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TOMATO PRODUCTION, NUTRITIONAL SIGNIFICANCE AND MAJOR INSECT PESTS: HORTICULTURAL PRACTICES AND PEST–WEATHER RELATIONSHIPS

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) represents an indispensable horticultural commodity cultivated worldwide for direct dietary intake and industrial processing. Economic profitability is governed by total fruit yield alongside marketable attributes such as uniform sizing, coloration, mechanical firmness, nutrient retention, and post-harvest durability. In India, tomato farming spans diverse agro-ecological zones; government figures for 2023–24 record an area of 0.854 million hectares yielding 21.32 million metric tonnes, reflecting an average productivity of approximately 25.0 t ha^{-1}. Fruits offer vital human nutritional benefits, being rich in ascorbic acid, provitamin A carotenoids, potassium, folate, dietary fibre, and the potent lipophilic antioxidant lycopene. Nevertheless, agricultural productivity and fruit quality remain persistently threatened by an aggressive insect-pest complex comprising Helicoverpa armigera, Tuta absoluta, Bemisia tabaci, aphids, thrips, leafminers, jassids, and Spodoptera litura. The population dynamics of these insect pests are shaped by meteorological factors—primarily temperature, relative humidity, precipitation, bright sunshine, and wind speed—as well as crop growth stages; however, the correlation coefficients differ substantially across microclimates, seasons, and ecological niches. This review synthesises global and national production trends, biochemical and dietary relevance, essential cultural and agronomic requirements, diagnostic characteristics of key insect pests, and systematic methodologies for interpreting pest–weather correlations.

Keywords: *Solanum lycopersicum; tomato cultivation; crop productivity; agronomic interventions; insect-pest complex; meteorological variables; correlation modelling; integrated pest management*

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1. INTRODUCTION

Tomato (*Solanum lycopersicum* L., family Solanaceae) ranks among the premier vegetable crops grown worldwide, celebrated for its wide environmental adaptability, comparatively rapid phenological cycle, high yield potential, and versatile gastronomic and processing utility. Freshly harvested fruits are consumed raw in salads, cooked in regional cuisines, canned, dehydrated, or processed into commercial commodities such as purée, paste, ketchup, and clarified juice. Tomato farming takes place both under open-field conditions and within protected environmental structures (e.g., polyhouses and shade nets), facilitating year-round market supply across diverse agricultural corridors. Net farm returns depend substantially on appropriate cultivar or hybrid selection, vigorous seedling establishment, precision nutrient and irrigation regimes, pest and pathogen suppression, appropriate harvest maturity, and meticulous post-harvest preservation (Naika *et al.,* 2005; ICAR-IIVR). From an agronomic perspective, tomato production is uniquely multifaceted because vegetative flushing, anthesis, fruit set, and fruit ripening frequently co-occur throughout an extended reproductive cycle. This persistent availability of tender succulent foliage, blossoms, and developing fruits provides continuous nutritional resources and microhabitats for an array of herbivorous arthropods. While certain species inflict direct mechanical and tissue-feeding injury, others—notably whiteflies, aphids, and thrips—serve as vectors for destructive plant viruses that induce systemic crop failures. Insect feeding diminishes functional photosynthetic canopy area, triggers flower drop, causes premature fruit shedding, degrades marketable grades, and predisposes wounds to opportunistic fungal and bacterial soft rots. Consequently, sustainable insect-pest regulation must be systematically woven into baseline horticultural operations and phenological schedules rather than managed as a disconnected, reactive intervention (Raghavendra *et al.,* 2022; agMOOCs, 2024).

