamin A.

Pulses show a third pattern, contributing 43.8 % of the folate lost while supplying 8.5 % of the lost energy, so folate targeting selects yet another group. Iron is the most evenly distributed, with cereals at 39.3 %, vegetables at 20.2 % and pulses at 17.2 %, which means iron is the nutrient for which loss reduction anywhere helps and no single intervention dominates.

The practical implication is that "reduce post-harvest loss" is not one objective. It is at least three, with different beneficiary groups, different technologies and different costs, and the choice between them is a nutrition policy decision rather than an agricultural engineering one.

3.3 Consequences for dietary adequacy

Table 5. Modelled prevalence of inadequate intake

Nutrient	If nothing were lost	At observed losses	Attributable to loss
Energy	65.0 %	82.3 %	17.3 points
Protein	10.8 %	21.2 %	10.4 points
Iron	0.5 %	2.0 %	1.5 points
Zinc	10.9 %	24.5 %	13.6 points
Vitamin A	61.3 %	78.0 %	16.7 points
Vitamin C	5.7 %	14.5 %	8.8 points
Folate	8.9 %	22.2 %	13.3 points

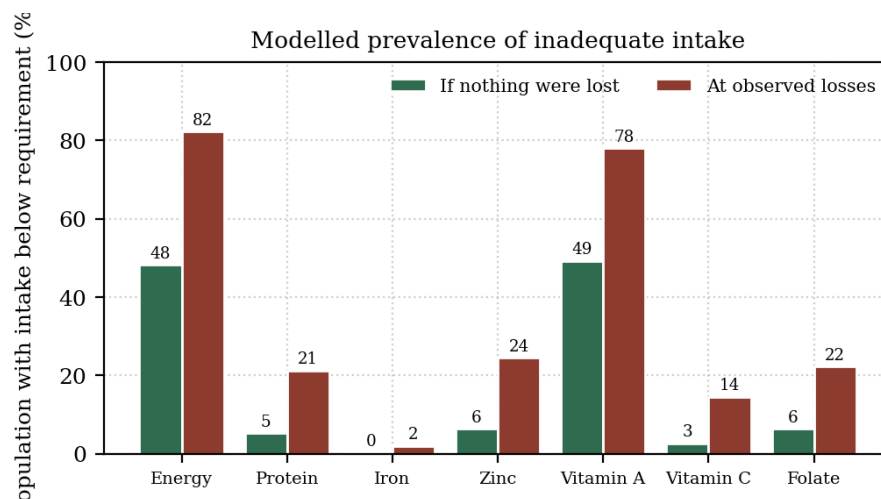


Figure 4. Modelled prevalence of inadequate intake with and without post-harvest loss.

The final column expresses the loss as a public health quantity: the increase in the proportion of the population whose intake falls below requirement. It ranges from 1.5 points for iron, where supply is comfortably above requirement in this model even after losses, to 16.7 points for vitamin A and 17.3 for energy.

The energy row should be read with care and is discussed further in Section 4.3: because oils, fats and sugars are not among the modelled groups, energy supply is understated by construction and the absolute prevalence of 82.3 % is not a credible estimate for any population. The change attributable to loss remains informative, since the omitted groups are not the ones being lost.

The vitamin A row is the one that carries the argument. Nearly four fifths of the modelled population falls below requirement at observed losses, and a sixth of that shortfall is created between the farm gate and the market rather than in the field or the kitchen. The food to meet the requirement was grown; it did not arrive.

3.4 What targeting achieves

Table 6. Reduction in inadequate intake from halving losses in one group (percentage points)

Group whose losses are halved	Energy	Iron	Vitamin A
Cereals	9.2	0.7	0.1
Roots & tubers	1.5	0.1	0.2
Pulses	1.2	0.3	0.0
Vegetables	0.9	0.4	12.2
Fruits	1.1	0.1	1.5
Dairy	0.5	0.0	0.7
Meat & fish	0.9	0.1	0.2

