Suspended Onion Particles and Potential Corneal Injury in Onion Harvesters

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ABSTRACT. The authors suspected that suspended onion particles contributed to corneal ulcers in onion harvesters in southern Taiwan. In the present study, the authors used manikins to study suspended onion particles in fields in an effort to simulate typical conditions experienced by onion harvesters. An animal eye-exposure simulation study was also performed by the authors, who impacted suspended soil grains or onion particles onto the corneas of guinea pigs via aerosol generated from the Palas® dispersion nozzle. The average size of 25.9 µm for suspended particles collected during the digging of onions was the largest one of those for various harvesting activities. Some onion skin flakes were found in samples obtained from gathering and packing activities; the typical flake size was approximately 3.5 × 2.5 mm². The results of the animal study indicated that the size of soil grains has a demonstrable effect on the severity of corneal injury (*p* = .009). With respect to onion skin flakes, wind velocity was also associated significantly with the occurrence of corneal injury (*p* = .0004). A wind velocity threshold of 7 m/sec is recommended for the maintenance of safety, and if the wind speed exceeds this threshold level, workers should not engage in harvesting activities. Furthermore, use of appropriately designed goggles is necessary for the protection of onion harvesters who work in high-wind conditions.
<Key words: cornea, onion, soil, suspended onion particles, wind>

IN A CASE STUDY AND AN EPIDEMIOLOGICAL STUDY, investigators reported that during the past several years there were 7 onion harvesters who suffered from corneal ulcers in southern Taiwan—a monsoon area with prevailing gusty winds.[1,2] This finding was the first reported cluster of occupational corneal ulcers among onion farmers in Taiwan. In agricultural settings, however, the occurrence of corneal ulcers is not uncommon, especially during the dry and windy season. Many corneal ulcer cases have been reported among farmers in China and Indonesia,[3,4] and most cases occur during the windy harvest season. In addition, investigators indicated that before a corneal ulcer occurs, there must be physical injury to the corneal epithelium, so that a bacteria or fungus could infect the cornea, thus causing a corneal ulcer, unless proper treatment occurs first.[5] In agriculture, an eye injury is usually caused by foreign bodies that make contact with human eye(s). The sizes of such bodies range from 0.5 mm to 4.0 mm (e.g., debris of dead insects, vegetables, flowers, seeds, miscellaneous plant tissues[4,6]). Or, eye injury may be caused by the sharp edges of stems or leaves. Given the abundance of fungi in the agricultural environment, an eye injury becomes more complicated than usual if it ends up with a fungal corneal ulcer.

Growing onions is very popular in the Heng-Chun Peninsula (southern end of Taiwan), 97% of which is devoted to the growth of onions. This area is also well known for its local "downhill-gust" phenomenon. The formation of the downhill gust is associated with the monsoons and local topology. The gust occurs when the front of monsoon passes over the 1,000-ft-high mountain ridge and incurs accelerated high winds blowing downhill along the plain. According to the Central Weather Bureau, the seasonal average wind velocity varies from 4.4 m/sec to 6.1 m/sec, and the average daily highest wind velocity during the downhill-gust season ranges from 10 m/sec to 17 m/sec; the all-year record high of 37.2 m/sec was observed in 1987.[7] This characteristic seasonal wind prevails from October through March in the following year. Basically, the time frame for growing onions parallels the occurrence of the downhill gust, beginning with onion planting during late summer and ending with onion harvest in late February and March of the following year. An onion is a hydrophobic plant during the second half of its growth stage; therefore, a special climate is required for onion growth (i.e., low humidity and strong winds). The strong wind may pull the onion leaves down, thus resulting in nutrients being directed toward the onion bulb.