2. GLOBAL AND INDIAN PRODUCTION, PRODUCTIVITY, AND ECONOMIC RELEVANCE

Tomato is cultivated across tropical, subtropical, and temperate zones. India stands as one of the world's leading producers, with major production clusters located across Madhya Pradesh, Andhra Pradesh, Karnataka, Gujarat, Odisha, West Bengal, Maharashtra, and Bihar. Official agricultural reports for 2023–24 documented an all-India cultivation area of 853.99 thousand hectares, generating an estimated harvest of 21,323.22 thousand metric tonnes with an average national productivity of approximately 25.0 t ha^{-1}. These statistics underscore the crop's immense contribution to domestic nutritional security, rural household earnings, industrial agro-processing, and agricultural employment (Department of Agriculture and Farmers Welfare, 2025).Nonetheless, significant productivity variations exist across individual states and farming topologies, dictated by germplasm vigor, regional weather regimes, irrigation dependability, soil ed aphic qualities, adoption of protected structures, crop duration, and pest severity. The national productivity figure should therefore not be viewed as an attainable ceiling for every agricultural pocket. In research trials, investigators should rigorously segregate total biological yield from marketable fruit yield, methodically cataloguing individual fruit counts, mean fruit weight, commercial grade distributions, cull percentages, and harvesting spans. Arthropod-induced economic losses are most reliably quantified by recording both the percentage of infested or unmarketable fruits and the net marketable yield deficit in relation to uninfested, fully protected control blocks (Department of Agriculture and Farmers Welfare, 2025; Raghavendra *et al.,* 2022).

3. NUTRITIONAL AND FUNCTIONAL SIGNIFICANCE

Fresh tomato fruits are characterised by high water content and minimal caloric density. A standard 100 g edible serving of fresh, ripe red tomato supplies roughly 18 kcal of energy, 3.9 g of carbohydrates, 0.9 g of crude protein, 1.2 g of dietary fibre, and 237 mg of elemental potassium. In addition, tomatoes provide meaningful amounts of ascorbic acid (vitamin C), dietary folate (vitamin B9), and phylloquinone (vitamin K), alongside carotenoid pigments—principally lycopene and β-carotene—which impart distinctive organoleptic coloration and biological health value. The precise biochemical profile fluctuates across genetic backgrounds, physiological maturity stages, environmental growing conditions, post-harvest handling workflows, and analytical extraction methodologies (USDA, 2019; USDA FoodData Central).

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Lycopene is an acyclic tetraterpene carotenoid endowed with robust singlet-oxygen quenching and antioxidant capabilities, constituting the predominant functional attribute of mature red tomatoes. Concurrently, β-carotene provides provitamin A activity, while ascorbic acid enhances physiological immune responses and overall antioxidant buffering. Culinary thermal processing and tissue homogenization enhance lycopene bioavailability by breaking down cellular walls and isomerising trans-lycopene into more bioavailable cis-isomers within the lipid matrix, although excessive thermal duration may degrade heat-labile vitamins. In horticultural investigations, comprehensive fruit quality evaluations should encompass total soluble solids (°Brix), titratable acidity, juice pH, ascorbic acid concentration, lycopene and β-carotene content, total dry matter percentage, pericarp firmness, and Hunter/CIELAB colorimetric values (Rao and Rao, 2007; USDA FoodData Central). Feeding punctures and internal boring by insect pests indirectly degrade nutritional and industrial processing traits. Infestation often induces uneven or premature coloration, external scarring, necrotic oviposition marks, entry conduits for microbial decay, and deformed locular cavities. For this reason, high-standard horticultural research must assess arthropod damage in tandem with biochemical profiles and marketable grading criteria, moving beyond sole reliance on gross physical yield.

4. HORTICULTURAL REQUIREMENTS AND CROP MANAGEMENT

4.1 Agro-Climatic and Edaphic Requirements

Tomato thrives in warm, moderately dry climatic conditions supported by abundant solar radiation. Mean daily temperatures between 20°C and 30°C are generally considered ideal for vegetative development and reproductive success, though exact thermal optima vary across cultivars and growth phases. Elevated day temperatures exceeding 35°C—especially when accompanied by elevated nocturnal temperatures above 22–24°C—drastically impair pollen grain viability, hinder pistil receptivity, prevent successful fertilisation, and trigger blossom drop. Conversely, cold thermal regimes below 10–12°C decelerate vegetative growth and impede fruit development. Tomato crops are highly vulnerable to frost damage and cannot withstand saturated, waterlogged root zones. Well-drained, organically enriched loamy to sandy-loam soils with a mildly acidic to neutral reaction (pH 6.0–7.0) provide the best root environment (ICAR-IIVR; Naika *et al.,* 2005).

