Reducing Pesticide Exposure and Associated Neurotoxic Burden in an Ecuadorian Small Farm Population

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The contribution of community-based interventions, including farmer field schools (FFSs) in integrated pest management (IPM), to reducing pesticide exposures and associated neurotoxic burden among small-farm families in Ecuador was assessed in three Andean farming communities in a co-design of targeted action–research. Baseline questionnaire surveys elicited pesticide-related knowledge, practices, and exposure and neurobehavioral assessments were done using an adapted WHO battery. Pesticide applications on plots farmed by FFS versus non-FFS participants were compared. A year later, repeated surveys of participating households (n = 29) and neurobehavioral testing of individuals (n = 63) permitted comparisons of pre- and post-intervention values. The FFS graduates applied pesticides on their plots less frequently (p = 0.171). FFS households had increased pesticide-related knowledge of labels and exposure risk factors (both $p < 0.004$), better pesticide-handling practices ($p < 0.01$), and less skin exposure ($p < 0.01$). Neurobehavioural status had improved, particularly digit span and visuo-spatial function, resulting in overall z-score increases. Thus, community interventions reduced pesticide use, reported skin exposure, and neurotoxic burden among smallholder farm families.
Key words: pesticides; developing countries; environmental exposures; nervous system disorders; agricultural workers; intervention studies; health education; prevention and control.

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Agrochemicals are a US$32.2-billion market worldwide, with approximately $8 billion in insecticides.[1] The distribution of highly hazardous pesticides in lower- and middle-income countries (LMICs) is a contentious international issue of concern to occupational health practitioners and public health officials.[2] To date the primary concern has centered on acute poisonings,[3] including pesticide-related suicides,[4] yet evidence of impaired neurologic and mental performances associated with pesticide exposures is growing.[5,6] Given the widespread use of highly hazardous pesticides on a range of food and non-food crops in LMICs, pesticide exposure probably contributes to the global burden of disease from neuropsychiatric disorders, 13.0% of all disability-adjusted life years.[7]

Few evaluations of interventions to reduce exposures and risks of poisoning have been carried out.[8] The farmer field school (FFS) method, which explores integrated pest management (IPM) through problem-based learning and action,[9] is a promising alternative for advancing national productivity and sustainability objectives,[10] but the contribution of FFS to improved health is less clear. One of the few evaluations of the results of using knowledge-based approaches to IPM found increases in cholinesterase levels as an indicator of health improvements,[11] while another study employed an ecological design to document decreased adverse reproductive outcomes in a county with more widespread use of IPM promoted through FFSs.[12]

Earlier work with highland Ecuadorian potato farm households documented associations between the use of highly hazardous pesticides in agriculture, neurotoxic health impacts,[13] and poorer economic performance.[14] Highly hazardous pesticides (Ib according to the WHO acute toxicity classification[15]) in widespread use included methamidophos and carbofuran, both severely restricted in most high-income countries. Clinical problems included peripheral neurologic symp-

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TABLE 1 Intervention Evaluation Methods Used in Three Carchi Communities

	Unit	Measures	Statistical Analysis
Post–post comparison of detailed agronomic records	Potato plots of farmer field school (FFS) participating farmers vs. non-FFS farmers	1. Number of pesticide applications over entire crop cycle 2. Chemical type of pesticide used 3. Amount of active ingredient used	Independent t-tests of continuous measures
Pre–post responses to questions of person managing crops	Farm households participating in FFS and other community educational activities on pesticides and health	1. Information received 2. Knowledge of risks 3. Pesticide use practices 4. Applicator self-reported skin exposure	Chi-square tests of ordinal scales
Pre–post responses of woman and man (if both in farm household)	Individuals in participating farm households	1. Demographic information 2. Neurobehavioral tests, values converted to z-scores based on cantonal population not regularly exposed to pesticides in their work	Paired t-tests of continuous measures

toms and signs,[16] reductions in attention, and visuo-spatial coordination difficulties. Not only men, who typically applied pesticides, but also women and children were measurably affected. In cross-sectional work, we found recent use of highly hazardous pesticides (i.e., the number of applications during the six-month potato crop cycle) to be most strongly associated with decreased neurobehavioral function (compared with lifetime exposures or weekly hours).

