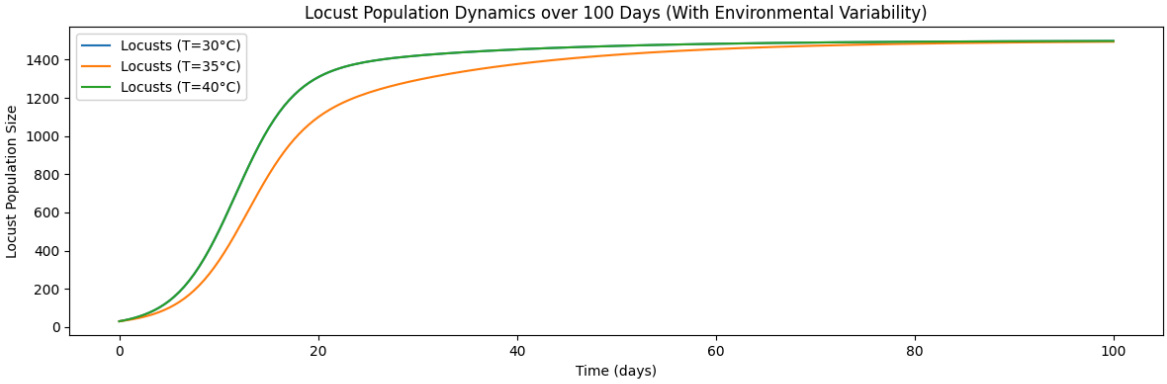
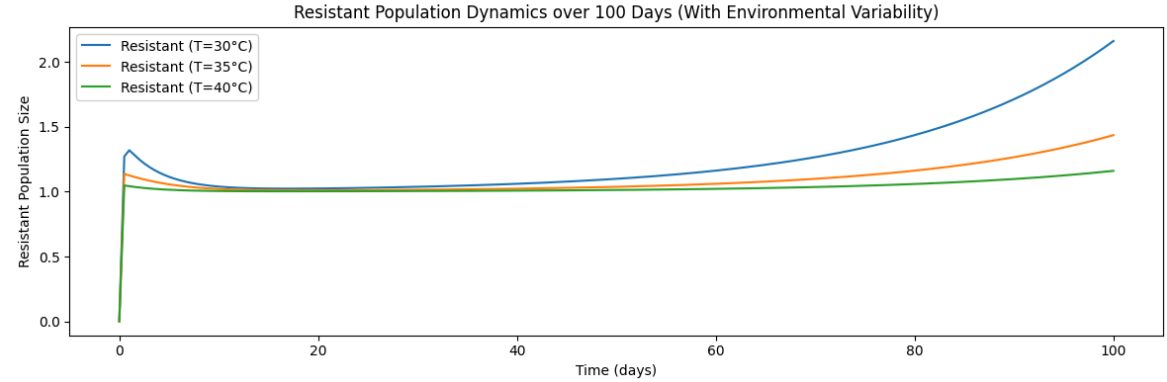
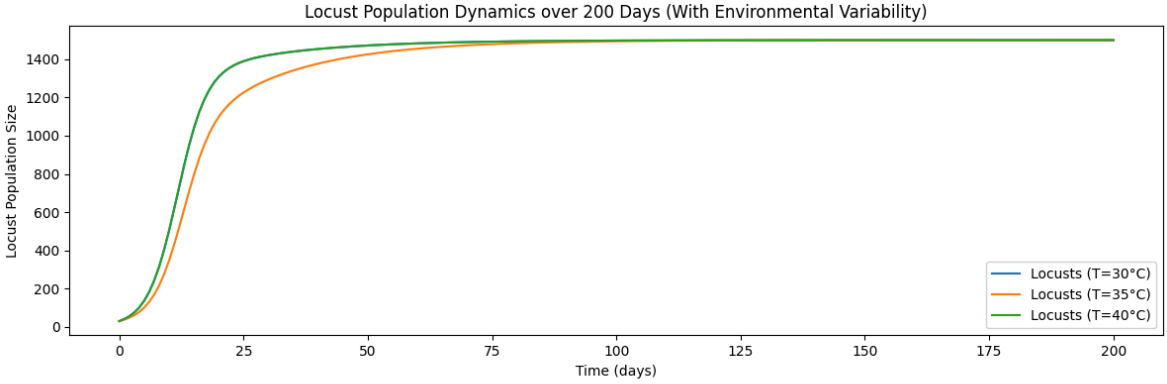
In [6]:
```
import numpy as np
from scipy.integrate import odeint
import matplotlib.pyplot as plt

# Define the differential equations
def locust_model(y, t, r0, Topt, alpha_T, mu0, alpha_M, beta_T, K, gamma0
    N, R = y

    # Introducing variable environmental conditions over time
    if variability:
        M, I = variable_conditions(t)
    else:
        M = 0.5   # Moisture level (normalized between 0 and 1)
        I = 0.9   # Insecticide concentration

    # Temperature-dependent reproduction rate
    r_T = r0 * np.exp(-alpha_T * (T - Topt)**2)

    # Temperature and moisture-dependent mortality rate
    mu_TM = mu0 * np.exp(-alpha_M * (M - 0.5)**2) * np.exp(-beta_T * (T -

    # Temperature-dependent resistance development rate
    gamma_T = gamma0 * np.exp(beta_r * (T - Topt))

    # Locust population growth (temporarily relaxed carrying capacity for
    dNdt = r_T * N * (1 - N/(K * 1.5)) - mu_TM * I * N

    # Resistance population growth with mutation and selection
    dRdt = mutation_rate + gamma_T * N * I * (1 - R)

    return [dNdt, dRdt]