Harvesting of onions in the study area is usually performed by a team of 4–6 farmers, of whom most are female. From the viewpoint of occupational health, the occurrence of eye injuries is much more pronounced during the onion harvesting season. During harvesting activities, work teams have potential eye exposure to soil grains and/or plant debris. Harvesting activities include (1) digging out the onion bulb from inside soil, (2) drying the onion on site for 1 day, (3) screening onions and cutting leaves, (4) gathering onions, and (5) packaging onions for sale or storage. To understand the potential hazards for eye injury that can result from this work environment, we sought to (1) characterize the size distribution of suspended onion particles that may enter the eyes of the harvester and (2) estimate the effects of suspended onion particle size and wind velocity on the occurrence of corneal injury during the onion harvesting period.

Materials and Method

Characterization of suspended onion particles impacted onto the eyes of onion harvesters. We used a manikin to simulate an onion harvester's eye exposure to suspended onion particles while at work. The sampling medium was made of double tape; 1 side was adhered to eye-shaped supporting pads, which were, in turn, stuck onto the eyes of the manikin, and another sticky side was used as the sampling medium. The manikin was erected with a tripod support at the onion farms, and it was set as high as the approximate height of a harvester working in the field. The general setup for the sampling medium on the manikin is shown in Figure 1. For purposes of simulation, the manikin had a hat-hood on; it was viewing downward at 45º, and it was oriented directly toward, or at 45º and 135º away from, the wind direction, respectively. Some manikins wore goggles, which mimicked the use of personal protective equipment worn by some of the harvesters.

Passive sampling began with the peeling of the plastic cover of the sampling side of double tape that was already stuck on the manikin. The collection time for each sample was approximately 4 hr, which represented 1 work shift of onion harvesting. Following the sampling, the medium with collected suspended onion particles on it was removed from the manikin's eye and stored in a plastic culture plate. The collected samples were later counted and examined by 1 of the authors with an optical microscope (Nikon®, 10×, with Olympus® objective micrometer) to differentiate the substance that had impacted onto the sampling manikin, and the same author then measured the long diameter size.

At the same time that suspended onion particles were measured, meteorological conditions were also recorded, including weather conditions, wind direction, velocity (with Information and Electrical Technologies Thermistor Type Anemometer Model, V-01-A_N), temperature, and humidity (with Testo 600®).

Simulation of eye exposure to suspended onion particles from onion farms. In this part of the animal simulation study, soil grains and onion skin flakes served as eye exposure materials. We used the materials to estimate the potential corneal injury to guinea pigs at the specified size of suspended onion particles and at a

Fig. 1. Sampling manikin with hat/hood and sampling medium on eyes.

similar wind velocity that existed in the field study. Guinea pigs that were 8–12 wk of age were selected for study. The exposure soil grains and onion skin flakes were obtained from the local onion farms. In the simulation experiments, soil grains and onion skin flakes were impacted onto the eyes of the guinea pigs through the aerosol generated from the Palas® dispersion nozzle (Fig. 2). In this simulation, compression gas is connected to the Palas® dispersion nozzle, and its flow can be changed by adjusting the valve to obtain the desired wind velocity for exposure simulation. The internal structure of the Palas® dispersion nozzle is made on the basis of Bernoulli's theory. Therefore, while the compression gas flow enters through the inlet (C), the soil grains or the onion skin flakes are sucked into the nozzle (B) and dispersed out from nozzle (A); they are in turn, impacted onto the guinea pig's cornea—5 cm from the opening of the nozzle (A).

A 0.02-gm aliquot of soil grains or 100 pieces of onion skin flakes were applied for each eye-exposure simulation experiment. The sizes of the soil grains used for the eye exposure simulation were classified into 10 categories, which ranged from < 20 µm to 355–500 µm, in accordance with the American Society for Testing and Materials standard siever, No. 35 through No. 625. In addition, 2 onion skin flake sizes (i.e., approximately 1.5 $mm^2 \times 1.5\ mm^2$ and 3 $mm^2 \times 3\ mm^2$, respectively) were also used in this eye-exposure simulation study. The onion flakes were torn off, rather than cut, thus mimicking the real onion flake edge experienced in the field. Either material (i.e., soil gra ins and/or onion flakes) was dispersed onto the guinea pig's eyes at 5 different wind velocities, which ranged from 2 m/sec to 15 m/sec.