Hence, we decided to engage community leaders in actions to reduce pesticide use and exposure.[17] Specifically, we hypothesized that community interventions over a one-year period would result in: 1) reductions in pesticide applications on the plots of participating farmers; 2) increases of pesticide-related knowledge and practices and associated reductions in self-reported pesticide exposure among participating households; and 3) improvement in neurobehavioral functioning among participating individuals.

METHODS

Setting

Carchi is a northern Ecuadorian province located on the Colombian border (see UN-approved Ecuador map at <http://www.un.org/Depts/Cartographic/map/profile/ecuador.pdf>). The economy of its highland rural people is primarily based on potato and milk production. In an extended program of multidisciplinary research on the health, productivity, and environmental impacts of pesticide use in Carchi,[18] we found frequent backpack sprayer applications and high-risk handling practices, resulting in widespread contamination of farm households.[19] Active pesticide poisoning surveillance (clinician training, standardized reporting form, and biweekly physician visits to health care organizations) documented an incidence of clinical poisonings among the world's highest reported rates—171 cases per 100,000 rural population.[4]

Design

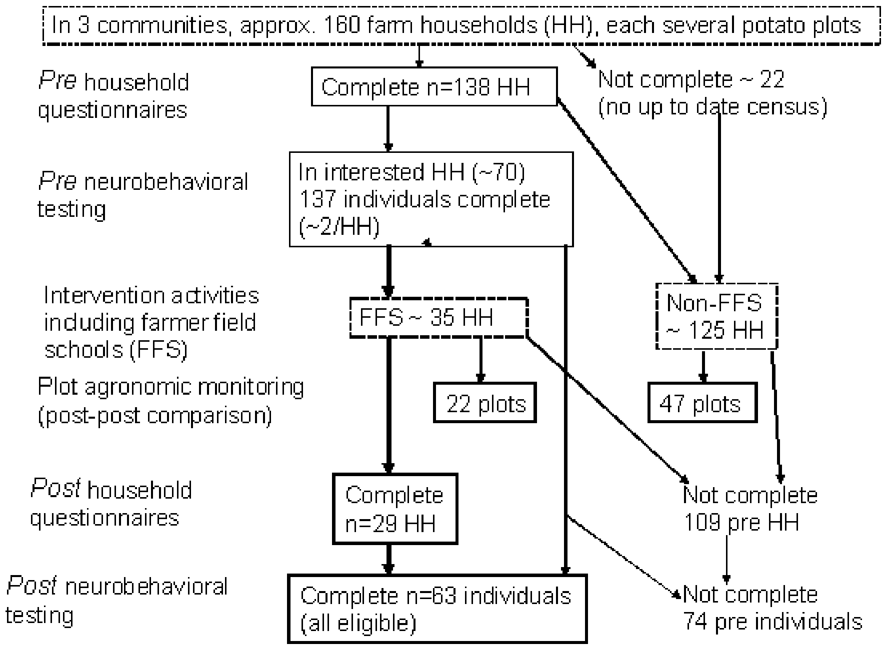
We involved three communities in an action–research project named *EcoSalud*, a Spanish translation of the participatory approach to changing ecosystem management to improve human health, advocated by Canada's International Development Research Centre (IDRC)*.[20,21] We evaluated change using a set of contrasts for different units of analysis as set out in Table 1.