4.2 Nursery Management and Transplanting

The establishment of a uniform, high-yielding crop depends directly on raising vigorous, pathogen-free nursery stock. Seedlings are typically reared in nursery beds or multi-cavity pro-trays filled with sterile, aerated potting media (e.g., coco peat, vermiculite, and perlite) and are ready for field transplanting within 25–30 days after sowing. Pre-transplant hardening via gradual water withholding toughens seedling tissue and reduces post-transplant shock. Field planting dates must be aligned with local agro-ecological calendars to prevent peak flowering and initial fruit set from coinciding with harsh thermal extremes, frost episodes, or prolonged monsoon downpours (ICAR-IIVR). Open-field spacing of 60 × 45 cm is commonly recommended by institutions like ICAR-IIVR; however, plant geometry must be tailored to determinate or indeterminate growth habits, hybrid vigor, seasonal humidity, soil fertility, irrigation layout, and canopy training structures. Wider plant spacing promotes air circulation within the lower canopy and eases intercultural operations, whereas overly dense planting creates a humid microclimate, impedes spray coverage, and accelerates foliar disease and pest build-up. In empirical field studies, both inter-row and intra-row spacing must be explicitly documented and maintained uniformly across experimental plots (ICAR-IIVR).

4.3 Nutrient Management and Recommended Fertiliser Doses (RDF)

Fertiliser regimens should be formulated on the basis of comprehensive soil testing, realistic yield targets, cultivar requirements, irrigation infrastructure, and organic amendments like well-decomposed farmyard manure (FYM). A standard baseline schedule suggested by ICAR-IIVR comprises 150:80:100 kg $N:P_2O_5:K_2O$ ha^{-1} supplemented with 20–25 t FYM ha^{-1}. In contrast, guidelines from the National Horticulture Board outline 120:80:50 kg $N:P_2O_5:K_2O$ ha^{-1} for open-pollinated varieties, with scaled-up nutrient inputs for vigorous commercial hybrids. These figures

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highlight the site-specific nature of fertiliser prescriptions, cautioning against uniform universal applications (ICAR-IIVR; National Horticulture Board). In scientific publications, the term Recommended Dose of Fertiliser (RDF) must be unambiguously defined with its source citation. Researchers should systematically report macronutrients on an elemental (N-P-K) or oxide ($N-P_2O_5-K_2O$) basis, indicate specific carrier fertilisers, and detail basal versus split top-dressing schedules. Nitrogen is traditionally partitioned into multiple splits to enhance uptake efficiency and prevent leaching, whereas total phosphorus and a major portion of potassium are applied at basal field preparation; pressurized drip fertigation allows for precision stage-specific feeding. Excessive nitrogen dressing leads to overgrown, succulent foliage that delays crop maturity and attracts heavy infestations of sucking pests and foliage-feeding lepidopterans. Adequate potassium fertilization, balanced calcium supplementation (to avert blossom end rot), and steady soil moisture are imperative for structural fruit integrity and post-harvest shelf life (ICAR-IIVR; National Horticulture Board).

4.4 Irrigation Scheduling, Mulching, and Cultural Operations

Tomatoes require consistent, regulated soil moisture, most critically during flower initiation, fruit set, and rapid fruit sizing. Moisture deficits during these stages trigger flower abortion and undersized fruits, whereas heavy, sudden irrigation following dry intervals promotes physiological fruit cracking. Irrigation intervals must be calibrated against soil physical properties, phenological stages, atmospheric evaporative demand, and precipitation events. Drip irrigation systems markedly enhance water-use efficiency and facilitate automated fertigation, while organic or reflective plastic mulches conserve moisture, control weed proliferation, and limit soil splashing. Indeterminate cultivars and greenhouse plantings require regular staking, single- or double-stem training, and strategic lateral pruning to optimize canopy light interception and improve pesticide deposition (Vikaspedia; ICAR-IIVR).