Prior to each eye exposure simulation experiment, we stained each study guinea pig's corneas with 2% fluorescein solution and examined them with a slit-lamp microscope individually to ensure that the corneas were healthy. In the exposure experiment, each guinea pig was initially temporarily anesthetized for approximately 1 min with diethyl ether. Its eyelid was then propped open and exposed to the aerosol of soil grains or onion skin flakes generated by the Palas® dispersion nozzle (Fig. 2). Following impaction with soil grains or onion skin flakes, the exposed cornea of the study guinea pig was stained. The cornea was again examined with the same procedures described earlier, prior to the eye being exposed to soil grains or onion skin flakes. The extent of corneal injury was rated for 5 levels (Table 1), from intact (0) to serious injury (4). Each experiment with the specific wind velocity and size of soil grains or onion skin flakes was repeated 6 times with different healthy corneas; therefore, a total of 50 and 10 experiments were performed for soil grains and onion skin flakes, respectively. The procedure used in the present study was approved by the Institutional Review Board prior to its conduct.

Given the log-normal distribution, the soil grain size data obtained in the field study were transformed to their log equivalents for further descriptive analysis and presentation. In addition, we applied the statistical methods of the general linear model (GLM) and Scheffé's posttest and performed the Statistical Analysis System computer program to evaluate the effects of suspended onion particle size and wind velocity on the occurrence of corneal injury.[8]

Results

It was sunny during the 3-day survey of the suspended particles of the onion harvesting period. The daily wind velocity mode ranged from 1.5–2 m/sec to 8–10 m/sec, whereas the daily maximum wind velocity ranged from 2.5 m/sec to 13 m/sec. The average temperatures during the sampling period of these 3 consecutive days were 28.1 ºC, 23.3 ºC, and 28.7 ºC, respectively, and the average relative humidity values were 67.3%, 63.5%, and 53.5%, respectively.

According to the microscopic examination, more than 95% of the suspended materials collected on the sampling manikin were soil grains. Fewer onion skin flakes were found only on the sampling medium obtained for the gathering and packing activities, and sizes of typical flakes were approximately 3.5 × 2.5

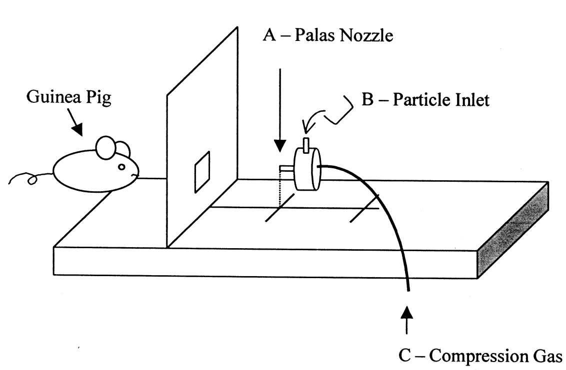

Fig. 2. Device for simulating particle exposure by applying the Palas for aerosol generation.

Table 1.—Classification of Guinea Pigs' Corneal Injury as Examined with a Slit-Lamp Microscope

Level of injury	Observation
0 (none)	No color change on cornea
1	Light green color observed on cornea
2	Deep green color observed on cornea
3	Shiny green color observed on cornea
4	Extremely shiny green color observed

Note: Guinea pigs were exposed to study particles (i.e., soil or onion flakes) of a specific size. Exposure occurred under different wind-velocity conditions. Prior to being examined with a slit-lamp microscope, the guinea pig's cornea was stained with 2% fluorescein solution.

