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Transfer factor calculated using dermal exposure and dislodgeable foliar residue and exposure assessment for reentry worker after pesticide application in cucumber field

Hoon Choi[1,2*]

Abstract

This study aimed to determine the transfer factor (TF) of methidathion for cucumber harvesters in greenhouses using the dermal exposure rates (DERs) and dislodgeable foliar residues (DFRs) measured simultaneously in my previous works. The DERs recalculated using the reference body surface area for the Korean adult males were 31.5–1281.1 µg/h, and the DFR values were 12.1–222.5 ng/cm^2 over 7 d after application. A strong correlation between the DERs and DFRs was observed, with a regression coefficient of 0.9982. The TF for cucumber harvesters in greenhouses was determined to be 6020.4 cm^2/h, which was five times higher than that proposed by the US Environmental Protection Agency (EPA). Additionally, based on TF value of methidathion, the reentry intervals (REIs) with or without personal protective equipment (PPE) were estimated for 82 pesticides registered on cucumber. The REIs with PPE, obtained from acceptable operator exposure levels and TF value, were less than 0 d, indicating the lowest risk possibility. However, REIs without PPE were estimated between 0.04 and 4.4 d for seven pesticides, including chlorothalonil, emamectin benzoate, flubendiamide, fluquinconazole, iminoctadine tris(albesilate), propineb, and pyridaben. In conclusion, cucumber harvesters should wear PPE for health safety when they reenter the greenhouse to harvest cucumbers following application of pesticides.

Keywords Cucumber, Dermal exposure rate, Dislodgeable foliar residue, Reentry interval, Transfer factor

Introduction

Occupational exposure to pesticides can occur mainly in factory workers during manufacturing and in farmers during mixing/loading, spraying, and harvesting the agricultural commodities. Acute and chronic health threats of pesticide exposure greatly concern farmers, which arise from the amount and frequency of pesticide use, the time farmers spend in their fields, and the potential unsafe exposure levels in these situations. To deal with concerns about pesticide hazards, their exposure should be appropriately controlled to ensure the health of agricultural workers.

Following pesticide application to agricultural crops, its exposure is primarily attributed to dermal deposition and inhalation. Dermal deposition/adsorption is the main route of exposure to farmers and occurs indirectly through contact between the skin and the leaf surface stained with the spraying solution, but not through direct contact with the pesticide droplet after application [1]. Dislodgeable foliar residues (DFRs) of pesticides can easily translocate to the body surface of workers during pesticide application, pruning,

*Correspondence:
Hoon Choi
hchoi0314@wku.ac.kr
[1] Department of Life and Environmental Sciences, Wonkwang University, 460, Iksan-Daero, Iksan 54538, Republic of Korea
[2] Institute of Life Science and Natural Resources, Wonkwang University, 460, Iksan-Daero, Iksan 54538, Republic of Korea

thinning, and harvesting [2]. Therefore, a dissipation study of DFRs was conducted to predict the dermal exposure of farm workers to pesticide and determine the safe reentry interval (REI). Transfer factor (TF) can be considered a link between dermal exposure rates (DERs) and DFRs [3]. TF is the ratio of exposure to the DFRs and calculated using DERs and the foliage surface area contacted by the worker per hour [4, 5]. Consequently, the estimation of dermal exposure to other pesticides is possible using specific TF values established for specific crops, activities, and field conditions [6].

The number of greenhouse farms and the cultivation area have increased globally, particularly in Korea, because of the high production capacities per unit area and year-round cultivation. In 2020, greenhouse acreage and production reached 60,866 hectares and 2.3 million tons, respectively, in the Republic of Korea [7]. Moreover, farm workers frequently reenter the facility for the continuous harvesting of agricultural commodities such as cucumber, which has grown 87% of the total production in the greenhouse. As a result, the probability of farmworker exposure to pesticides also increased in specific work tasks, which could be attributed to the enclosed greenhouse farm system, frequent pesticide application and reentry. The resultant health effects among greenhouse farm workers have continued to be reported, including hormonal, neurological, and respiratory disorders [8–11].