4.5 Harvest Maturity and Post-Harvest Operations

Picking stage is governed by intended end-use and transit duration. Harvesters categorize maturity into mature-green, breaker, turning, pink, light-red, and fully red-ripe stages. Picking fruits at the appropriate physiological milestone, minimizing mechanical abrasion, grading uniformly, and packing in well-ventilated plastic crates protect visual appeal and reduce transit spoilage. Post-harvest temperature management must be strictly maintained; storing fruits below 10–12°C can cause chilling injury, manifesting as surface pitting, uneven color development, and flavor loss. For experimental trials, harvesting stages and picking intervals must be standardized across all experimental blocks to prevent maturity-induced experimental bias (Naika *et al.,* 2005; ICAR-IIVR).

5. PRIMARY INSECT PESTS OF TOMATO AND NATURE OF DAMAGE

The arthropod pest complex of tomato shifts across geographic regions, cropping seasons, phenological phases, and cultivation systems. Key insect pests infesting Indian tomato crops include fruit borers, whiteflies, aphids, thrips, leafminers, jassids, tobacco caterpillars, and the South American tomato pinworm. Although phytophagous mites represent major arthropod pests, their arachnid taxonomy requires distinct recording in entomological sampling. The diagnostic characteristics of major tomato insect pests are summarised in Table 1 (agMOOCs, 2024; Raghavendra *et al.,* 2022)

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Table 1: Primary insect pests of tomato, vulnerable crop stages, diagnostic damage symptoms, and monitoring parameters.

Pest (scientific name)	Key stage / feeding site	Typical symptoms	Monitoring focus
Tomato fruit borer (*Helicoverpa armigera*)	Larvae feed on leaves, flowers and fruits	Circular entry holes, frass and internal fruit feeding; damaged fruits rot or become unmarketable	Larvae per plant; fruit infestation (%) and marketable yield
Tomato pinworm (*Tuta absoluta*)	Larvae mine leaves, stems and fruits	Blotch mines, galleries, leaf drying and pinholes in fruits	Leaf mines, larvae per plant, pheromone-trap catches and fruit damage
Whitefly (*Bemisia tabaci*)	Nymphs and adults on leaf undersides	Sap removal, honeydew/sooty mould and transmission of begomoviruses	Adults per leaf, nymphs per leaf and virus incidence
Aphids (*Aphis gossypii, Myzus persicae*)	Colonies on tender shoots and leaf undersides	Leaf curling, honeydew, stunting and virus transmission	Aphids per leaf or shoot and natural-enemy abundance
Thrips (*Thrips tabaci*, *Frankliniella* spp.)	Adults and immature stages on leaves, flowers and buds	Silvery feeding scars, bronzing, flower injury and possible virus transmission	Thrips per flower/leaf and symptom incidence
Serpentine leaf miner (*Liriomyza trifolii*)	Larvae mine within leaves	White serpentine mines, reduced photosynthetic area and premature leaf drying	Mines per leaf, mined leaf area and parasitoid activity
Jassid/leafhopper (*Amrasca* spp.)	Nymphs and adults on leaf undersides	Yellowing, marginal curling and hopper-burn symptoms	Nymphs/adults per leaf and canopy injury
Tobacco caterpillar (*Spodoptera litura*)	Gregarious early instars; later larvae feed on foliage	Skeletonisation, irregular holes and severe defoliation	Egg masses, larvae per plant and defoliation percentage

5.1 Tomato Fruit Borer, *Helicoverpa armigera*

Helicoverpa armigera (Hübner) is a destructive, highly polyphagous noctuid pest responsible for severe economic losses in tomato. The female moths deposit single spherical eggs on young leaves, flower buds, and sepals. Upon

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emergence, early-instar larvae scrape foliage and bore into flower buds, while maturing caterpillars bore into green and ripening fruits, typically leaving clean, circular entry holes surrounded by conspicuous deposits of wet fecal matter (frass). Because a single larva moves among multiple fruits during its development, economic damage frequently exceeds direct larval consumption. Routine crop surveillance must begin at flower initiation and continue throughout fruit picking, sampling flower buds, young fruit clusters, and caterpillars. While sex-pheromone traps serve as effective biosensors for adult flight activity, trap catches should always be calibrated against on-plant scouting before triggering intervention thresholds (agMOOCs, 2024; Raghavendra *et al.,* 2022).

