

Safety aspects in greenhouse spraying

Causes and preventive measures

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Ensuring operator safety is an important concern in the application of plant protection chemicals under greenhouse operating conditions. Plant protection chemicals under the greenhouse can be applied by a variety of means, including traditional (lever-operated and battery-powered knapsack sprayers), walk-behind type and riding-type vertical boom sprayers. Among these, traditional sprayers are the most common means of pesticide application due to easy availability, wide applicability and cost-effectiveness. These sprayers in greenhouse working environments (high temperature and relative humidity), improper ventilation, dense crop geometry and working at heights pose higher chemical risks (potential dermal and inhalation exposure). It causes health hazards such as skin irritation and difficulty in breathing which can impact the worker's life. To reduce and mitigate dermal and inhalation exposure, proper care needs to be taken in terms of equipment, personal protection and application techniques to reduce exposure and increase safety of the operator. These interventions can reduce significant exposure and improve the efficiency of the working environment without adopting or investing in any technological interventions. Further, the adoption of robotic technology for spraying in the greenhouse will eliminate the human interface and significantly improve yield quality and quantity of produce.

Keywords: Chemical application, Exposure, Greenhouse, Robot, Safety, Sprayers

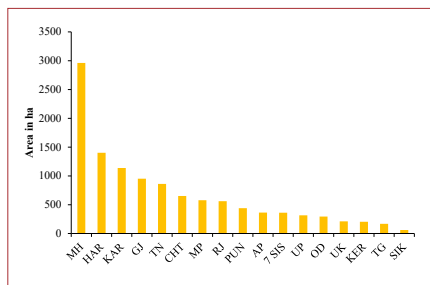
Globally greenhouse horticulture market was valued at ₹2,755 billion in 2022 and is expected to reach ₹5,475 billion by 2032 at a compound annual growth rate (CAGR) of around 7.7% between 2023 and 2032. In India, the production of horticultural crops is 342.33 million tonnes from 28.08 million ha in 2022-23. It has increased 20.8% in area and 33% in production compared to 2011-12. Horticulture witnessed remarkable growth and contributes 9 times to the agricultural production and 30.4% to the agriculture GDP of the country, and also accounts for 37% of India's total agricultural commodity exports. This increase in production was made possible with open-field horticulture and as well as with protected cultivation. The yield and quality of produce in protected cultivation are higher

than in open fields. Therefore, this sector is currently emerging as high in demand.

Protected cultivation was introduced in the early 1990's. The total area under protected cultivation increased significantly from 3.2 thousand ha in the 1990's to 0.251 million ha in 2018. About 14,366 ha area of greenhouses were constructed from 2005 to 2020, with 7,622 ha (53%) low-tech (i.e., shade net house and walk-in tunnels), 6,387 ha (44%) mid-tech (i.e., naturally ventilated) and 357 ha (3%) was high tech (i.e., climate controlled) greenhouses. In India, the major crops grown in greenhouses are vegetables, flowers, nurseries and fruits (60%, 24%, 15% and 1%, respectively). Among the vegetable are 50% sweet pepper (red, yellow and green), 35% cucumber, and 15% tomatoes and other crops. In case of

flower production, 50% Roses, 25% Gerbera, and 25% Orchids and other flowers.

The major operations performed in the greenhouse are seedbed preparation, transplanting, irrigation, intercultural operations, spraying, pollination, pruning, harvesting, and transportation. Among these, pesticide application is a significant operation due to specific agro-eco systems inside the greenhouse having higher insects and pest infestation. Due to these conditions, greenhouse crops require frequent application of pesticides to maintain produce quality. It is also stated that covering one acre of greenhouse pesticide application requires nearly 24 working days per annum. However, direct contact with pesticides by operators that handle and apply these pesticides can lead to harmful



Area under greenhouse cultivation in different states of the country

effects depending on the level of exposure and toxicity of pesticide compounds.

The accompanying exposure to pesticides through ingestion, inhalation, and dermal contact leads to potential adverse health impacts on the operators, such as skin irritation, respiratory, digestive and neurological disorders. Among different routes of exposure, dermal exposure accounts for up to 98% of total exposure for operators, and also the number of people poisoned by pesticides due to skin absorption accounted for more than 90%. In addition, farmers often neglect the use of proper personal protective equipment due to the lack of knowledge and awareness. Operators typically apply chemicals below elbow height in open fields. Although mixing and loading are associated with higher exposure values due to the concentrated products being handled, however application stage in the greenhouse is particularly prone to higher exposure due to the enclosed environment without proper ventilation, high and tall crop density, and prolonged activity compared to open field agriculture. Operators typically apply chemicals below elbow height in field crops, causing less exposure, whereas

in the greenhouse, the application is above shoulder height which leads to higher exposures. To address the issues of higher chemical exposure during the application stage of plant protection products in greenhouse cultivation, some safety aspects are suggested.