In Korea, exposure to mixers and sprayers during pesticide application has been a great deal of focus in the past [1, 12–14]. The exposure characteristics for applicators were reported in open fields, including green pepper fields, paddy fields, mandarin, and apple orchards [1, 12, 13], and were also compared by diverse formulations and different application methods [1, 13]. Moreover, the exposure pattern for agricultural workers was investigated during the application of the pesticide suspension to the cucumber in a greenhouse environment [1, 14]. However, there is also the possibility of exposure in a field sprayed previously with pesticides, where agricultural workers reenter for picking, harvesting, pruning/thinning, maintenance, etc. In Korea's farming situation, agricultural workers generally prefer to wear long-sleeved shirts and long trousers instead of personal protective equipment (PPE) during the harvest, because of the inconvenience of the work, thereby causing a higher possibility of risk to pesticides [15, 16]. My research group previously reported the exposure and risk to methidation for workers during harvesting cucumber for 7 days in the greenhouse, which showed that workers exposed mainly through hands, thighs, and arms by the direct contact with the pesticides on crop foliage or cucumber [17]. Besides, the deposition and dissipation characteristics of methidathion on cucumber foliage were also investigated in my previous publication [18].

As mentioned above, exposure to reentering workers could be estimated using the TF value calculated from the DERs and DFRs. To the best of my knowledge, no previous reports on the DERs for harvesters and DFRs have been published in the Republic of Korea, except for my previous papers. Hence, this study aimed to derive the TF value using reentry DERs and DFRs measured concurrently in the same cucumber greenhouse, reported in my previous works [17, 18]. In addition, the REIs of 82 pesticides registered on cucumber were determined to set priorities for pesticide exposure management.

Materials and methods

Recalculation of dermal exposure to pesticides in the cucumber field

The DERs to harvesters for 7 d post pesticide application, reported in my previous study [17], was reassessed based on numerous assumptions concerning harvesting time per day, body surface area, and reference value. The dermal exposure rate (DER, μg/h) was calculated by extrapolating the exposure amount (μg/cm^2; measured by dosimeters) to the body surface area (cm^2) and dividing it by the work time (h). The calculation is based on the assumption that pesticide exposure through direct foliar contact is proportional to work duration. The body surface area for Korean adult male suggested by Kim et al. [19] was used to calculate the DER (Table 1).

Determination of TF

TF (cm^2/h) was determined using the following formula:

$$\mathrm{TF}\left(\mathrm{cm}^2/\mathrm{h}\right) = \mathrm{DER}(\mu g/\mathrm{h}) \times 1000/\mathrm{DFR}\left(\mathrm{ng}/\mathrm{cm}^2\right)$$

DFRs of methidation measured in my previous study [18] were used for calculation of TF. A linear regression curve was obtained by plotting DERs versus DFRs at an

Table 1 Body surface area for the Korean adult male

Body parts	Surface area (cm^2)	Body parts	Surface area (cm^2)
Head	484	Upper arm	1537
Face	484	Forearm	1127
Front of Neck	242	Thigh	2769
Back of Neck	182	Lower leg	2197
Chest/Abdomen	3324	Feet	1266
Back	3336	Hand	935

interval of 1, 2, 3, 5, and 7 d post application. The linear relationship between the DERs and DFRs was evaluated using the F-test, linear regression equation, and regression coefficient (R^2). Statistical analysis was conducted using SPSS 18.0 (SPSS Inc., Arming, NY, USA). The slope of the linear regression equation was determined as TF.