5.2 Tomato Pinworm / Leafminer, *Tuta absoluta*

Tuta absoluta (Meyrick) is an invasive gelechiid pest of South American origin that poses a severe threat to open-field and greenhouse tomato production. Caterpillars mine into foliar parenchyma, forming extensive, irregular, transparent blotch-like mines that subsequently turn necrotic. The larvae can also bore into apical stems, growing tips, and young fruits, leaving small pin-sized puncture holes under the sepals. This endophytic feeding behavior shelters larvae from standard contact insecticides, necessitating early detection. Management programs require female sex-pheromone monitoring traps, rogueing and disposal of infested crop trimmings, physical exclusion screens in protected structures, and the conservation of mirid predators (e.g., *Nesidiocoris tenuis*). Because *T. absoluta* exhibits rapid evolution of resistance to multiple insecticide classes, rotational use of chemicals with differing modes of action is essential (Biondi *et al.,* 2018; Acharya *et al.,* 2023).

5.3 Whitefly, *Bemisia tabaci*

Bemisia tabaci is a tiny, polyphagous phloem feeder residing on the abaxial surface of tomato leaves. Both immature nymphs and adults deplete plant sap, impairing crop vigor and excreting sticky honeydew that encourages black sooty mould (*Capnodium* spp.) growth on leaves and fruits, impairing photosynthesis and marketability. Most critically, *B. tabaci* acts as the primary insect vector of Tomato leaf curl begomovirus (ToLCV), which causes severe stunting, foliar curling, crinkling, and near-complete yield failure when transmission occurs during early growth stages. Suppression requires raising seedlings under insect-proof nursery netting, deploying yellow sticky traps, conserving aphelinid parasitoids (*Encarsia* and *Eretmocerus* spp.), utilizing reflective silver mulches, and applying selective insecticides based on established economic thresholds. In academic trials, whitefly abundance and viral disease incidence must be documented as distinct variables (Raghavendra *et al.,* 2022; agMOOCs, 2024).

5.4 Aphids, Thrips, Leafminers, and Other Secondary Pests

Aphids (*Aphis gossypii, Myzus persicae*) congregate on tender terminals and leaf undersides, causing severe curling, leaf distortion, and sap loss while transmitting viral pathogens such as Cucumber mosaic virus (CMV). Thrips species (Thrips tabaci, *Frankliniella occidentalis*, *Scirtothrips dorsalis*) lacerate epidermal cells and suck exuded sap, resulting in silvery foliar patches, bronzing, and blossom drop; certain species transmit Groundnut bud necrosis orthotospovirus (GBNV). Serpentine leafminers (*Liriomyza trifolii*) generate winding chlorophyll-depleted foliar galleries that reduce total assimilatory surface, while Amrasca leafhoppers induce leaf yellowing and hopper-burn symptoms. Spodoptera litura caterpillars inflict extensive defoliation, particularly during gregarious early larval stages. Proper species identification and documentation of developmental life stages are vital for determining precise economic thresholds and implementing targeted controls (agMOOCs, 2024; Raghavendra *et al.,* 2022).

6. INFLUENCE OF AGROMETEOROLOGICAL PARAMETERS ON PEST POPULATION DYNAMICS

Abiotic weather factors exert profound regulatory control over insect physiology, development rates, fecundity, seasonal survival, flight activity, host phenology, and natural-enemy efficiency. Ambient temperature dictates metabolic activity, embryonic incubation, larval instar progression, and generation intervals. Atmospheric relative humidity directly influences insect desiccation resistance, egg hatchability, and the viability of entomopathogenic

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fungi. Precipitation events can physically dislodge exposed larval stages, drown small nymphs, and disrupt adult mating flights, while also stimulating succulent host flushes. Bright sunshine hours and ambient wind velocities regulate canopy microclimates, evapotranspiration rates, and active or passive pest dispersal. Crucially, these biometeorological influences are species-specific and fluctuate substantially across regional microclimates and seasonal cropping cycles (Sharma *et al.,* 2013; Bhati *et al.,* 2016).