mm^2. Table 2 presents the size distribution of suspended materials collected on the sampling manikin during the onion harvesting period. Although the sampling manikin's orientations were set at 45º and 135º away from the wind direction and the wind speed mode of 3–5 m/sec was significantly weaker than the speed during other sampling periods, average sizes of the suspended materials collected during the onion digging-out period (i.e., 25.9 μm [geometric standard deviation {*GSD*} = 1.75] and 26.4 μm [*GSD* = 2.03]), were relatively larger than those collected during leaf cutting and packing periods. On the other hand, the average counts of suspended materials per sample obtained during the onion leaf cutting and packing periods of harvesting works were generally more than those obtained during the onion digging-out period. Extremely high values of 1,732 counts/sample and 1,121 counts/sample were observed for the onion packing activity.

Results of the eye exposure simulation experiment with guinea pigs are summarized in Table 3. Individual ratings for the extent of corneal injury are presented in each cell of (1) the specific wind velocity, (2) the exposing material, and (3) its size. For soil grain exposure, results of the general linear model (GLM) analysis, considering the effects of soil grain's size and wind velocity simultaneously in 1 model, indicated that the size of soil grains had a demonstrable effect on the severity of corneal injury (p = .0090), whereas the wind velocity did not show such effect within the wind speed range imposing on the study guinea pigs. The impacting effect of onion flakes on corneal injury is also presented in Table 3. With the GLM analysis, wind velocity was

Table 2.—Size Distribution of Suspended Particles (in μm) Collected on a Sampling Manikin during the Onion Harvesting Period

Harvest activity	Away from wind direction	*GM*	*GSD*	Range	Average counts per sample	Wind speed mode (m/sec)
Digging out onion	45º	25.9	1.75	5–158	31.1	3.0–5.0
	135º	26.4	2.03	10–150	14.5	3.0–5.0
Cutting onion leaves	0º	23.3	1.81	5–350	213.0	8.0–10.0
	0º*	19.8	1.59	5–85	214.0	8.0–10.0
Packing	0º	20.0	1.73	8–90	30.7	1.5–2.0
	0º	19.6	1.64	8–565	1,732.0	8.0–10.0
	0º*	15.9	1.54	10–103	1,121.0	8.0–10.0

Notes: GM = geometric mean, and *GSD* = geometric standard deviation.
*Goggles were on the sampling manikins.

Table 3.—Corneal Injury in Guinea Pigs in the Simulation of Soil Particle Exposure, by Particle Size and Wind Velocity*

Particle size	Wind velocity (m/sec) 2–3	3–5	5–7	7–10	10–15	*p*
Soil grains (μm)						
< 20	0,0,1,0,0,0	0,0,0,0,0,0	0,0,0,0,2,1	3,1,1,2,1,0	0,0,0,0,0,1	
20–32	0,0,0,0,2,0	0,0,1,1,0,2	0,1,1,1,0,0	2,1,0,1,2,1	1,0,0,0,1,0	
32–38	0,1,0,0,1,0	0,0,1,0,0,1	0,0,1,0,0,0	0,0,1,0,0,0	1,0,0,1,1,0	
38–53	0,0,0,0,0,2	2,2,2,0,1,0	2,1,2,1,2,2	0,1,1,1,0,1	2,1,0,3,0,1	
53–63	2,0,0,0,0,0	0,0,1,0,0,2	4,1,0,0,0,1	1,0,0,0,0,0	0,2,0,0,0,1	*p* = .009
63–75	2,0,0,0,2,1	0,1,0,0,0,3	0,0,0,0,3,2	0,0,0,1,0,0	0,0,0,0,2,0	
75–106	2,0,0,0,0,0	0,0,0,0,1,1	1,1,1,0,0,1	0,2,0,0,1,1	0,0,0,0,1,1	
106–212	4,0,1,1,0,1	0,4,0,0,0,3	1,0,0,0,1,0	1,0,0,2,1,0	0,0,0,1,1,0	
212–355	1,2,1,1,1,1	1,2,2,0,1,1	0,1,2,1,2,1	2,1,0,0,1,1	0,1,0,1,2,1	
355–500	3,2,1,0,0,1	0,2,0,1,0,0	1,0,1,1,0,0	0,1,2,0,0,1	1,0,1,2,0,1	
Onion skin flakes (mm2)						
1.5 × 1.5	2,1,2,0,1,1	2,1,1,0,2,1	2,2,3,0,2,1	3,3,1,1,3,4	2,4,3,4,3,2	*p* = .080
3.0 × 3.0	1,0,0,2,0,0	3,0,1,2,1,1	1,2,1,1,2,1	1,1,3,0,4,1	3,0,3,2,2,4	
			p = .0004			