Dermal exposure assessment

The initial DFR (DFR_0, ng/cm^2) for each pesticide compound was calculated using the following formula:

$$\mathrm{DFR}_0\left(\mathrm{ng/cm^2}\right) = \mathrm{DV} \times \mathrm{A.I.} \times 10/\mathrm{DF},$$

where DV is the foliage deposit volume of the spraying solution (nL/cm^2), A.I. is the active ingredient (%), and DF is the dilution factor of pesticide products. Assuming that foliage DV is the same regardless of the pesticide type and formulation, the foliage DV of methidathion spraying solution was used to determine the DFR_0 for each pesticide compound. Accordingly, the DV value was set as 888.8 nL/cm^2 using DFR_0 of 355.5 ng/cm^2, A.I. of 40%, and DF of 1000 [18]. The initial DER (DER_0, μg/h) for each pesticide was calculated by multiplying the DFR_0 with the TF value. The potential dermal exposure (PDE, μg/day) per day was expressed as the corresponding DER_0 multiplied by the harvesting time per day (H/D) of 8 h, deduced using an H/D of 8.3 h/day in the melon greenhouse [8, 18]. The actual dermal exposure (ADE, μg/day) to harvesters in the cucumber greenhouse was calculated by extrapolating PDE to the penetration rate (PEN) through personal protective equipment (PPE) and skin absorption (ABS). The default values of PEN and ABS were assumed to be 10%, respectively [18].

Determination of reentry intervals and safe work time

The REIs and safe work times (SWTs) were calculated for pesticides registered on cucumber. The REI for harvesters in the cucumber greenhouse was derived using the following formula:

$$\mathrm{REI}\ (\mathrm{days}) = [\ln(\mathrm{AOEL} \times \mathrm{BW}) - \ln(\mathrm{ADE})] \times k^{-1},$$

where AOEL is the acceptable operator exposure level (μg/kg b.w./day), BW is the body weight of adult Korean males (kg b.w.), ADE is the initial ADE, and k is the dissipation constant for DFR. AOELs established and reported by the Rural Development Administration (RDA) were used for this study [20], the body weight taken was 70 kg [1, 14, 18], and the dissipation constant was assumed to be −0.4915 [18]. The SWT is the maximum harvesting time per day for which the exposure to pesticides is below the AOEL and was calculated using the following formula:

$$\mathrm{SWT}\left(\mathrm{h/day}\right) = (\mathrm{AOEL} \times \mathrm{BW})/\mathrm{ADE} \times \mathrm{H/D}.$$

Table 2 Dislodgeable foliar residues (DFRs) and dermal exposure rates (DERs) for harvesters to methidathion in my previous works [17, 18]

After application	DFRs (ng/cm^2)	DERs (μg/h)	Re-cal-DERs[a] (μg/h)
Day 1	222.5 ± 46.5	1343.5 ± 1209.6	1281.1 ± 1197.1
Day 2	146.3 ± 56.0	828.6 ± 763.5	792.5 ± 751.4
Day 3	82.6 ± 27.3	427.7 ± 337.6	413.3 ± 333.2
Day 5	29.0 ± 6.3	80.2 ± 65.4	80.2 ± 65.4
Day 7	12.1 ± 2.2	34.8 ± 23.4	31.5 ± 22.7

[a] Dermal exposure rates (DERs) recalculated using the reference body surface area for Korean adult males [19]

Results and discussion

Reassessment of dermal exposure to pesticides for workers in the cucumber field

DERs to methidathion in the cucumber greenhouse were determined in my previous experiment [17] using the surface area of the appropriate body region suggested by the US Environmental Protection Agency (EPA) [21] and Vercruysse et al. [22]. The reported DER values were 34.8–1343.5 μg/h over 7 d after application of methidathion during cucumber harvest in the greenhouse with dermal dosimetry (Table 2). In addition, inhalation exposure was not observed in any of the workers. Currently, the exposure of agricultural workers to pesticides in Korea is determined using the reference body surface area values by each body parts for a Korean adult male suggested by Kim et al. [19]. Therefore, DERs to methidathion were recalculated using the reference body surface area value (Table 2). The recalculated DERs were 31.5–1281.1 μg/h over 7 d after application during cucumber harvesting, approximately 95% similar to the DERs in previous work [17].