6.1 Empirical Evidence from Indian Tomato Field Investigations

Field research across Indian agro-climatic zones highlights the regional variability of pest–weather correlations. In Jammu, Sharma *et al.* (2013) identified significant positive correlations between ambient temperature and populations of *H. armigera* and *B. tabaci*, while relative humidity and cumulative rainfall were generally negatively associated with pest incidence. In western Uttar Pradesh, Bhati *et al*. (2016) mapped distinct population peaks for whiteflies, leafhoppers, and fruit borers, tracing these dynamics to prevailing microclimatic conditions and predatory arthropod populations. Conversely, in eastern Uttar Pradesh, peak infestations of fruit borer, whitefly, leafminer, aphids, and thrips occurred during distinct standard meteorological weeks (SMW), with evening relative humidity exhibiting positive correlations with multiple pest species (Relative abundance study, 2022).

In western Manipur, Salam *et al.* (2023) demonstrated that *H. armigera* incidence correlated positively with minimum temperature, whereas aphid colonies and other sucking pests showed negative correlations with relative humidity metrics. However, in a rabi-season trial in Kanpur, Singh *et al*. (2021) observed that aphid and thrips populations correlated positively with selected humidity and rainfall metrics, with weather conditions displaying mixed influences on fruit borer infestation. These contradictory observations demonstrate that entomological researchers must avoid assuming universal correlation patterns between a pest species and a single meteorological parameter across disparate agro-climatic belts.

6.2 Interpretation and Recording Protocols for Agrometeorological Variables

Table 2: Agrometeorological parameters, biological impacts on insect pests, and standardized data-collection protocols.

Weather parameter	Potential biological influence	Recommended recording
Maximum and minimum temperature	Controls development rate, survival, activity and generation time; extreme heat may reduce survival or host suitability.	Daily maximum and minimum (°C); calculate weekly mean and thermal range.
Morning and evening relative humidity	Influences desiccation, egg/immature survival, plant vigour and pathogen pressure.	Record both observations (%) using the same observation times.
Rainfall	May wash off exposed stages, alter flight and disturb populations; effects depend on intensity and timing.	Daily rainfall (mm), rainy days and cumulative weekly rainfall.

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Bright sunshine / solar radiation	Influences canopy microclimate, plant growth and adult activity.	Sunshine hours day^{-1} or solar radiation (MJ m^{-2} day^{-1}).
Wind speed	Affects adult dispersal, flight, spray deposition and microclimate.	Daily mean wind speed (km h^{-1} or m s^{-1}).
Evaporation / vapour-pressure deficit	Represents atmospheric drying demand and may interact with plant water status and insect survival.	Pan evaporation (mm day^{-1}) or calculated VPD.

6.3 Robust Experimental Protocols for Pest–Weather Correlation Modeling

To ensure valid statistical inferences, researchers must maintain genetic uniformity across experimental plots or explicitly account for cultivar variances within randomized complete block designs (RCBD). Pest monitoring should follow a weekly schedule from crop establishment to final harvest. Standardized sampling units must be maintained consistently: whiteflies recorded as adults per top, middle, and bottom leaves; thrips counted per blossom or terminal shoot; lepidopteran larvae quantified per plant; leafminers assessed by active mines per leaf; and fruit borers evaluated by percentage fruit damage per plant. Meteorological datasets should be retrieved from a calibrated agro-meteorological station situated near the experimental plots, aligning pest sampling with the corresponding meteorological week or an explicit biological time-lag period (e.g., lag-1 week to capture incubation delays).

Statistical evaluations must begin by inspecting raw data distributions. Pearson's product-moment correlation (r) is valid only for bivariate normal, linear distributions; when counts are skewed or contain outliers, Spearman's rank correlation (rho) should be applied. While multiple linear regression (MLR) models help examine composite weather influences, researchers must rigorously assess multicollinearity (using Variance Inflation Factors, VIF < 5), spatial and temporal autocorrelation (Durbin-Watson test), and homoscedasticity. Because field pest counts represent discrete non-negative integer data exhibiting overdispersion, Generalized Linear Models (GLMs) employing Poisson or Negative Binomial error distributions are statistically superior to ordinary least squares (OLS) regressions. Finally, correlation establishes association rather than mechanistic causation, requiring careful biological interpretation alongside crop phenology and predatory pressure (Sharma *et al.,* 2013; Salam *et al.,* 2023).