Populations

The multi-disciplinary *EcoSalud* field team, composed of a nurse, an agronomist, and an educator, initially approached four communities with substantial proportions of households engaged in potato farming, with existing community organizations with whom we could work (e.g., parish council, dairy cooperative, active parents' organization), and with an interest in education by team members. The team conducted multiple community-level activities to share past information on pesticide use in potato farming in Carchi, to identify any health concerns associated with pesticide use and exposure, and to explore opportunities for improving farm productivity through decreased reliance on agrochemicals. In three of the four communities approached, interested volunteers agreed to take part in research information gathering and to co-design and co-implement interventions. Initially, 138 households completed pre-intervention interviewer-administered household questionnaires, one by the person

*IDRC approved the initial study design set out in the proposal and commented on the intervention process but played no further role in study implementation, analysis, write up or decision to submit the paper for publication.

Figure 1—Population flow in the intervention evaluation. Solid-line boxes indicate those for which data are presented. Thicker boxes represent populations important for key comparisons relevant to the evaluation.



managing the crops (usually a man) and one by the person managing the home (usually a woman). Only about half of these households were interested in neurobehavioral testing, but most commonly the man and woman participated (n = 137 individuals pre-intervention) (see Figure 1 re populations involved, noting that lack of complete community censuses and intervention participation records mean that approximate numbers had to be used for non-participating households and individuals).

During the intervention period, Carchi suffered its worst economic crisis in over a century,[22] leading to substantial reductions in potato plantings as well as some emigration from the communities. *EcoSalud* faced considerable challenges to participation in both intervention and further data-collection activities (see below). Nevertheless, some FFS and non-FFS farmers agreed to record individual production activities and input use, including pesticide use, on at least one plot throughout a six-month potato-production cycle (n = 69 plots). A research team member visited periodically to review the farmers' records and to clarify product names and quantities.

Household participation in post-intervention knowledge and practice surveys was limited (n = 29). As a group, these households were more likely to have received prior information about pesticides (52% vs 31% in pre-intervention survey only), but fortunately the post-intervention households were otherwise similar to the pre-intervention—only responding households, reducing concerns about selection biases (Table 2).

Within the post-intervention households, 63 individuals completed post-intervention neurobehavioral testing. Fortunately, no significant differences in individual age, gender, education, and baseline neurobehavioral status were observed between these individuals and the pre-intervention–only individuals, reducing concerns about selection biases (Table 3).

Individual participants ranged from 16 to 60 years old, with roughly equal numbers across the first three decades and fewer in the older decades. Fifty-four percent were women. The majority had only primary-level education (70% 3–6 years) but several individuals had completed high school. Consistent with global ethics standards for environmental health research,[22] we provided all participants explicit information about the study and obtained signed written informed consent. Subsequently, we provided participants individual feedback on the results of neurobehavioral testing. The McMaster University Research Ethics Board and the Ecuadorian National Scientific Council independently reviewed and approved the project.

Community Interventions

Interventions included: cross-sectoral interactions (e.g., involvement of members of the provincial health council); broad awareness-raising activities (community fairs, health week, and radio spots); targeted household-level education (use of fluorescent tracers in backpack sprayers to demonstrate exposure pathways, women's group discussions on priority concerns, including pesticide use by men); problem-based, hands-on discovery learning (FFS and cross-farm visits); and participatory research on IPM alternatives and on means of decreasing exposures to pesticides.[17,21]

Participating households also received individual visits from *EcoSalud* staff for assistance with safer storage of agrochemicals, demonstrations of the use of a low-volume and constant-pressure application nozzle, and

TABLE 2 Household Pesticide Information, Knowledge, and Practice Indices*, Pre-intervention