TF for workers harvesting in the cucumber greenhouse

Methidathion DFRs on cucumber leaves measured in my previous study [18] were in the range of 12.1–222.5 ng/cm^2 for 7 d after application (Table 2). The correlation between the DERs and DFRs measured concurrently in the same cucumber field was investigated. The linear regression analysis between the DERs and DFRs of methidathion showed that the regression model was significant at the F-value ($p < 0.05$),

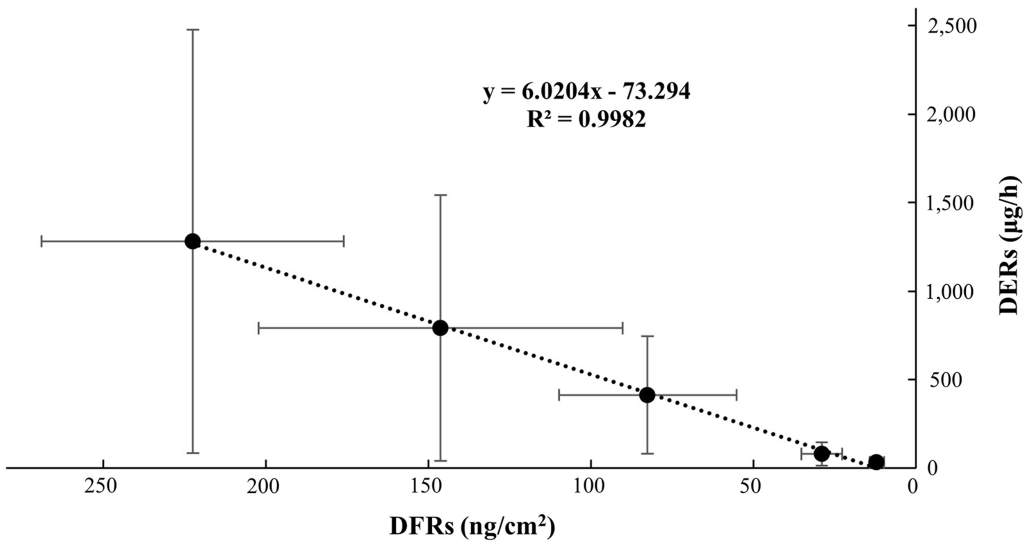

Fig. 1 Correlation between dislodgeable foliar residues (DFRs) and dermal exposure rates (DERs) to methidathion for harvesters in the cucumber greenhouse

demonstrating a high linear relationship between the two variables for 7 d after application. The R^2 was 0.9982, indicating that 99.8% of the variation in DERs explained by the DFRs. Therefore, DERs could be estimated from the DFRs. The TF of methidathion for harvesters was determined to be 6020.4 cm^2/h (95% CI; 5544.7–6496.2), as shown in Fig. 1.

In the 1980s, a Zweig factor of 5000 cm^2/h (based on a one-sided surface area) was used as the TF to estimate worker exposure [23]. However, this factor tends to overestimate exposure to low-crop workers and underestimate exposure to high-crop workers [24]. Meanwhile, the US EPA has established TFs based on detailed conditions, including crop height and work activity [6]; the proposed TFs for harvesting and irrigation activities by hands were 550 and 1900 cm^2/h, respectively, in cucumber fields with low crop height and full foliage density. Greenhouse floral production presents a unique cultural situation, with planting rows between narrow walkways to maximize the growing area. This results in foliar contact and a higher possibility of workers' exposure to pesticide residues while using these walkways for harvesting or other tasks [25]. Therefore, the US EPA suggested a TF of 1200 cm^2/h for harvesting vegetables with a high crop height and full foliage density in greenhouses. However, the TF value of 6020.4 cm^2/h determined in this study was five times higher than that proposed by the US EPA. These results demonstrate that Korean harvesters could be at a higher risk of pesticide exposure in a greenhouse than US workers. Over the past few decades, the US EPA has been actively engaged in refining its methodologies and developing data for assessing exposure and establishing TFs for all crops, activities, and field conditions. Therefore, further studies are needed to establish TFs specialized for the Korean situation.