7. INTEGRATED PEST MANAGEMENT (IPM) STRATEGIES IN TOMATO

Integrated Pest Management (IPM) incorporates cultural, physical, biological, behavioural, and chemical tactics to suppress insect populations below economic injury levels (EIL) while minimising ecological disturbance, worker exposure, and chemical residues. An effective tomato IPM program should begin during pre-planting nursery preparation and extend through post-harvest crop destruction. Routine calendar-based insecticide spraying should be replaced with scouting-based threshold interventions. Indiscriminate reliance on broad-spectrum insecticide cocktails accelerates chemical resistance, induces secondary pest flare-ups, and elevates production costs (Raghavendra *et al.,* 2022; Biondi *et al.,* 2018).

7.1 Cultural, Physical, and Mechanical Measures

Cultural sanitation forms the primary barrier against pest outbreaks. Growers should raise clean seedlings in insect-screened nursery houses (40–50 mesh), rogue volunteer tomato plants and alternate solanaceous weed hosts, and destroy heavily infested post-harvest crop residues to break insect lifecycles. Practicing crop rotation with non-

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solanaceous crops (e.g., pulses, cereals, or brassicas) prevents build-up of specialized soil-borne pupae and pests. Balanced nutrition and avoid excess nitrogenous fertilization avert lush vegetative flushing that favors sucking pests. Silver reflective mulches deter incoming winged whiteflies, thrips, and aphids by altering solar light reflection. Hand-picking egg masses and gregarious early caterpillars of *S. litura*, along with pruning borer-damaged terminal shoots and fruits, significantly reduces field populations. Pheromone traps deployed at 8–10 traps ha^{-1} enable population tracking, while higher densities (30–40 traps ha^{-1}) support mass trapping and mating disruption for *T. absoluta* and *H. armigera* (agMOOCs, 2024; Raghavendra *et al.,* 2022).

7.2 Biological Control and Natural-Enemy Conservation

Conserving endemic natural enemies is central to sustainable biological suppression. The tomato ecosystem harbors beneficial predators including coccinellid beetles (*Coccinella septempunctata*, *Cheilomenes sexmaculata*), green lacewings (*Chrysoperla carnea*), predatory mirid bugs (*Nesidiocoris tenuis*), and lycosid spiders, alongside hymenopteran parasitoids such as Trichogramma chilonis (egg parasitoid of *H. armigera*) and Encarsia formosa (nymphal parasitoid of *B. tabaci*). Protecting these natural enemies requires avoiding broad-spectrum synthetic pyrethroids and organophosphates and establishing flowering border strips (e.g., marigold, coriander, or sweet alyssum) to provide nectar and pollen refugia. Microbial formulations provide valuable biocontrol options: commercial preparations of *Bacillus thuringiensis* kurstaki (Bt @ 1.0–1.5 kg ha^{-1}), *Helicoverpa armigera* Nucleopolyhedrovirus (HaNPV @ 250–500 LE ha^{-1}), and entomopathogenic fungi such as *Beauveria bassiana* and *Lecanicillium lecanii* suppress caterpillar and sucking pest populations when applied during humid, low-UV conditions (Raghavendra *et al.,* 2022; Biondi *et al.,* 2018).

7.3 Judicious Chemical Intervention and Insecticide Resistance Management (IRM)

Chemical insecticides should be reserved as targeted interventions when pest populations breach established Economic Threshold Levels (ETL), such as 1 larva plant^{-1} or 5–10% fruit infestation for *H. armigera*, and 4–5 whitefly adults leaf^{-1}. Applicators must select registered plant-protection products approved by regulatory agencies, strictly adhering to recommended dosages, protective equipment protocols, and pre-harvest intervals (PHI). To delay resistance development, insecticides must be rotated based on their Insecticide Resistance Action Committee (IRAC) Mode of Action (MoA) classifications rather than alternating commercial brand names. For example, diamides (Group 28, e.g., chlorantraniliprole) should be rotated with spinosyns (Group 5, e.g., spinetoram) or avermectins (Group 6, e.g., emamectin benzoate) for borer management; ketoenols (Group 23, e.g., spiromesifen) or pyridine carboxamides (Group 29, e.g., flonicamid) provide targeted control for sucking pests while protecting pollinator populations (IRAC, 2024; Biondi *et al.,* 2018).