*Definitions of guinea pig's corneal injury are available in Table 4. Each cell contains corneal injury results of 6 guinea pig exposure experiments with specific soil particle size and wind velocity.

Table 4.—Effect of Critical Wind Velocity on the Corneal Injury of Guinea Pigs Exposed to Onion Flakes (Scheffé's Posttest)*

	Wind velocity (m/sec)			
Wind velocity (m/sec)	2–3	3–5	5–7	7–10
3–5	–0.90~1.73			
5–7	–0.65~1.98	–1.07~1.57		
7–10	–0.07~2.57	–0.48~2.15	–0.73~1.90	
10–15	0.52~3.15†	0.10~2.73†	–0.15~2.48	–0.73~1.90

*Each cell presents the 95% confidence interval of the difference of mean corneal injury ranks of study guinea pigs of every 2 wind-velocity categories.
†$p < .05$.

associated significantly with corneal injury ($p = .0004$), and only a borderline—but not statistically significant—effect was found for the size of onion skin flake ($p = .080$). Table 4 presents the comparisons of cornea-injuring effects of every 2 wind velocity levels, with flake sizes collapsed as 1 level. As is clearly shown in Table 4, the cornea injuring effect of wind velocity at 10–15 m/sec differed significantly from the wind velocity level less 5 m/sec, whereas wind velocity that ranged from 5 m/sec through 10 m/sec had a moderate effect, and clear differentiation was difficult.

Discussion

Suspended onion particles in onion field. In accordance with previous clinical findings, most observed materials on the eyes of workers were less than 5 mm in size.[4,6] The results of the present study suggested that the size of collected suspended onion particles ranged from micrometers to a few millimeters. This observation was consistent with clinical findings, and the findings endorsed the use of a sampling device developed in the present study for exposure assessment of suspended onion particles. However, we also recognized that the sampling manikin did not breathe or blink, which would, to some extent, reduce the level of exposure to suspended onion particles; therefore, the potential hazard at work could have been overestimated. Nevertheless, from the viewpoint of occupational health, the findings from the present study provide a conservative, but worthy estimate of potential hazards for the onion harvesting works and could be used for the establishment of protection guidelines.

Most of the suspended onion particles collected in the field likely originally from the loosened soil grains on the ground and from the onion surfaces that appeared following the digging of onions, which were dried by wind and sunshine, as well as from the activities of cutting leaves and gathering and packing the onions. In addition, the onions were knocked about and were squeezed during the gathering and packing periods; onion skin flakes were, therefore, readily generated and suspended, and eventually collected on the sampling manikin. These observations explained the presence of the coarse suspended particles found in the present study.

We asked the onion harvesters to wear protective goggles, which are used in industry for spray or injection protection. Despite the fact that the geometric mean particle size was smaller for samples collected from manikins wearing goggles than for samples collected from manikins without goggles, considerable amounts of suspended particles were obtained on the sampling medium (Table 2) (i.e., the protective effect was less than we had anticipated). This observation raised the concern that the goggles may not have been designed appropriately and may not have met the protective needs of the onion field workers. If goggles are to be used in onion field workers, special focus should be placed on the fit of the protective goggles. In the absence of adequate goggles, the suspended particles would flow inside the goggles, thus exposing the eyes—especially when the workers are looking down. In addition, there are concerns about heat and humidity when one aims to design an effective and comfortable goggle for field use.