	All Pre-intervention (n = 138) No. (%)	Pre-intervention Only (n = 109) No. (%)	Both Pre- and Post-intervention (n = 29) No. (%)	P for Chi-square, Both vs Pre-intervention Only
Had received general information on pesticides				
None	86 (65)	72 (69)	14 (48)	
Some	28 (21)	21 (20)	7 (24)	0.043†
A lot	19 (14)	11 (11)	8 (28)	
Knowledge of risk from pesticide label and color code (higher score, greater knowledge)				
0	65 (48)	54 (51)	11(38)	
1	53 (40)	42 (40)	11 (38)	
2	12 (9)	7 (7)	5 (17)	0.132
3	4 (3)	2 (2)	2 (7)	
4	0	0	0	
Knowledge of risk associated with pesticide practices (higher score, greater knowledge)				
≤ 6	24 (17)	21 (19)	3 (10)	
7–10	60 (44)	45 (41)	15 (52)	0.441
11–12	54 (39)	43 (40)	11 (38)	
Self-reported general pesticide practices (higher score, better practices)				
≤ 2	29 (22)	25 (24)	4 (14)	
3–4	71 (53)	57 (55)	14 (48)	0.146
5–8	33 (25)	22 (21)	11 (38)	
Self-reported use of personal protective equipment (higher score, more use)				
0	116 (85)	88 (82)	28 (97)	
1	17 (13)	16 (15)	1 (3)	0.151
2	3 (2)	3 (3)	0	
Self-reported number of skin areas not exposed (higher score, *less* exposure)				
≤ 2	83 (61)	65 (61)	18 (62)	
3–4	33 (24)	27 (25)	6 (21)	0.835
≥ 5	20 (15)	15 (14)	5 (17)	

*See Methods.
†$p < 0.05$.

discussions of improved hygienic practices, such as those associated with post-application wash-up and separate laundering of contaminated clothing. Due to the absence of high-quality personal protective equipment (PPE) (e.g., neoprene gloves, impermeable overalls, and charcoal filter masks) in local stores, participating farm households asked *EcoSalud* to obtain equipment from health and safety companies in the capital. To cushion the substantial costs associated with PPE, the project provided no-interest, two-month credit towards the purchase price of PPE (about $34/set).

Measures

Drawing on earlier research on pesticide-related knowledge and practice,[18] we identified those items (response options either yes/no or short scale) found to be significantly associated with exposure. When more than one item tapped a domain, we constructed additive indices.

As part of individual health assessments, conducted at least 24 hours after any pesticide application, we included a set of neurobehavioral tests with proven psychometric properties based on World Health Organization (WHO) organized collaborative work.[24] Criteria for test selection included associations with recent pesticide use in the literature and earlier experience in the same region,[13] as well as administrative practicality in remote community halls and health dispensaries. For attention and short-term recall, we employed the digit-span test. For visuo-spatial function, we applied block design and a 15-figure Benton visual retention test. For psychomotor function, we used simple visual and auditory reaction time, trails A and B, Santa Anna in both dominant and non-dominant hand, and the pursuit-aiming test. We based procedures on a Spanish-language translation of the WHO manual (WHO Nicaraguan team's translations) as well as an Ecuadorian adaptation of the Weschler Intelligence and Apti-

TABLE 3 Individual Socio-demographic Characteristics and Neurobehavioral Scores, Pre-intervention

	All Pre-intervention (*n* = 137) No. (%)	Pre-intervention Only (*n* = 74) No. (%)	Both Pre- and Post-intervention (*n* = 63) No. (%)	*P*, Chi-square for Both vs Pre-intervention Only
Age (years)				
16–23	38 (28)	25 (34)	13 (21)	0.108
24–32	33 (24)	14 (19)	19 (30)	
33–42	34 (25)	21 (28)	13 (21)	
43–60	32 (23)	14 (19)	18 (28)	
Gender				
Male	70 (51)	41 (55)	29 (46)	0.274
Female	67 (49)	33 (45)	34 (54)	
Education (years)				
< 6	12 (9)	5 (7)	7 (11)	0.279
6	80 (58)	43 (58)	37 (59)	
7–9	17 (12)	7 (9)	10 (16)	
≥ 10	28 (21)	19 (26)	9 (14)	
Neurobehavioral scores				
Z-Digits	NA	0.24 (1.15)	0.09 (1.29)	0.472
Z-Spatial		0.35 (1.74)	–0.08 (1.94)	0.395
Z-Motor		–1.04 (0.95)	–1.08 (0.97)	0.841
Z-Overall		–0.68 (0.70)	–0.79 (0.85)	0.401

