STUDY ON EFFECTS OF MICROCLIMATIC PARAMETERS ON DEVELOPMENT AND PRODUCTIVITY OF INSECT CULTURES

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Abstract. Modern technologies for cultivating entomological cultures are actively developing due to growing demand for biological products and alternative protein sources. Effective maintenance of insects requires precise regulation of abiotic factors: temperature, humidity, lighting, ventilation, and air gas composition. This study investigated how microclimatic parameters influence the development and productivity of Trichogramma, a model entomological culture. Laboratory experiments varied temperature (22-32 °C), relative humidity (45-85%), photoperiod (8:16-16:8), and CO_2 concentration (0.03-1.0%). Optimal conditions were identified as 27°C, 60-70% humidity, 12:12 photoperiod, and normal CO_2 (0.03-0.1%). Temperatures above 32°C or humidity exceeding 85% induced thermal stress, increasing mortality (18-22%), fostering pathogenic microflora, and reducing offspring quality (25-35%). Elevated humidity decreased larval survival by 20-30%, while insufficient humidity caused developmental delays in approximately 40% of individuals. Photoperiod disruption reduced mating efficiency by 25-30% and decreased viable egg production. Microclimatic factors operate in an interdependent manner; deviations in one parameter require compensation by others. Industrial insect rearing demands mechanical ventilation systems with controlled airflow, air quality sensors enabling automatic adjustment, and substrate aeration preventing anaerobic conditions. Automated monitoring systems incorporating CO_2 and NH_3 sensors and biosensor-based monitoring of insect behavioural responses as stress indicators are recommended. Such integrated systems prevent stress conditions and reduce production losses by at least 20-30% compared to uncontrolled conditions. These results provide a scientific basis for improving entomological culture rearing regimes, increasing viability, reducing loss risks, and ensuring sustainable development of entomological production.

Keywords: entomological production, temperature, relative humidity, lighting, air quality.

Introduction

Modern technologies for growing entomological crops are actively developing in response to the growing demand for biological preparations, entomophages, and alternative sources of protein. Successful maintenance and reproduction of insects in controlled conditions requires precise regulation of abiotic factors such as temperature, humidity, lighting, ventilation, and air composition [1-3], as well as control and optimisation of biotic factors – population density, food supply, interspecies interactions, and the influence of pathogens – that determine the productivity and stability of entomocultures.

Temperature is one of the key factors affecting the growth rate, fertility and lifespan of insects. Temperature is one of the most important abiotic factors affecting the life cycle of insects: their development, reproduction, activity, food consumption and even morphological characteristics. Each species has its own optimal temperature range within which its physiological processes function most effectively [4]. An increase in temperature to a certain limit accelerates metabolism and development (shortens the duration of the stages: egg – larva – pupa – imago). The temperature threshold for development is important: when the temperature drops below a certain level, growth stops or slows down sharply [5; 6]. For most thermophilic species, this threshold is 18-20 °C, while the optimum development temperature is 25-30 °C. Temperatures above 35-40 °C cause heat stress, deformities and increased mortality in many species.

Relative humidity is the second key abiotic factor in entomological crop cultivation, directly affecting insects' water balance, moulting processes, egg and pupa development, and disease resistance. Insects have a large body surface area relative to their volume, which makes them vulnerable to moisture loss. Low humidity (<40%) causes dehydration, decreased activity, developmental delays, or death, especially in the egg and larval stages. Excessive humidity (>80-90%) promotes the growth of mould fungi, which can lead to mass death or infection of the culture [7]. For many species, local microclimatic conditions, for example in the substrate, are critically important, not just in the air. Unstable humidity increases stress, which suppresses reproductive function. High relative humidity with low ventilation promotes the development of pathogenic microflora [8]. Optimising humidity levels can shorten the insect development cycle, reduce mortality, improve the quality of the final product (e.g., larvae or eggs), and reduce the risk of disease and microbial contamination.