Potential corneal injury. The cornea is a transparent organ that constitutes the front 1/6 of the eyeball. The cornea is composed of 5 layers: (1) epithelium, (2) Bowman's layer, (3) stroma, (4) Descemet's membrane, and (5) endothelium.[9] In addition, 3 layers of tear films on the cornea surface prevent direct exposure to the atmospheric environment.[10] In addition, corneal elasticity and ocular rigidity vary, and they are associated with internal and external pressures.[11,12] The eyeball can also be protected with a self-response system, which is characterized by (1) routine blinking, (2) Bell's phenomenon, (3) the sensory nerve system, (4) tear washing, (5) tearing in response to biological materials, and (6) the immune system.[10,13] These physical and physiological characteristics of the cornea are very subtle. Thus, evaluation of the potential effect of its exposure to suspended onion particles on corneal injury can be achieved only with live subjects in an experimental study. Given that the guinea pig reportedly has similar responses to eye exposures as humans,[14] we, therefore, chose the guinea pig as an alternative in this eye-exposure simulation experiment. Approximately 1 min after the guinea pig's eye was anesthetized for the study of suspended particles, the guinea pig's eyes soon recovered. This characteristic of anesthetization enabled us to observe the comprehensive effects of the eye's exposure to suspended particles by considering the creature's self-response to the impacted foreign bodies.

In accordance with previous studies, movement of airborne coarse dust would slow down as it approached the face and eyes of a human subject.[15,16] This movement becomes inert as the airborne coarse dust approaches and impacts on the subject's face. In the present study, we showed that at a wind velocity of 7 m/sec in the field, the measured wind velocity was only 2–3 m/sec at 5 cm in front the human subject's eyes. This result is consistent with the conclusion noted in a study mentioned earlier.[15,16] To mimic this effect, we determined the wind velocity set in the eye-exposure simulation study determined at 5 cm in front of the Palas nozzle, without study material being suspended in the generated airflow, and no study animal at the designated position for exposure. We then evaluated the impaction effects of suspended particles on the cornea with the guinea pig standing at the designated exposure point in front of the nozzle at the specified wind velocity. This experimental design allowed us to closely simulate eye exposure in the field by accounting for the changing movement of suspended particles as they approached the human subject's eyes; the comparability of the study results therefore increased. Meanwhile, a 0.02-gm aliquot of soil grains for eye exposure simulation was determined via a pilot study for the generation of homogeneous aerosol, for soil grains smaller than 500 µm, at 5 cm in front of the generator nozzle, with a cross-sectional area of 3 cm in diameter. Also, in the pilot study, we performed a similar process to determine whether 100 pieces of onion skin flakes per eye secured a sufficient amount of onion flakes to reach the guinea pig's eye. These verifications in the pilot study validated the use of this eye exposure simulation design in the present study, and they made the results of potential corneal injury on study guinea pigs more reliable for further comparison.

In accordance with the eye exposure simulation study with soil grains, size of soil grain, rather than wind velocity, had a significant effect on corneal injury. However, most corneal injuries were limited in severity, and only 3% of the eye exposure experiments presented corneal injury rated equal to or greater than 3. No serious case, such as epithelium scaling off, was observed. On the other hand, highly rated corneal injury could be found in the diagonal zone (Table 3) from high wind with small particles to low wind with large particles. In contrast, high score-related corneal injury could be observed more frequently in the diagonal zone of Table 3, from high wind along with small particles to low wind along with large particles. Therefore, even though the average means of soil grains observed in the field were not large (i.e., ranged from 9.2 µm to 31.9 µm), the exceptionally large soil grains (i.e., order of 100 µm), found occasionally in the field, still required more attention, thus eliminating the possibility of eye injury by impaction. Also, no soil grain implantation into the cornea was found, which might indicate that the guinea pig's cornea itself could expel the impacting soil grain of the size and at the wind velocity used in the present study. The most-often observed eye injuries attributed to foreign bodies were caused by metal dust resulting from refinery or distillery work with high-speed machines.[17] The soil grains found in our present study might not have had such a serious effect as does metal on the cornea, perhaps as a result of its relatively low hardness and low possibility of implantation onto the cornea. During the expelling process, however, the cornea might be abraded from the friction between soil grains and the cornea, resulting from the blinking activity as a self-protection response. A detailed effect of blinking activity is worthy of concern in the case of onion farmers' exposure to suspended particles, and it warrants further in-depth investigation.