tude Scale (used clinically by the project neuropsychologist). Procedures included maintaining adequate temperatures, lighting, and freedom from noise in the testing areas and neuropsychologist review of each set of results for consistency and individual interpretation and feedback. To calculate z-scores for each individual, we used data from our earlier work[13] relating age and education to neurobehavioral test results among a non-farming control population from the same area. For each test, we calculated a predicted value based on the individual's age and education, then divided by the standard deviation for that test among the earlier controls.[13] The result was a z-score for each test, which could be averaged across tests for each function and then across functions for an overall neurobehavioral z-score for each individual.

Also collected were data on covariates of importance for neurobehavioral tests, including demographics and relevant morbidity (trauma, systemic disease, alcohol impacts).

Statistical Analyses

We applied unpaired t-tests for evaluation of differences in the numbers of pesticide applications on FFS participants' plots versus non-FFS participants' plots using SAS.[25] Household pesticide information, knowledge, and practice were ordinal so we assessed pre–post change using chi-square tests in STATA.[26] For neurobehavioral z-scores, we employed paired t-tests for pre–post comparisons among those individuals completing both assessments. We conducted stratified analyses to assess for differential effects of household participation in particular intervention activities and potential confounding by co-morbidity. Given the small sample sizes, multivariable analyses were not feasible.

RESULTS

Farmers who participated in FFS applied pesticides on their fields about 14% less frequently than did non-participants (5.6 vs 6.5; Table 4), although, given the small sample, this effect size was nonsignificant. On average, FFS participants applied 12% less weight of pesticides, mean (SD) of 19.4 (9.6) kg/hectare for FFS versus 22.1 (11.6) kg/hectare for non-FFS. These differences in numbers of applications and weights of pesticides did not vary substantially across WHO acute-hazard categories.

Among participating households, the proportion who reported receiving general information about pesticides increased from 50% pre- to 83% post-intervention, consistent with their involvement in the interventions (Table 5). In terms of pesticide-related knowledge, we observed significantly greater understanding of the meaning of color codes on product labels (e.g., red signifying extremely or highly hazardous) and significantly greater perceptions of the risks associated with potential and actual pesticide-related practices (e.g., smoking when applying pesticides or not washing up before eating). Greater use of effective PPE was consistent with participating household reports of decreased dermal exposures (e.g., fewer spills on applicators' skin from leaky backpack sprayers or contamination of their hands during mixing and spraying).

Post intervention, participating individuals obtained significantly improved neurobehavioral z-scores, particularly for digit span and visuo-spatial functions (Table 6). Improvements in certain extremely poor scores,

TABLE 4 Plot-based Numbers of Pesticide Applications among Potato-producing Households in Three Communities Post-interventions

	Pesticide Applications/Crop Cycle per Plot Mean (SD)		
	Farmer Field School (FFS) Household Plots (*n* = 22)	Non-FFS Household Plots (*n* = 47)	*p**
WHO acute toxicity class			
Ib Highly hazardous	2.9 (2.2)	3.0 (1.9)	0.822
II Moderately hazardous	2.9 (2.0)	3.1 (2.3)	0.685
III Slightly hazardous	4.0 (2.8)	4.9 (3.1)	0.172
IV "Non" hazardous	8.0 (5.4)	8.6 (5.8)	0.604
Independent applications of active ingredients	29.2 (13.1)	30.7 (14.0)	0.661
Overall applications (with mixes of active ingredients)	5.6 (2.1)	6.5 (2.3)	0.171

*Independent t test.

though remarkable (about 4 standard deviations below the mean to only 0.27 below the mean for the visuo-spatial z-score), did not overly impact changes in median scores, which were all positive. Maximum scores increased in each domain, reducing the likelihood of statistical regression to the mean. Stratified analyses by comorbidity and gender did reveal significant heterogeneity in the results. Based on large mean changes for visuo-spatial function (+1.35, $p < 0.0001$) and digit span (+0.68, p 0.006) but less change in psychomotor function (+0.27, p 0.101), mean overall neurobehavioral performance increased by 0.7 standard deviations ($p < 0.0001$) to a mean of –0.09 post intervention.