The next important factor in entomological production is lighting – not only a source of energy, but also an important regulator of insect biorhythms, behaviour, development and reproduction. For many species, lighting serves as a signal for the start or end of activity, mating, moulting or metamorphosis. Elements of the lighting regime include light intensity (lux, $lm \cdot m^{-2}$), photoperiod (length of daylight hours) and spectral composition (wavelength – blue, red, ultraviolet, etc.). Circadian rhythms (day and night cycles) are necessary for the normal functioning of most species. Lighting affects the levels of hormones that regulate reproduction [9-11]. Some species need light for orientation, and some species do not progress to the next stage without a change in the lighting regime [12]. Constant lighting can cause stress, hormonal imbalances, and developmental delays. With insufficient lighting, insects cannot find mates. An unsuitable light spectrum does not elicit the desired behavioural responses.

Air quality is another key abiotic factor in the cultivation of entomological crops. It is determined not only by the presence of sufficient oxygen (O_2), but also by the absence of excessive carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulphide (H_2S), volatile organic compounds (VOCs) and metabolic products. Fresh, well-ventilated air prevents hypoxia (oxygen deficiency), reduces stress levels in insects and prevents the spread of fungal and bacterial diseases.

Materials and methods

Laboratory experiments were conducted – growing cultures with controlled changes in one factor (e.g., temperature) while recording life cycle indicators: stage duration (days from egg to adult), mortality rate (% of individuals dead at each stage), and mating success (% of females producing viable eggs).

Negative effects were quantified by direct comparison to the optimal mode: increased mortality, prolonged development time, reduced mating efficiency, and decreased offspring viability were considered adverse outcomes.

Biosensor monitoring was used to detect early stress indicators involving behavioural responses (reduced mobility, cannibalism, aggression, reduced feeding). Microbiological monitoring determined pathogenic microflora appearance as a secondary marker of stress conditions (indicating excessive humidity, poor ventilation, or substrate contamination). Environmental stress was further confirmed by observing insects' physical deformities, moulting disorders, and body asymmetry.

Three distinct experimental modes were designed for each parameter to establish: (1) suboptimal conditions reflecting field variability, (2) optimal conditions based on literature and preliminary trials, and (3) stress conditions approaching critical thresholds. This three-level design allows quantification of the gradient between tolerable and critical limits, providing practical guidance for industrial facilities.

Table 1

Experimental microclimatic regimes

Parameter	Mode 1	Mode 2	Mode 3
Temperature, °C	22	27	32
Relative humidity, %	45	65	85
Photoperiod, light:darkness	8:16	12:12	16:8
CO_2 concentration (atmospheric), %	0.03	0.5	1.0

Critically, in each experiment, one parameter was varied while others remained at optimal levels, isolating the specific effect of each factor. The insect developmental stages were observed throughout the complete life cycle.

Mode 2 (27 °C, 65%, 12:12, 0.03%) represents optimal conditions based on literature (optimal temperature 25-30 °C, humidity 60-75%). Mode 1 represents suboptimal conditions (cool, dry). Mode 3 represents high-stress conditions (hot, humid, high CO_2). In each experiment, only one parameter was varied while others remained at Mode 2 (optimal) levels, allowing isolation of individual factor effects on insect development and productivity.

In practice, the experiment involved placing groups of insects in chambers with a controlled microclimate. In each experiment, one parameter was varied and the insect developmental stages were observed.

Results and discussion

The systematic variation of individual parameters revealed clear dose-response relationships. The results confirm that microclimatic factors act in combination rather than in isolation, with each factor showing distinct thresholds. Maximum productivity was observed when parameters aligned with optimal conditions: temperature of 27°C, humidity of 60-70%, a photoperiod of 12:12, and clean air with normal CO_2 levels. Deviation of any single parameter from these optimal values resulted in measurable decreases in developmental rate, survival, or reproductive output, demonstrating the sensitivity of Trichogramma to environmental variation.

The microclimate is a critical regulator of entomoculture activity. The most effective functioning of systems is achieved through comprehensive control of all environmental parameters, rather than individual values.