8. STRATEGIC RESEARCH PRIORITIES AND METHODOLOGICAL RECOMMENDATIONS

Future horticultural and entomological research should systematically integrate plant breeding traits with pest population dynamics. Germplasm screening programs must evaluate architectural attributes—including trichome density (glandular types IV and VI producing 2-tridecanone and zingiberene), foliar insertion angle, and canopy architecture—against arthropod colonization rates. Concurrently, biochemical profiling should track total phenolics, reducing sugars, peroxidase activities, and protein concentrations to elucidate host resistance mechanisms across plant development stages. Promising pest-resistant genotypes must be evaluated for marketable fruit yield, commercial grading, shelf life, and organoleptic quality before being recommended for crop improvement programs.

Field experimental designs must incorporate: (i) replicated genetic or management treatments within an RCBD; (ii) documented seedling age, nursery protocols, and planting geometry; (iii) soil-test-based nutrient applications specifying precise N-P-K sources and split timings; (iv) weekly pest monitoring alongside beneficial predator and parasitoid tracking; (v) daily automated meteorological recording; (vi) picking-wise classification of damaged versus marketable fruits; and (vii) analytical evaluation of fruit physicochemical properties. Count data should be reported

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alongside percentage incidence, stating the exact sample denominator. Investigators must also distinguish direct herbivory damage from secondary systemic losses caused by insect-vectored viruses, validating correlation models over multiple seasons and diverse agro-climatic zones before generalizing regional pest management advisories.

9. CONCLUSION

Tomato remains an indispensable crop for global dietary health and agricultural commerce. However, achieving optimum biological and marketable yields requires managing a persistent insect-pest complex. High-standard horticultural management—anchored in vigorous seedling nursery care, balanced soil-test-based nutrition, controlled drip fertigation, canopy management, and stage-specific harvesting—provides the agronomic foundation for resilient crops. Meteorological factors govern pest population peaks, but the direction and intensity of these relationships are shaped by local microclimates, season, and pest biology. Accurate interpretation demands rigorous field sampling, consistent agrometeorological tracking, and appropriate statistical modeling (such as Generalized Linear Models). Bridging horticultural physiology, microclimatic monitoring, natural-enemy conservation, and threshold-directed IPM strategies offers a sustainable framework for tomato production in the face of ongoing climate variability.

10. REFERENCES

- Acharya, R. (2023). Biology, distribution, and management of invasive South American tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), in Asia. Archives of Insect Biochemistry and Physiology, 114(4), e22056.
- agMOOCs. (2024). Integrated pest management in tomato. Open Textbooks, Commonwealth of Learning.
- Bhati, R., Gaurav, S. S., Singh, R., Singh, B., Goswami, A., and Choudhary, N. (2016). Influence of abiotic and biotic factors on the incidence of major insect pests of tomato. International Journal of Agriculture, Environment and Biotechnology, 9(2), 200–203.
- Biondi, A., Guedes, R. N. C., Wan, F.-H., and Desneux, N. (2018). Ecology, worldwide spread, and management of the invasive South American tomato pinworm, *Tuta absoluta*: Past, present, and future. Annual Review of Entomology, 63, 239–258.
- Department of Agriculture and Farmers Welfare. (2025). Agricultural statistics at a glance 2024. Ministry of Agriculture and Farmers Welfare, Government of India.
- ICAR–Indian Institute of Vegetable Research. Tomato: Cultivation details.
- IRAC. (2024). IRAC mode of action classification scheme. Insecticide Resistance Action Committee.
- Naika, S., van Lidt de Jeude, J., de Goffau, M., Hilmi, M., and van Dam, B. (2005). Cultivation of tomato: Production, processing and marketing. Agromisa Foundation and CTA.
- National Horticulture Board. Tomato: Manuring and fertilization and package of practices. Government of India.