# Function to simulate environmental variability
def variable_conditions(t):
    # Example: Moisture follows a seasonal pattern, Insecticide decays ov
    M = 0.5 + 0.1 * np.sin(2 * np.pi * t / 365)  # Seasonal variation in
    I = 0.9 * np.exp(-0.05 * t)  # Insecticide decays exponentially over
    return M, I

# Initial conditions
N0 = 30   # Initial population (15 males, 15 females)
R0 = 0    # Initial resistant population
y0 = [N0, R0]

# Time points (days)
time_windows = [100, 200, 300, 400, 500]  # Time windows for simulation

# Parameters
r0 = 0.5         # Increased reproduction rate
Topt = 35        # Optimal temperature (°C)
alpha_T = 0.01   # Sensitivity to temperature change
mu0 = 0.3        # Increased mortality rate due to insecticide
alpha_M = 0.1    # Moisture sensitivity
beta_T = 0.05    # Temperature sensitivity for insecticide efficacy
K = 1000         # Lowered carrying capacity for smaller population
gamma0 = 0.5     # High baseline resistance development rate
beta_r = 0.2     # Higher temperature sensitivity for resistance developm
mutation_rate = 2.0  # High mutation rate for resistant locusts
```

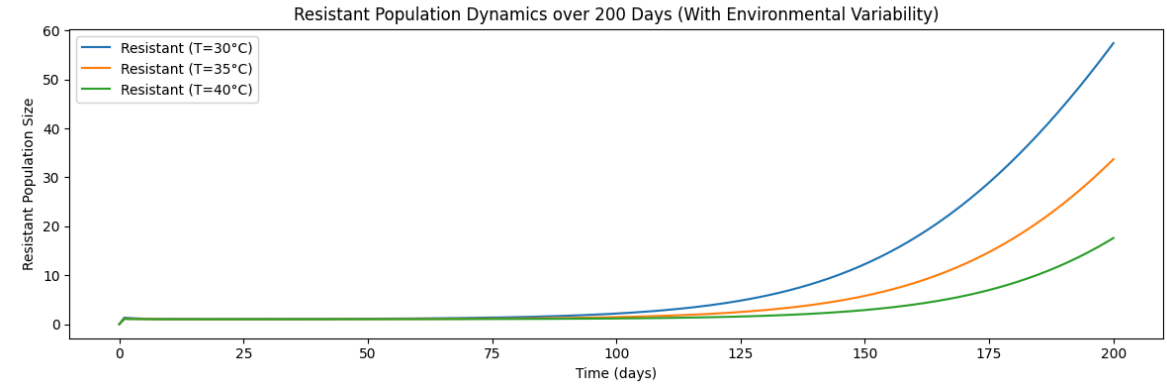
```
# Environmental conditions
T_values = [30, 35, 40]  # Different temperatures to simulate (°C)