Optimal and critical parameter levels were also established for each of the key abiotic and biotic environmental factors affecting the viability of entomocultures (temperature, humidity, lighting, gas composition, feed quality, etc.) – Table 2. Optimal values ensure normal growth, reproductive capacity and high product quality. The critical limit is the threshold value of an abiotic factor (temperature, humidity, gas composition, etc.) above which the organism's vital functions are disrupted, and it loses its ability to develop, reproduce or exist normally.

Table 2

Optimal and critical levels of key factors for entomoculture cultivation

Environmental factor	Optimal range	Critical lower limits	Critical upper limits	Consequences of exceeding/violating
Temperature, °C	25-30	< 15	> 35	Slowed development, high mortality, stress, deformities
Relative humidity, % RH	60-75	< 40	> 85	Dehydration/mould, diseases, reduced fertility
Photoperiod, light:darkness	12:12 or 14:10	< 8:16	> 16:8	Disruption of biorhythms, lack of mating
Illumination, lux	200-500 (Daylight /LED)	< 100	> 1000	Decreased activity, stress, reduced reproduction or overheating
CO_2 concentration%	0.03-0.1	< 0.03 (substrate hypoxia)	> 0.5-1.0	Metabolic suppression, death, developmental disorders
Ammonia (NH_3), ppm	0-10	–	> 25	Toxic effects on the respiratory system, high mortality rate
Feed quality (protein content)	15-25% (for protein mass)	< 10%	> 30% (excesses are not absorbed)	Reduced growth, poor moulting, metabolic disorders
Feed/substrate moisture content	50-70% (for larvae)	< 35%	> 80%	Desiccation/anaerobic processes, decay, death of larvae
Population density	Within the species limit	> limit density	> limit density	Cannibalism, reduced fertility, stress, resource scarcity

For some types of entomocultures (*Trichogramma, Sitotroga cerealella, Hermetia illucens, Habrobracon*), the optimal ranges of temperature and relative humidity are shown in the d-h diagram (Fig. 1).

All parameters are interrelated, and a violation of one may require compensation for others (for example, an increase in temperature requires higher humidity). Production facilities should have an automatic microclimate control system with data recording. Weekly testing of feed for moisture, protein content and microbiological safety is recommended. CO_2 and ammonia threshold sensors should be used, especially in closed or multi-layer facilities. Some species require precise lighting control, including UV-A.