A soil grain of 565 µm, with a density of 2.66 gm/cm^3 obtained in the present study, is equal to 0.25 mg, and a piece of onion skin flake of 1.5×3.5 mm^2 weighs approximately 0.3 mg. From the viewpoint of mass, these 2 materials with the aforementioned sizes may have very close dynamics at the same wind velocity. However, according to the findings in the animal study, corneal injury caused by soil grains of approximately 355 µm to 500 µm was not as serious as injury caused by onion flakes with equivalent weight. Generally, the cornea was more seriously injured by impaction of onion skin flakes than soil grains—in terms of injury area and/or depth on cornea. Study results demonstrated that the extent of corneal injury was associated significantly with wind velocity (p = .0004). Especially when the wind speed exceeded 7 m/sec, the percentage of corneal injury rated as 3 or 4 was significantly increased; this injury appeared as an extremely bright green spot observed microscopically with the fluorescence stain. This level of injury might have implied that Bowman's layer had been compromised. Although in the present study we identified only a borderline effect, the effect of the size of the onion skin flakes on corneal injury was highly likely. This phenomenon likely resulted because only 2 sizes of onion skin flakes were used in the eye exposure simulation study. Had we been able to study additional sizes of onion skin flakes (e.g., 5–10 sizes), we believe that we could have shown that the size of onion flake would have significantly affected the occurrence and severity of corneal injury.

The onion skin flake's shape and size may have produced a more serious corneal injury than the injury caused by the soil grain. Given that the onion flake is flat, with a cutting edge, a slice-cut injury on the cornea would be anticipated and could be identified microscopically on the study cornea. The onion skin flakes could adhere to the flat-surfaced cornea that contains moisture on the tear film; this condition could then lead to an area abrasion on the cornea from the pressure and friction that result from the self-protective response (i.e., eye blinking). With this expelling function of blinking activity, the onion flake imposed on the cornea might be removed. However, if the flake is not successfully removed, it might closely adhere to the corneal surface, and the corneal epithelium might be injured.

Conclusions

In this study, we found that corneal injury in onion harvesters in southern Taiwan may be associated with the impaction of onion skin flakes, resulting from high-speed downhill gusts of wind in the local area. Onion harvesters should wear appropriate eye protection while they are in potentially hazardous working environments (i.e., wind velocity ranging between 5 m/sec and 10 m/sec), and they should avoid working (especially onion gathering and packing) if the wind velocity exceeds 10 m/sec. The findings from the animal exposure study indicated that a wind speed of 7–10 m/sec was sufficiently strong to cause the most serious level-4 corneal injury. To prevent occupational injury, individuals should not harvest onions if the wind velocity exceeds 7 m/sec.

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The authors gratefully acknowledge the kind assistance of Dr. Yun-Tsie Chen of the Heng-Chun Christian Hospital during our field survey at the onion farm. The authors also owe special thanks to Dr. Chuan-Yu Lai, Dr. Seng-Hsiou Huang, and Mr. Wei-Yu Chen for their continuous help in the laboratory work.

Submitted for publication August 21, 2000; revised; accepted for publication December 8, 2000.

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