DISCUSSION

We found FFS participation to be associated with modest measurable pesticide use reductions, consistent with other studies.[10, 27] The economic crisis or other community intervention activities may have contributed to the reduction in numbers of pesticide applications from a mean of more than seven per crop cycle in the early 1990s[18] to 6.5 among non-FFS and 5.6 among FFS participants. Encouragingly, research has found pesticide use reductions through FFS contributing to productivity increases both in Carchi and internationally,[28,29] an important concern where poverty remains a key health determinant.

Participating households also increased their knowledge of pesticide-associated health risks. Such knowledge not only assisted farm households in improving exposure-relevant practices but also contributed to a social countervailing force, as exemplified by one FFS graduate cited in Paredes' ethnographic work[31]: "Prior to the Field School coming here, we used to go to the pesticide shops to ask what we should apply for a problem. Then the shopkeepers wanted to sell us the pesticides that they could not sell to others, and they even changed the expiry date of the old products. Now we know what we need, and we do not accept what the shopkeepers want to give us."

Participating households reported increased use of PPE and reductions in dermal exposures. Despite the known effectiveness of PPE in reducing overexposure incidents,[8] distribution channels for effective PPE are grossly inadequate in most LMICs, compared with far better distribution channels for highly hazardous pesticides.[2]

Improved neurobehavioral scores post-intervention were consistent with econometric modeling scenarios that predicted improved neurobehavioral outcomes and greater productivity with reduced use of highly hazardous pesticides.[14] Although some of the improvements might be attributable to a learning effect, the long time period between measures would attenuate such an effect and the magnitude of the change is greater than would be expected by this mechanism alone. Partial reversibility of neurobehavioral performance deficits with reduction in exposures has been shown for other neurotoxins, particularly lead.[30] Further, our quantitative findings were supported by qualitative research,[31] as the wife of one FFS graduate claimed: "Carlos no longer has headaches after working in the fields. He used to return home [from applying pesticides] and could hardly keep his eyes open from the pain. After the Field School and buying the protective equipment, he is a far easier person to live with."

The substantial macroeconomic changes occurring during the intervention period and project constraints resulted in participation declines, which limit the generalizability of our findings beyond more highly committed participating farm households.[32] Nevertheless, no health-status–based attrition was observed, as occurred among U.S. farm operators, where those experiencing adverse health problems were more likely to seek out ways to reduce exposure and environmental contamination.[33] Independent, direct ascertainment of exposures, as we had carried out previously,[19] was not possible due to both resource constraints and our prioritization of intervention activities. The substantial exposures to highly hazardous pesticides among our farm populations, while common to most

TABLE 5 Participating Household Pesticide Information, Knowledge, and Practice indices, Pre- and Post-intervention

	Pre-intervention No. (%)	Post-intervention No. (%)	P, Chi-Square for Change
Had received general information on pesticides			
None	14 (48)	4 (17)	
Some	7 (24)	2 (9)	0.004
Substantial	8 (28)	17 (74)	
Knowledge of risk from pesticide label and color code (higher score, greater knowledge)			
0	11(38)	0	
1	11 (38)	2 (9)	
2	5 (17)	6 (26)	0.000
3	2 (7)	10 (43)	
4	0	5 (22)	
Knowledge of risk associated with pesticide practices (higher score, greater knowledge)			
≤ 6	3 (10)	0	
7–10	15 (52)	4 (15)	0.001
11–12	11 (38)	23 (85)	
Self-reported general pesticide practices (higher score, better practices)			
≤ 2	4 (14)	3 (14)	
3–4	14 (48)	5 (23)	0.144
5–8	11 (38)	14 (64)	
Self-reported use of personal protective equipment use (higher score, more use)			
0	28 (97)	10 (36)	
1	1 (3)	6 (21)	0.000
2	0	12 (43)	
Self-reported number of skin areas *not* exposed (higher score, *less* exposure)			
≤ 2	18 (62)	4 (14)	
3-4	6 (21)	9 (32)	0.001
≥ 5	5 (17)	15 (54)	

LMICs, means that one might expect less dramatic changes in lower exposure and toxicity contexts.