Factors of pesticide exposure

Work environment, equipment and operator-related factors

- Lack of awareness of occupational hygiene among farm workers during application
- Lack of information and training on pesticide safety and application techniques
- Inadequate use of personal protection equipment during application
- Unawareness of restricted entry level of operator specified on pesticide labels
- Poor knowledge of the effective working parameters (spray pressure) during spray



Different types of sprayers

(a) Battery-powered knapsack sprayer, (b) Electric-powered sprayer

applications or neglecting to check them entirely

- Abnormal exposure from an accidental splash from a spray tank leak. Therefore, regular checking and maintenance of the spray equipment is necessary to avoid unexpected exposure
- During the mixing and loading stage, operators mostly do not wear gloves and frequently wipe sweat off their faces with the back of their hands, resulting in high exposure
- The sprayers having small tank capacity require a number of refills to cover a large area; preparing and loading the spray suspension for every refill exposes the operator to chemicals
- Hot and humid environment in a greenhouse, sweating during the activity, and being trapped within the clothes enhance the penetration of plant protection products
- Reuse of personal protective equipment (PPE) without prior cleaning or from storage on premises that are already contaminated
- Spraying above shoulder height expose the operator to higher chemical exposure

Technical factors

- Properties of the chemical compound
- Type of work activity (mixing, loading, application, disposal, cleaning)
- Duration of activity
- Application pattern
- Crop type (or) crop geometry
- Spray equipment
- Droplet size of the spray



(a)



(b)

Spraying of chemical

(a) In greenhouse (above shoulder height) and (b) In field crops (below shoulder height)