Exposure assessment and REIs for harvesters in the cucumber greenhouse

The TF is not dependent on the pesticide applied [2, 5], and is generally used to quickly assess exposure to any pesticide-active ingredient using estimates of exposure time and the concentration of residue that workers will contact [5]. Crop type is a major factor in determining DFR values without excluding the effect of formulation type [2]. Exposure of workers to pesticides registered for cucumber was estimated using the TF value of 6020.4 cm^2/h determined in this study, followed by the assessment of health risks. As of 2022, 163 pesticides in 1374 products have been registered for application to cucumber fields in Korea. Of these, only 82 pesticide-active ingredients used for foliage sprays have been assessed for exposure and health risks, for which RDA established the AOEL values. Using the specific dissipation constant of DFR may be inappropriate for calculating REIs of other pesticides, because the dissipation of DFRs depends on the physico-chemical properties and degradation characteristics of each pesticide. Therefore, the REI calculations in this study were restrictively performed to prioritize pesticides for pesticide exposure management. Table 3 shows the estimated ADEs and REIs for cucumber harvesters in Korea.

REIs for harvesters using the PPE were −17.6 to −0.3 d, corresponding to 0.02–84.9% of the AOEL value.

Table 3 Estimated dermal exposure and reentry interval for harvesters to pesticides registered for the cucumber greenhouses

Pesticides	A.I.[a] (%)	Dilution	AOEL[b] (mg/kg b.w./day)	DFR_0 estimate[c] (ng/cm^2)	PDE estimate[d] (mg/day)	ADE[e] (mg/day)		REI[g] (days)		SWT[h] (h/day)	
						PPE +[f]	PPE−	PPE +	PPE−	PPE +	PPE−
Abamectin	1.8	3000	0.0025	5.3	0.3	0.003	0.03	− 8.6	− 3.9	545.1	54.5
Acetamiprid	8	2000	0.07	35.6	1.7	0.02	0.2	− 11.5	− 6.8	2289.5	228.9
Acrinathrin	5.7	2000	0.0071	25.3	1.2	0.01	0.1	− 7.5	− 2.9	325.9	32.6
Afidopyropen	2.5	2000	0.087	11.1	0.5	0.01	0.1	− 14.3	− 9.6	9105.6	910.6