We did not have a set of control communities, partly because of resource limitations, but primarily because the participants wanted some kind of concrete benefit for putting their time into research. The alternative, a dose–response analysis of improvements in neurobehavioral scores with reductions in farm pesticide use, would have been helpful, but the overlap between the set of farmers providing post measures of plot pesticide usage and the individuals undergoing repeat neurobehavioral testing was not large enough to permit such an analysis. Intervention participation records were not adequate to construct an overall household or individual participation score with which to determine effects of differential intensity of intervention. Further, the sample size was insufficient to engage in multivariable modeling, adjusting for cluster effects associated with communities and households, and exploring potential confounding in a more nuanced way.

Nevertheless, participation in intervention activities was associated with concurrent changes in knowledge and practices as per "adequacy evaluations" in public health.[34] Further, the pre- and post intervention measurements are consistent with "plausibility evaluations" of public health interventions. Evaluation on a wider scale with multiple referent communities and time-lagging of the interventions across communities could improve the quality of available evidence. For such evaluations, selection of indicators that maintain sensitivity to changes in use, knowledge, exposure, and health outcomes but without onerous monitoring demands, would be crucial.

To our knowledge, no published scientific studies to date have demonstrated partial reversibility of pesticide-associated neurotoxic effects linked with reductions in ongoing highly hazardous pesticide use and exposure. Even modest improvement is important for millions of small-farm households in LMICs as a means of addressing worrisome chronic neurotoxicity highlighted in other high-exposure settings[35] and reviews, both synthetic[6] and systematic.[36] Our findings add to the limited currently available literature on the potential of interventions to reduce pesticide-related adverse health impacts.[8] Specific education combined with the availability of protective clothing and masks and alter-

TABLE 6 Individual Neurobehavioral Z-scores* Pre- and Post-ntervention

	Z-Digits		Z-Visuospatial		Z-Psychomotor		Z-Overall	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Minimum	–2.05	–2.45	–4.04	–0.27	–3.77	–2.72	–3.04	–2.05
25%	–0.88	–0.18	–1.56	0.31	–1.55	–1.14	–1.30	–0.53
Median	–0.05	0.74	–0.38	1.42	–0.87	–0.75	–0.74	–0.02
75%	0.99	1.59	1.06	2.24	–0.45	–0.22	–0.12	0.42
Maximum	3.62	4.01	2.24	2.82	0.48	0.89	0.49	1.26
Mean	0.09	0.77	–0.27	1.08	–1.08	–0.81	–0.79	–0.09
(SD)	(1.29)	(1.43)	(1.46)	(1.42)	(0.97)	(–0.78)	(0.85)	(0.65)
Post vs Pre paired t-test	2.82		5.26		1.65		5.20	
p	(0.006)		(0.000)		(0.101)		(0.000)	

*Z scores adjusted for age and education.

native crop management strategies, such as IPM, have roles to play in reducing pesticide-associated neurotoxic and potentially overall neuropsychiatric burden in LMICs.

Our results are relevant to the public debate around the problematic sale and distribution of highly hazardous pesticides in LMICs, despite their known public health consequences. Targeting of interventions should become more possible as open-access international data become available from the Food and Agricultural Organization (<www.fao.org>). In addition to recommendations for tighter controls on the distribution and use of highly hazardous pesticides for purposes of preventing acute poisonings,[2] community-based interventions for pesticide-use reduction, particularly FFSs and innovative participatory education approaches,[37] could decrease the neurotoxic burden placed on small-farm households in many countries worldwide.

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