- Climatic conditions
- Operator experience
- Hygienic behaviour of the operator

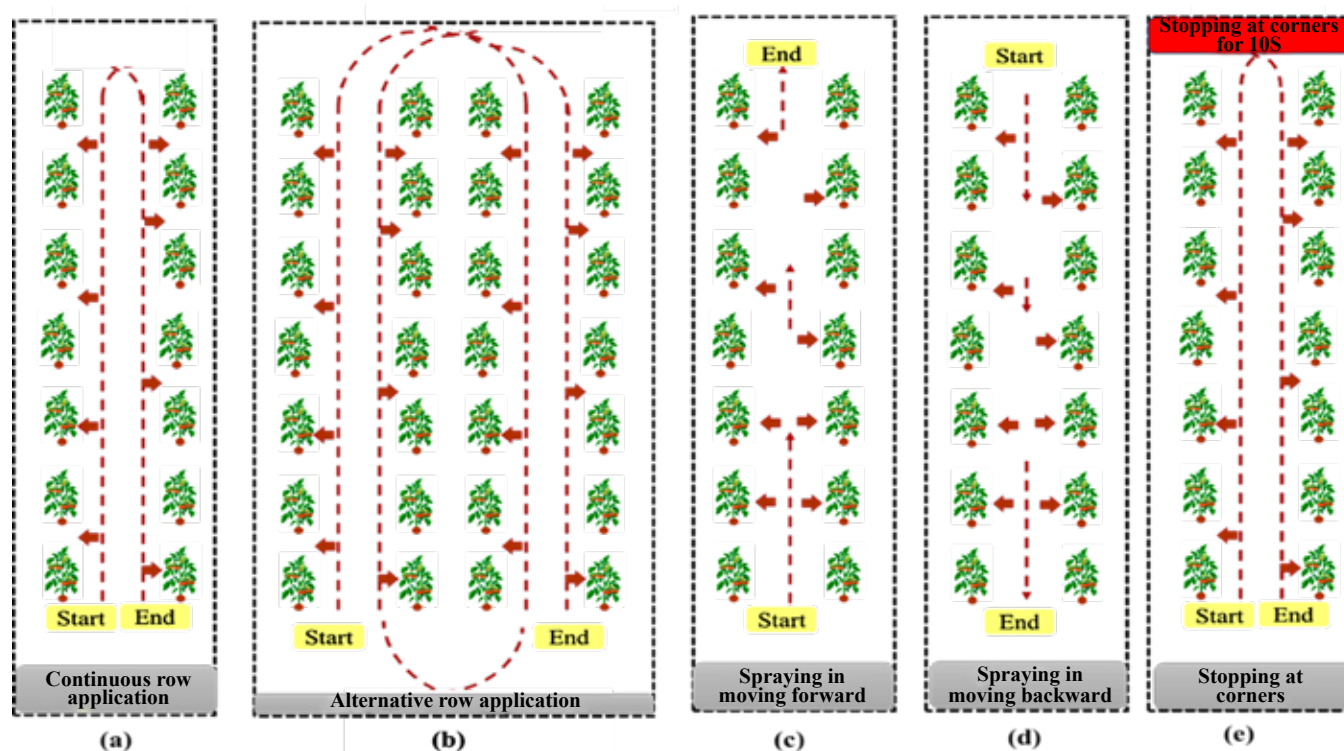
Equipment-related factors

- **Type of nozzle:** The nozzle type and size are paramount factors that affect exposure. So, proper selection of nozzle type and size is important for reducing chemical exposure and for appropriate deposition of chemicals on the targets. Air injection nozzle causes lower exposure ($4.737 \mu\text{g}/\text{cm}^2$ of body area) compared to standard cone nozzle ($20.885 \mu\text{g}/\text{cm}^2$ of body area).
- **Application pressure:** Increasing or higher pressure of the spraying equipment increases (780 mL/h) the potential dermal and inhalation exposure compared to low pressure (132 mL/h). Potential dermal exposure will increase six to eight times when application equipment changes from low pressure to high pressure. It is because high-pressure creates finer mists and increases skin contact compared to low pressure, thus increasing dermal exposure.
- **Power source:** A motorized hydraulic powered knapsack sprayer causes higher exposure ($7,494 \mu\text{g}/\text{day}$) compared to a trolley sprayer ($967.5 \mu\text{g}/\text{day}$) (walk behind) type or riding type trolley sprayer. A great reduction in dermal exposure can be achieved by using self-propelled sprayers rather than hand-held sprayers.
- **Droplet size:** Droplet size (which depends on the type of sprayer and the working pressure) also has an impact; smaller droplets cause higher exposure rates compared to large droplets. It is due to smaller droplets drifting more in air and evaporating faster due to their high surface area to volume ratio, causing potential dermal and inhalation exposures.
- **Length of lance:** Length of the spray lance also plays a role, as a lance is shorter than 0.3 m and may cause higher exposure because of closeness to the operator's body. The 0.3 m length of the lance causes a higher exposure value of 698 mL/h than the 0.5 m length spray lance which has lower chemical exposure of 107 mL/h.
- **Crop characteristics:** Crop

characteristics influence the operator's chemical exposure; chemical spray exposure increases when the crop is taller compared to smaller crops. It is due to the swing of the spray lance, a greater contact between the operator's body with the foliage. In the tomato crop at the fully developed vegetation stage, PDE exposure was 626 mL per 1000 L of application, whereas in the flowering stage, the exposure was 226 mL, respectively.

Greenhouse spraying patterns

- **Continuous row spraying:** In this technique, the operator starts spraying the left side of the row while moving forward in the field inside the greenhouse. After reaching the end of the row, turns 180 degrees and sprays the right side of the same row while returning.
- **Alternative row spraying:** In this technique, operator starts spraying the left side of the row while moving forward. After reaching the end of the row, the operator continues spraying in the next row.
- **Spraying forward:** In this technique, operator starts



Different spraying techniques for exposure reduction

spraying with a view to cover both sides of the crop in a single pass while moving in the alley.

- **Spraying backward:** In this technique, operator starts spraying with a lance in front with a view to cover both sides of the crop in a single pass while walking backward into the unsprayed area.
- **Stopping at corners:** In this technique, the operator starts spraying on one side of the crop while moving forward, stops for 10 seconds at the corners and sprays the next side of the crop row while moving back in the same row.