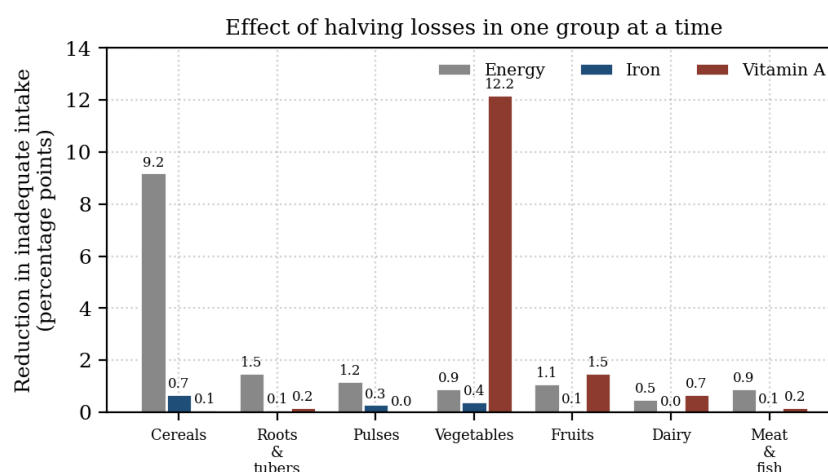


Figure 5. Effect of halving losses in each food group in turn, on three nutrients.

The table is close to diagonal, which is the finding. Halving cereal losses reduces energy inadequacy by 9.2 points and vitamin A inadequacy by 0.1. Halving vegetable losses reduces vitamin A inadequacy by 12.2 points and energy inadequacy by 0.9. The two interventions barely overlap in what they achieve.

Iron behaves differently again: no single group delivers more than 0.7 points, because iron supply is already adequate in this model and because its loss is spread across cereals, vegetables and pulses. Where iron deficiency is the priority, loss reduction is the wrong instrument and fortification or dietary diversification would be the comparison to make.

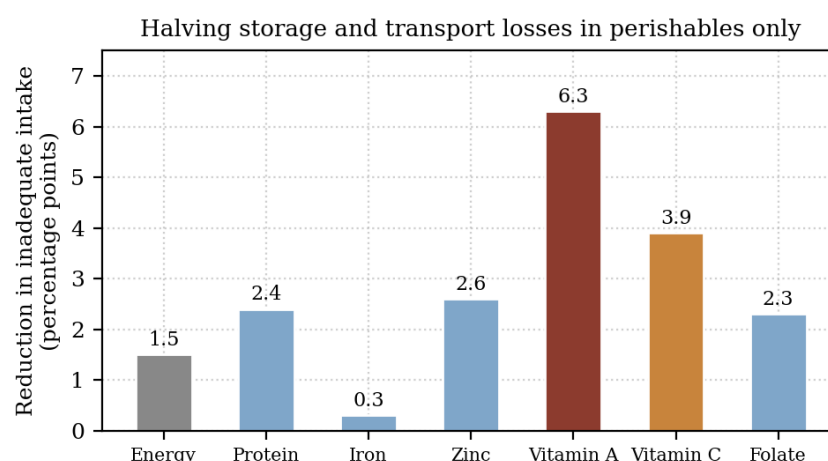


Figure 6. Effect of halving storage and transport losses in perishable groups only.

Table 7. Cold-chain scenario: halving storage and transport losses in perishables

Nutrient	Reduction in inadequate intake
Vitamin A	6.3 points
Vitamin C	3.9 points
Zinc	2.6 points
Protein	2.4 points
Folate	2.3 points
Energy	1.5 points
Iron	0.3 points

The cold-chain scenario is more realistic than the single-group scenarios because refrigerated storage and distribution act on several perishable groups at once and on the two stages where those groups lose most. It reduces vitamin A inadequacy by 6.3 points and vitamin C by 3.9, about half of what halving all vegetable losses would achieve, for an intervention that is a recognisable infrastructure programme rather than a hypothetical.

It also illustrates the ordering that runs through these results. The intervention delivers 4.2 times as much benefit for vitamin A as for energy, and twenty-one times as much as for iron. Evaluated on tonnage or calories saved it would appear a poor investment; evaluated on micronutrient adequacy it is the strongest of those examined.

4. Discussion

4.1 Principal findings

Four results follow. Losses differ by a factor of two between food groups, from 18.5 % in cereals to 39.2 % in fruits. Expressed in nutrients rather than mass, 21.3 % of energy is lost against 35.6 % of vitamin A and 36.7 % of vitamin C. The groups responsible are almost disjoint: cereals supply 58.5 % of the energy lost and 0.7 % of the vitamin A, vegetables 6.1 % and 81.1 % respectively. And the targeting consequence is correspondingly sharp, with halving cereal losses worth 9.2 points of energy inadequacy and 0.1 of vitamin A, while halving vegetable losses is worth 0.9 and 12.2.