Amisulbrom	13.5	2000	0.18	60.0	2.9	0.03	0.3	− 12.4	− 7.7	3488.7	348.9
Azoxystrobin	21.7	1000	0.21	192.9	9.3	0.1	0.9	− 10.3	− 5.6	1266.1	126.6
Benthiavalicarb-isopropyl	15	2000	0.1	66.7	3.2	0.03	0.3	− 11.0	− 6.3	1744.4	174.4
Bifenthrin	2	1000	0.0075	17.8	0.9	0.01	0.1	− 8.4	− 3.7	490.6	49.1
Bistrifluron	10	2000	0.095	44.4	2.1	0.02	0.2	− 11.7	− 7.0	2485.7	248.6
Bitertanol	25	2500	0.01	88.9	4.3	0.04	0.4	− 5.7	− 1.0	130.8	13.1
Boscalid	49.3	1500	0.097	292.1	14.1	0.1	1.4	− 7.9	− 3.2	386.1	38.6
Broflanilide	5	2000	0.0031	22.2	1.1	0.01	0.1	− 6.1	− 1.4	162.2	16.2
Chlorantraniliprole	5	2000	0.36	22.2	1.1	0.01	0.1	− 15.8	− 11.1	18,839.1	1883.9
Chlorfenapyr	10	2000	0.0042	44.4	2.1	0.02	0.2	− 5.3	− 0.6	109.9	11.0
Chlorothalonil	75	600	0.009	1111.0	53.5	0.5	5.4	− 0.3	4.4	9.4	0.9
Clothianidin	8	1000	0.1	71.1	3.4	0.03	0.3	− 10.8	− 6.1	1635.3	163.5
Copper hydroxide	77	1000	0.072	684.4	33.0	0.3	3.3	− 5.5	− 0.9	122.3	12.2
Copper sulfate	15	500	0.072	266.6	12.8	0.1	1.3	− 7.5	− 2.8	314.0	31.4
Cyazofamid	10	2000	0.3	44.4	2.1	0.02	0.2	− 14.0	− 9.3	7849.6	785.0
Cyclaniliprole	4.5	2000	0.027	20.0	1.0	0.01	0.1	− 10.7	− 6.1	1569.9	157.0
Cyflumetofen	10	1000	0.11	88.9	4.3	0.04	0.4	− 10.6	− 5.9	1439.1	143.9
Cypermethrin, zeta	3	1000	0.019	26.7	1.3	0.01	0.1	− 9.4	− 4.8	828.6	82.9
Deltamethrin	1	1000	0.0075	8.9	0.4	0.004	0.04	− 9.8	− 5.1	981.2	98.1
Difenoconazole	10	2000	0.16	44.4	2.1	0.02	0.2	− 12.7	− 8.1	4186.5	418.6
Dimethomorph	25	1000	0.15	222.2	10.7	0.1	1.1	− 9.3	− 4.6	785.0	78.5
Dinotefuran	20	1000	0.22	177.8	8.6	0.1	0.9	− 10.6	− 5.9	1439.1	143.9
Emamectin benzoate	5	4000	0.00028	11.1	0.5	0.01	0.1	− 2.6	2.0	29.3	2.9
Ethaboxam	25	1000	0.16	222.2	10.7	0.1	1.1	− 9.5	− 4.8	837.3	83.7
Etofenprox	20	1000	0.06	177.8	8.6	0.1	0.9	− 7.9	− 3.2	392.5	39.2
Fenbuconazole	12	2000	0.017	53.3	2.6	0.03	0.3	− 7.8	− 3.1	370.7	37.1
Fenpyrazamine	30	1000	0.25	266.6	12.8	0.1	1.3	− 10.0	− 5.3	1090.2	109.0
Flometoquin	10	2000	0.01	44.4	2.1	0.02	0.2	− 7.1	− 2.4	261.7	26.2
Flonicamid	50	10,000	0.025	44.4	2.1	0.02	0.2	− 9.0	− 4.3	654.1	65.4
Flubendiamide	20	2000	0.006	88.9	4.3	0.04	0.4	− 4.6	0.04	78.5	7.8