Reduction in exposure - Potential solutions

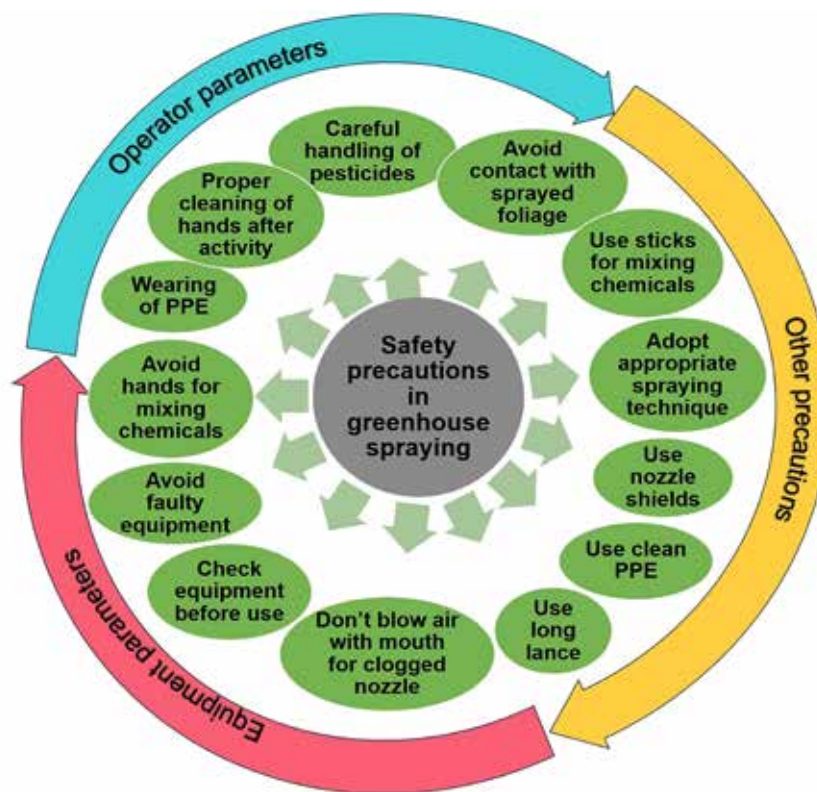
Spraying in continuous rows and forward poses higher chemical exposure due to regular contact with the sprayed foliage and droplet clouds not dissipating while spraying in the same row. Stopping for a few seconds at corners and spraying in alternative rows, allowing the previously sprayed droplet cloud to dissipate, the level of exposure decreases significantly; a similar reduction can also be observed with walking backward and spraying in alternative rows as the droplets can disappear due to evaporation, or bigger particles can fall to the ground. Although walking backward during spraying would not be easy for operators to spray for a long time, when applying pesticides to high and dense plants or working in a greenhouse for a short time, walking backward can be an alternative. The dermal exposure was reduced up to 20 times when the operator walked backward away from the spray compared to moving in the sprayed area.

Safety precautions for exposure prevention

Different safety precautions (including operator-related, equipment-related and other precautions) during the greenhouse are represented diagrammatically.

Technological interventions

Nozzle cover shield: Nozzle cover shield help to minimize the



Safety precautions in greenhouse spraying

spray particles falling onto the operator, minimizing lateral droplet movement and containing them within a specific area. It reduces the risk of operators coming into contact with drifting chemicals, significantly lowering the chance of harmful exposure.

Pressure sensor: Pressure sensor indicates the system pressure in spraying equipment. High pressure can lead to significant exposure. When the system pressure exceeds the desired level, the sensor alerts the operator with audio-visual signals, prompting pressure regulation.

Wind sensor: Wind sensors measure wind speed and direction for even spray distribution and chemical application. Exceeding safe wind thresholds prompts alerts to operators via audio-visual signals, minimizing the risk of dermal exposure to harmful substances.