4.2 Implications for policy and practice

Table 8. Implications

Finding	Implication	Recommendation
Micronutrient loss exceeds mass loss by two thirds	Tonnage understates the nutritional problem	Report post-harvest loss in nutrient units alongside mass
Cereals dominate energy lost, vegetables vitamin A	"Reduce loss" is several different objectives	State which nutrient a loss programme is intended to protect
Halving cereal loss gained 0.1 points of vitamin A	Grain-focused programmes cannot address deficiency	Do not credit grain storage programmes with micronutrient benefit
Halving vegetable loss gained 12.2 points	Perishable chains are where the nutrition is	Prioritise perishables where deficiency, not hunger, is the burden
Cold chain gained 6.3 points for vitamin A	A deliverable intervention captures much of it	Evaluate cold-chain investment on nutrient outcomes, not tonnage
Iron gained little from any scenario	Loss reduction is not a universal instrument	Compare against fortification for nutrients spread across groups
Losses concentrate in storage and transport for perishables	The stage matters as much as the group	Target the stage where the chosen group actually loses

The first row is the cheapest recommendation and the one with the widest reach. National and institutional loss statistics are collected as mass already; converting them to nutrient units requires only food composition tables that every nutrition ministry holds. The conversion would make visible a quantity that current reporting hides, and it would change which projects appear worthwhile.

The third row is worth stating plainly because the opposite claim is common. Grain storage programmes are valuable and they protect calories, income and food security in the energy sense. They do not protect micronutrient adequacy, and a programme document that claims both is not supported by the arithmetic of what grain contains.

4.3 Limitations

This is a supply-side model and per-capita supply is not intake. It ignores household waste, inedible portions, unequal distribution within households and between income groups, and any effect of storage or processing on the nutrient content of what survives — which is a real omission, since vitamin C and folate degrade during storage even in produce that is never discarded. Including that degradation would increase the micronutrient losses reported here and strengthen the direction of the findings.

Prevalence of inadequate intake is estimated by the cut-point method applied to a log-normal distribution around per-capita supply, which requires that intake and requirement are independent and is known to be unreliable for iron in menstruating women, where requirement is strongly skewed. The energy column is distorted for a different reason: oils, fats, sugars and beverages are not among the modelled groups, so energy supply is understated and the absolute prevalence figures for energy should not be quoted.

All loss fractions, availabilities and nutrient densities are representative assumptions rather than measurements for any country or commodity. Real loss varies enormously with season, distance to market, commodity within group and year, and the composition of a "vegetables" group differs so much between food systems that its vitamin A density is among the least transferable numbers in Table 2. The results should be recomputed with local data before being used for any decision.

Finally, the analysis quantifies nutrient supply and modelled adequacy, not health outcomes, and says nothing about the cost of any intervention. A comparison between cold-chain investment and, say, biofortification or supplementation requires cost per unit of deficiency averted, which this study does not provide and which would be the natural extension.

5. Conclusion

When post-harvest loss is measured in nutrients rather than tonnes, the picture changes in a way that matters for policy. In the food system modelled here, 21.3 % of energy was lost between farm gate and consumer but 35.6 % of vitamin A and 36.7 % of vitamin C, because loss is concentrated in the perishable groups that carry those nutrients. Cereals supplied 58.5 % of the calories lost and 0.7 % of the vitamin A; vegetables supplied 6.1 % and 81.1 %.

The consequence for targeting is that loss-reduction programmes selected on tonnage and those selected on nutritional benefit are nearly disjoint. Halving cereal losses reduced modelled energy inadequacy by 9.2 percentage points and vitamin A inadequacy by 0.1; halving vegetable losses reversed those figures. A cold-chain intervention confined to perishable storage and transport — a recognisable and deliverable programme — reduced vitamin A inadequacy by 6.3 points, more than four times its effect on energy.

The recommendation is not that grain storage should be abandoned but that loss statistics should carry the unit the decision requires. Where the burden is hunger, tonnes are the right measure. Where it is deficiency, the food that needs to arrive is the food that currently does not, and only a nutrient-denominated statistic will show it.

Declarations

Ethical approval. Not applicable. This is a modelling study using published composition and requirement values; no human participants, dietary survey data or identifiable information were involved.

Funding. [To be completed by the authors.]

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

Scope disclaimer. No country, commodity, supply chain or programme is evaluated. Loss fractions, availabilities and nutrient densities are representative assumptions; absolute prevalence figures are indicative of relative burden and must not be cited as estimates for any population.

Nutrition disclaimer. Per-capita supply is not dietary intake, and modelled prevalence of inadequate intake is not a measurement of deficiency. Nothing here constitutes dietary guidance or a basis for individual nutritional advice.

Data and code availability. No survey or production data were used. All results are computed from the parameters in Tables 1 and 2; the code 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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