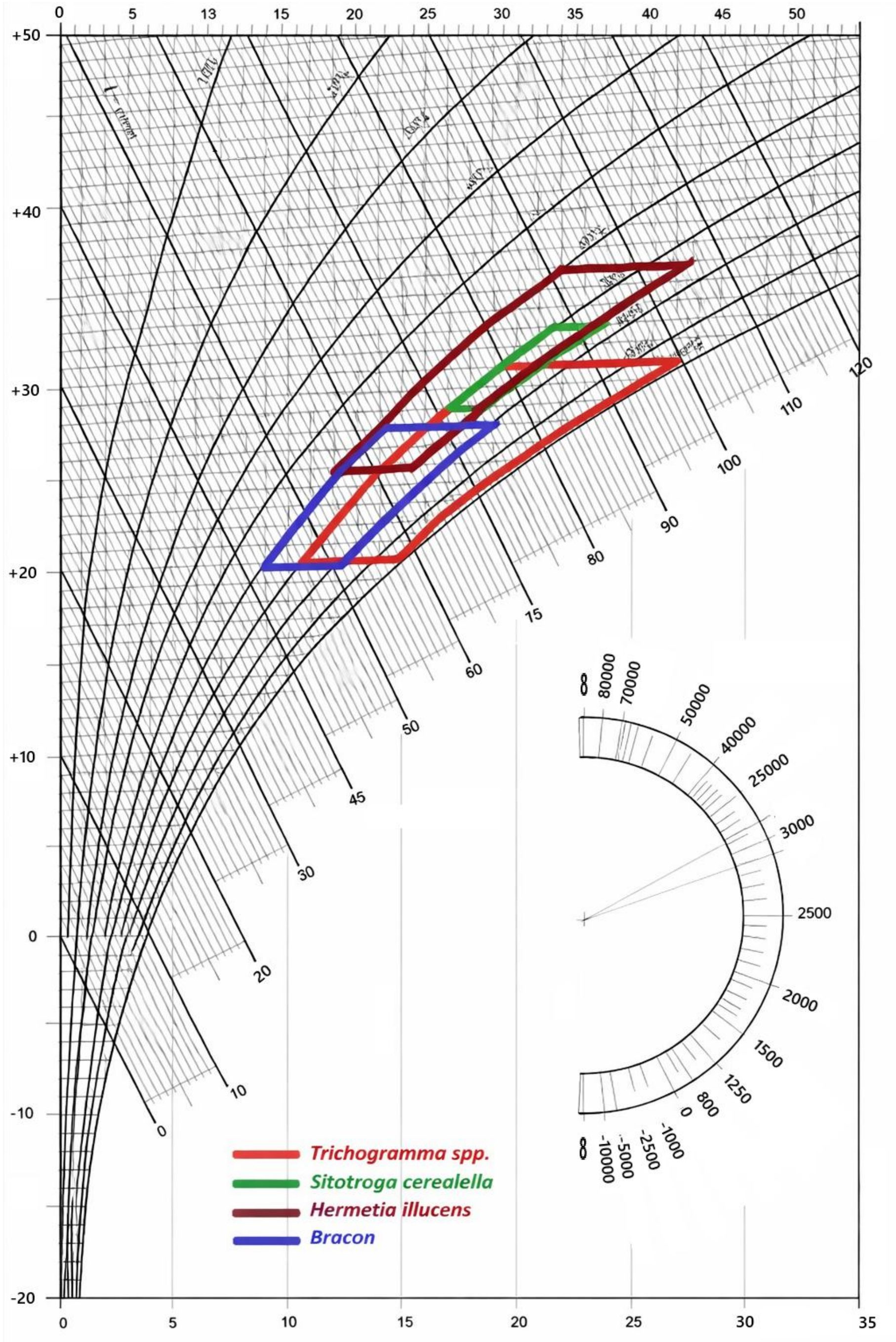

Fig. 1. **d-h diagram of optimal air parameters for rearing entomocultures**

Typical signs of reaching critical limits are decreased appetite, growth, weight, body asymmetry, molting disorders, decreased reproductive capacity (no egg laying, decreased viability of offspring), mass death of larvae/imagoes, and the appearance of odours of decay, excess ammonia, and mould.

A number of studies have been conducted on the effect of changes in temperature and relative humidity on various indicators of Trichogramma quality at different stages of its development (Fig. 2, Fig. 3).

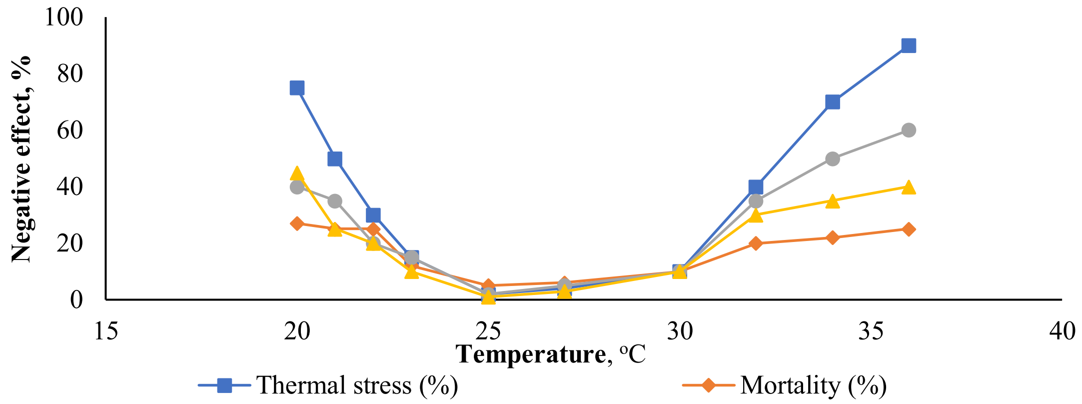

Fig. 2. **Effect of temperature on thermal stress, mortality, pathogenic microflora, and offspring quality**

Optimum at 27 °C, sharp increase in negative effects after 32 °C, mortality 18-22%, deterioration in offspring quality 25-35%.