Table 3 (continued)

Pesticides	A.I.[a] (%)	Dilution	AOEL[b] (mg/kg b.w./day)	DFR_0 estimate[c] (ng/cm^2)	PDE estimate[d] (mg/day)	ADE[e] (mg/day)		REI[g] (days)		SWT[h] (h/day)	
						PPE +[f]	PPE−	PPE +	PPE−	PPE +	PPE−
Fludioxonil	20	2000	0.59	88.9	4.3	0.04	0.4	− 14.0	− 9.3	7718.8	771.9
Fluopyram	40	4000	0.054	88.9	4.3	0.04	0.4	− 9.1	− 4.4	706.5	70.6
Fluquinconazole	25	2000	0.0012	111.1	5.4	0.05	0.5	− 0.9	3.8	12.6	1.3
Flutianil	2	2000	0.35	8.9	0.4	0.004	0.04	− 17.6	− 12.9	45,789.5	4578.9
Fluxametamide	9	2000	0.022	40.0	1.9	0.02	0.2	− 8.9	− 4.2	639.6	64.0
Fluxapyroxad	15.3	4000	0.041	34.0	1.6	0.02	0.2	− 10.5	− 5.8	1402.3	140.2
Hexaconazole	5	5000	0.0082	8.9	0.4	0.004	0.04	− 10.0	− 5.3	1072.8	107.3
Imidacloprid	10	2000	0.08	44.4	2.1	0.02	0.2	− 11.3	− 6.6	2093.2	209.3
Iminoctadine tris(albesilate)	30	1000	0.0024	266.6	12.8	0.1	1.3	− 0.5	4.1	10.5	1.0
Indoxacarb	15.84	3000	0.0036	46.9	2.3	0.02	0.2	− 4.9	− 0.2	89.2	8.9
Iprodione	50	1000	0.19	444.4	21.4	0.2	2.1	− 8.4	− 3.7	497.1	49.7
Isofetamid	36	1500	0.053	213.3	10.3	0.1	1.0	− 7.3	− 2.6	288.9	28.9
Isopyrazam	12.57	2000	0.036	55.9	2.7	0.03	0.3	− 9.2	− 4.6	749.4	74.9
Kresoxim-methyl	50	3000	0.92	148.1	7.1	0.07	0.7	− 13.8	− 9.2	7221.7	722.2
Lepimectin	2	2000	0.013	8.9	0.4	0.004	0.04	− 10.9	− 6.2	1700.8	170.1
Lufenuron	5	2000	0.01	22.2	1.1	0.01	0.1	− 8.5	− 3.8	523.3	52.3
Mefentrifluconazole	10	2000	0.016	44.4	2.1	0.02	0.2	− 8.1	− 3.4	418.6	41.9
Metaflumizone	20	2000	0.01	88.9	4.3	0.04	0.4	− 5.7	− 1.0	130.8	13.1
Methoxyfenozide	4	1000	0.11	35.6	1.7	0.02	0.2	− 12.4	− 7.7	3597.7	359.8
Metrafenone	25.2	2000	0.43	112.0	5.4	0.05	0.5	− 12.9	− 8.2	4464.7	446.5
Milbemectin	2	2000	0.0086	8.9	0.4	0.004	0.04	− 10.1	− 5.4	1125.1	112.5
Myclobutanil	6	1000	0.031	53.3	2.6	0.03	0.3	− 9.0	− 4.3	675.9	67.6
Novaluron	10	2000	0.012	44.4	2.1	0.02	0.2	− 7.5	− 2.8	314.0	31.4
Penthiopyrad	20	4000	0.11	44.4	2.1	0.02	0.2	− 12.0	− 7.3	2878.2	287.8
Phenthoate	47.5	1000	0.1	422.2	20.3	0.2	2.0	− 7.2	− 2.5	275.4	27.5
Picarbutrazox	10	2000	0.11	44.4	2.1	0.02	0.2	− 12.0	− 7.3	2878.2	287.8
Prochloraz	50	2000	0.018	222.2	10.7	0.1	1.1	− 5.0	− 0.3	94.2	9.4
Procymidone	50	1000	0.035	444.4	21.4	0.2	2.1	− 5.0	− 0.3	91.6	9.2
Propamocarb HCl	66.5	1000	0.29	591.1	28.5	0.3	2.8	− 8.7	− 4.0	570.5	57.1
Propineb	70	400	0.046	1555.4	74.9	0.7	7.5	− 3.0	1.7	34.4	3.4
Pydiflumetofen	18.35	4000	0.18	40.8	2.0	0.02	0.2	− 13.2	− 8.5	5133.3	513.3
Pyflubumide	10	2000	0.0062	44.4	2.1	0.02	0.2	− 6.1	− 1.4	162.2	16.2
Pyraclostrobin	22.9	4000	0.015	50.9	2.5	0.02	0.2	− 7.6	− 3.0	342.8	34.3

Table 3 (continued)