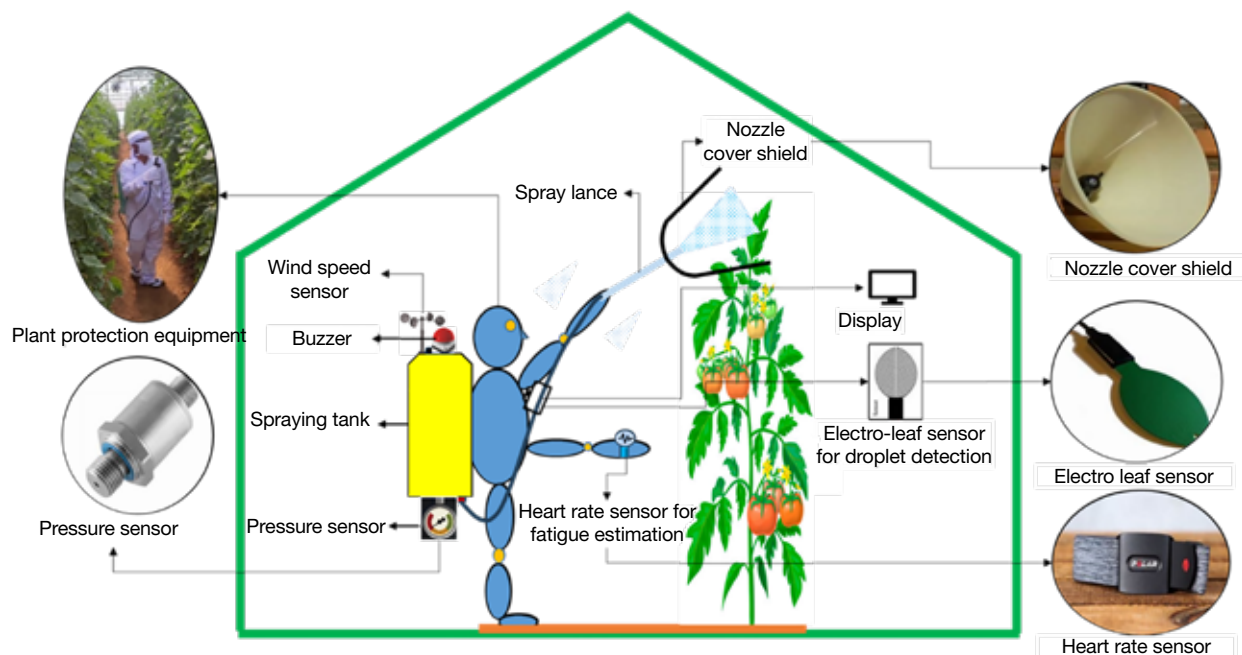
Patch sensor: This sensor detects droplet deposition on operator clothing, assessing potential dermal exposure. It alerts operators in real-time via audio-visual signals, providing immediate awareness of exposure levels.

Heart rate sensor: Heart rate monitor sensors track the operator's real-time heart rate to gauge fatigue

and stress levels. If the heart rate deviates from the desired range during activity, the sensor alerts the operator with audio-visual signals, promoting safety awareness.

Way forward

Wearing personal protection equipment and using appropriate spraying techniques during pesticide application stages does not prevent complete exposure but they do reduce it. Incorporation of robots to perform spraying tasks can help to avoid the complete human interface with the spraying activity and cost, while improving overall production and quality of the produce. The robotic agricultural machinery business is also expected to reach a global turnover of ₹12,300 billion by 2031. The recent developments in pesticide spraying technologies are still in the research phase. Some developed robotics technologies are only suited for hi-tech greenhouses and can navigate only on pre-installed pipe rails. These technologies need to be revitalized for a basic design for a reduction in initial costs and to suit Indian conditions are much required. Further, these robotic technologies consist of some sensing



Different sensors for operator safety

units to apply pesticides selectively, which will reduce chemical usage, environmental degradation and cost

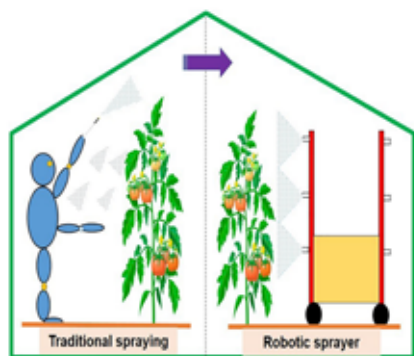
of production. In addition, these robots carry large spraying tanks to reduce the cost and time compared to the traditional methods.

greenhouse production is a low level of mechanization. Some casual and technical preventive measures are suggested here to safeguard the operator from the risk of exposure. These can reduce the exposure but do not prevent exposure completely. These suggest an ample scope of working on robotic pesticide applicators suitable for Indian greenhouses and these technologies can completely prevent humans from chemical exposure. Further, it increases the efficiency and reduces the cost of cultivation.

SUMMARY

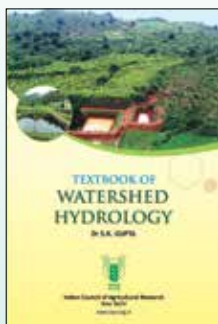
The existing spraying equipment and techniques adopted for spraying chemicals inside the greenhouse have constraints; they pose higher dermal and inhalation exposure. The manual method of pesticide application not only causes chemical exposure but also requires high manual labour compared to the open field, again causing an increase in the cost of production. One of the major constraints for increasing productivity under

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Schematic representation of spraying with traditional method (left) and spraying with robots (right) for complete prevention of humans from chemical exposure

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