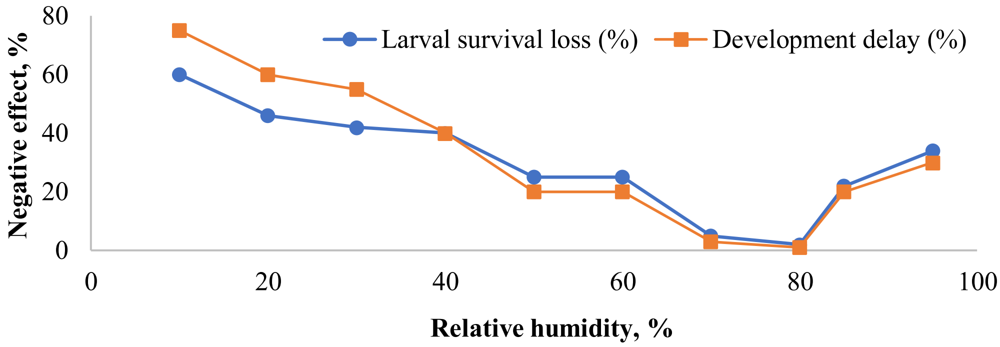

Fig. 3. **Effect of relative humidity on larval survival and development delay**

Optimum 70-80%, at > 85% survival rate decreases by 20-30%, at moisture deficiency development is delayed by up to 40%.

Knowledge of critical thresholds allows for the creation of warning systems on farms, the development of cultivation regimes for different climatic zones, the modelling of biomimetic environments while avoiding risk areas, and the reduction of losses when scaling up production. Effective maintenance of a stable temperature regime is critical for entomological production.

Although modern technologies allow the necessary conditions to be maintained accurately, they often require high initial costs. Further research should focus on optimising energy consumption and customising the temperature profile for each type of insect, which will increase the efficiency and sustainability of the industry.

Conclusions

1. The ideal approach is an integrated one, in which humidity, temperature, ventilation and lighting parameters are coordinated based on the biological needs of a particular species. A rational approach to adjusting abiotic parameters can shorten the growing cycle, increase crop yields and reduce stress and energy costs. It is important to synchronise the lighting regime with other factors – temperature, humidity, ventilation – as part of comprehensive climate control.
2. It has been established that the optimal conditions for development are a temperature of 27 °C, relative humidity of 60-70%, a photoperiod of 12:12, and clean air with a normal CO_2 concentration (0.03-0.1%). Temperatures above 32 °C or relative humidity above 85% lead to heat stress, increased mortality (18-22%), development of pathogenic microflora, and deterioration in the quality of offspring (25-35%). Insufficient or excessive humidity, as well as disruption of the light regime, cause dehydration, developmental delays and reduced mating. Increased relative humidity was accompanied by a 20-30% decrease in larval survival and deterioration in the quality of

offspring. With insufficient humidity, signs of developmental delay were observed in 40% of individuals. Violation of the photoperiod led to a 25-30% decrease in mating efficiency and a decrease in the number of viable clutches.

3. It has been proven that microclimatic factors act in a complex manner, and a deviation in one parameter requires compensation in others. Industrial insect farming requires introduction of mechanical ventilation systems with control over air flow speed and direction, air quality sensors that automatically adjust parameters, and prevention of anaerobic processes in the substrate through ventilation, mixing, or humidity control. Such systems make it possible to prevent the development of stressful conditions in a timely manner and reduce total production losses by at least 20-30% compared to uncontrolled conditions.

Author contributions:

Conceptualization, V.B. and N.P; methodology, A.A., V.B. and O.B.; software, Y.I.; validation, A.A. and A.R; formal analysis, V.B and A.P..; investigation, A.R., I.P., O.B. and A.P.; data curation, A.A., V.B. an N.P.; writing – original draft preparation, A.R.; writing – review and editing, A.A. and V.B.; visualization, N.P., O.B.; project administration, A.R.; funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

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