Pesticides	A.I.[a] (%)	Dilution	AOEL[b] (mg/kg b.w./day)	DFR_0 estimate[c] (ng/cm^2)	PDE estimate[d] (mg/day)	ADE[e] (mg/day)		REI[g] (days)		SWT[h] (h/day)	
						PPE +[f]	PPE−	PPE +	PPE−	PPE +	PPE−
Pyraziflumid	15	2000	0.071	66.7	3.2	0.03	0.3	− 10.3	− 5.6	1238.5	123.8
Pyridaben	20	1000	0.005	177.8	8.6	0.1	0.9	− 2.9	1.8	32.7	3.3
Pyridalyl	10	1000	0.036	88.9	4.3	0.04	0.4	− 8.3	− 3.6	471.0	47.1
Pyrifluquinazon	10	2000	0.013	44.4	2.1	0.02	0.2	− 7.6	− 2.9	340.2	34.0
Pyriproxyfen	10	2000	0.04	44.4	2.1	0.02	0.2	− 9.9	− 5.2	1046.6	104.7
Spinetoram	5	2000	0.0065	22.2	1.1	0.01	0.1	− 7.6	− 2.9	340.2	34.0
Spinosad	10	2000	0.012	44.4	2.1	0.02	0.2	− 7.5	− 2.8	314.0	31.4
Tebufenozide	8	1000	0.008	71.1	3.4	0.03	0.3	− 5.7	− 1.0	130.8	13.1
Teflubenzuron	5	1000	0.016	44.4	2.1	0.02	0.2	− 8.1	− 3.4	418.6	41.9
Tetraconazole	12.5	1000	0.03	111.1	5.4	0.05	0.5	− 7.5	− 2.8	314.0	31.4
Tetraniliprole	18.18	5000	0.37	32.3	1.6	0.02	0.2	− 15.1	− 10.4	13,313.0	1331.3
Thiamethoxam	10	2000	0.082	44.4	2.1	0.02	0.2	− 11.4	− 6.7	2145.6	214.6
Trifloxystrobin	50	4000	0.059	111.1	5.4	0.05	0.5	− 8.8	− 4.2	617.5	61.8
Triflumizole	30	3000	0.041	88.9	4.3	0.04	0.4	− 8.6	− 3.9	536.4	53.6
Valifenalate	12	1000	0.68	106.7	5.1	0.1	0.5	− 13.9	− 9.2	7413.5	741.4

[a] Active ingredient

[b] Acceptable operator exposure level

[c] Initial dislodgeable foliar residue (DFR_0), estimated using A.I., dilution, and deposit volume

[d] Potential dermal exposure (PDE), estimated using DFR_0, transfer factor (TF, 6020.4 cm^2/h), and harvesting time per day (H/D, 8 h/day)

[e] Actual dermal exposure (ADE) = PDE × 10% penetration rate through PPE × 10% skin absorption

[f] Personal protective equipment or clothing

[g] Reentry interval

[h] Safe work time

Agricultural workers generally harvest cucumbers daily in a greenhouse because it is a continuously harvested crop with a rapid growth rate. Therefore, these results demonstrate the lowest possibility of risk for workers wearing PPE, even when they reenter the greenhouse on the day of application. However, the use of PPE is considerably more limited for harvesters due to work-related inconvenience than for applicators. In Korea, agricultural workers generally harvest crops wearing long-sleeved shirts and long trousers [15, 16]. Consequently, for the harvesters not wearing PPE, the REIs were determined between 0.04 to 4.4 d for seven pesticides including chlorothalonil, emamectin benzoate, flubendiamide, fluquinconazole, iminoctadine tris(albesilate), propineb, and pyridaben; SWT for six pesticides (except for flubendiamide) was less than 4 h/day. The potential health risks of these pesticides were due to the lower AOEL values for emamectin benzoate, flubendiamide, fluquinconazole, iminoctadine tris(albesilate), and pyridaben and the higher DFR_0 for chlorothalonil and propineb. Therefore, a harvester must wear PPE for health safety when reentering a facility after spraying pesticides. Meanwhile, as mentioned above, REIs estimated in this study had a few limitations, such as the application of dissipation constant of methidathion. DFRs for pesticides with potential health risks should be further investigated to ensure the health safety of greenhouse workers more definitively.

Abbreviations

DFR	Dislodgeable foliar residue
TF	Transfer factor
DER	Dermal exposure rate
DV	Deposit volume of spraying solution
A.I.	Active ingredient
DF	Dilution factor
PDE	Potential dermal exposure
H/D	Harvesting time per day
ADE	Actual dermal exposure
PEN	Penetration rate
PPE	Personal protective equipment
ABS	Skin absorption
REI	Reentry interval
AOEL	Acceptable operator exposure level
BW	Body weight
RDA	Rural development administration
SWT	Safe work time
EPA	Environmental protection agency

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Author contributions
HC conceived and designed the project, collected the data, performed the analysis and interpretation, and wrote the paper. The author read and approved the final manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests
The authors declare that they have no competing interests.

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