# Solve the system of ODEs for each time window and temperature
for days in time_windows:
    t = np.linspace(0, days, 200)  # Simulate over specified days with 20

    solutions = {}
    for T in T_values:
        sol = odeint(locust_model, y0, t, args=(r0, Topt, alpha_T, mu0, a
        solutions[T] = sol

    # Plot the results
    plt.figure(figsize=(12, 8))

    # Plot locust population
    plt.subplot(2, 1, 1)
    for T in T_values:
        plt.plot(t, solutions[T][:, 0], label=f'Locusts (T={T}°C)')
    plt.title(f'Locust Population Dynamics over {days} Days (With Environ
    plt.xlabel('Time (days)')
    plt.ylabel('Locust Population Size')
    plt.legend()

    # Plot resistant population
    plt.subplot(2, 1, 2)
    for T in T_values:
        plt.plot(t, solutions[T][:, 1], label=f'Resistant (T={T}°C)')
    plt.title(f'Resistant Population Dynamics over {days} Days (With Envi
    plt.xlabel('Time (days)')
    plt.ylabel('Resistant Population Size')
    plt.legend()

    plt.tight_layout()
    plt.show()

    # Function to print final population sizes
    def print_final_populations(solutions, T_values, days):
        print(f"Final populations after {days} days:")
        for T in T_values:
            locust_pop = solutions[T][-1, 0]
            resistant_pop = solutions[T][-1, 1]
            print(f"At {T}°C: Locust population = {locust_pop:.2f}, Resis

    print_final_populations(solutions, T_values, days)
```






```
Final populations after 100 days:
At 30°C: Locust population = 1497.70, Resistant population = 2.16
At 35°C: Locust population = 1493.94, Resistant population = 1.44
At 40°C: Locust population = 1497.70, Resistant population = 1.16
```



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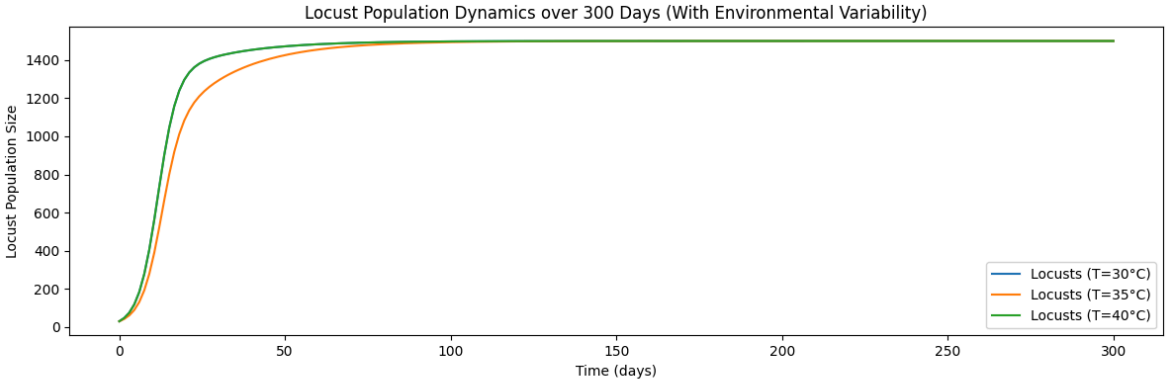
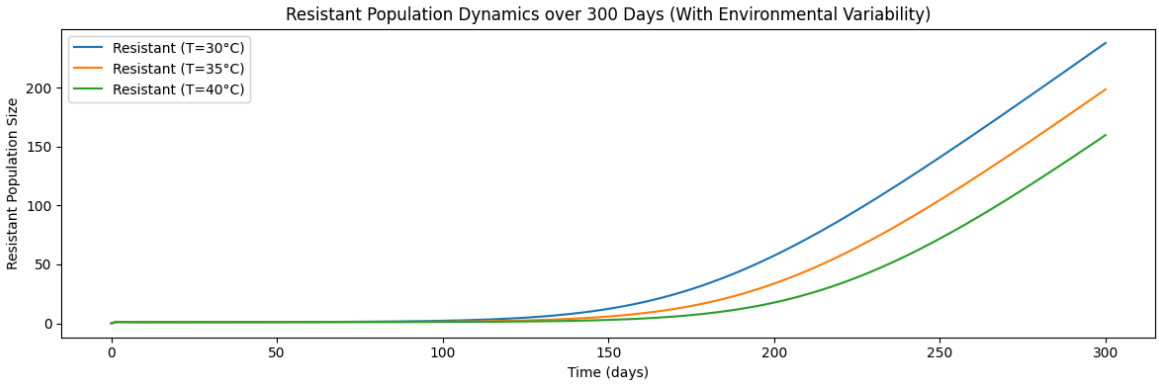
Final populations after 200 days:
At 30°C: Locust population = 1499.98, Resistant population = 57.42
At 35°C: Locust population = 1499.96, Resistant population = 33.69
At 40°C: Locust population = 1499.98, Resistant population = 17.59
```



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Final populations after 300 days:
At 30°C: Locust population = 1500.00, Resistant population = 237.91
At 35°C: Locust population = 1500.00, Resistant population = 198.47
At 40°C: Locust population = 1500.00, Resistant population = 159.71
```
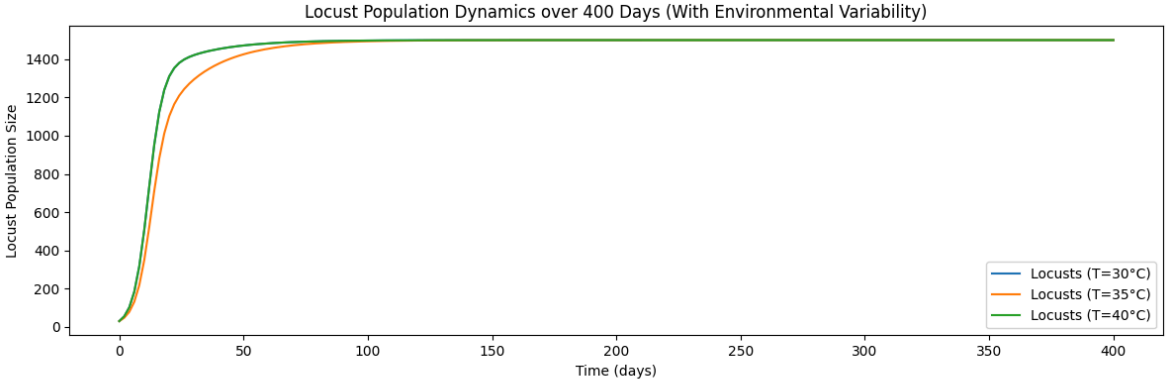
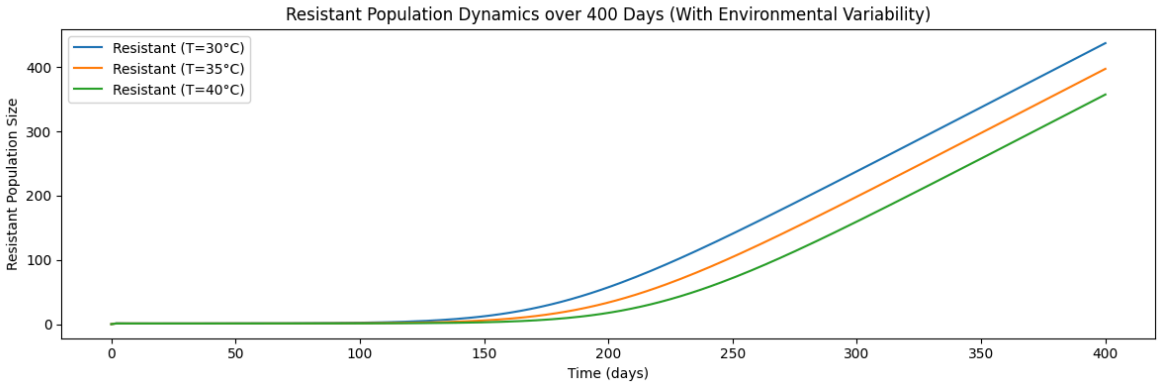
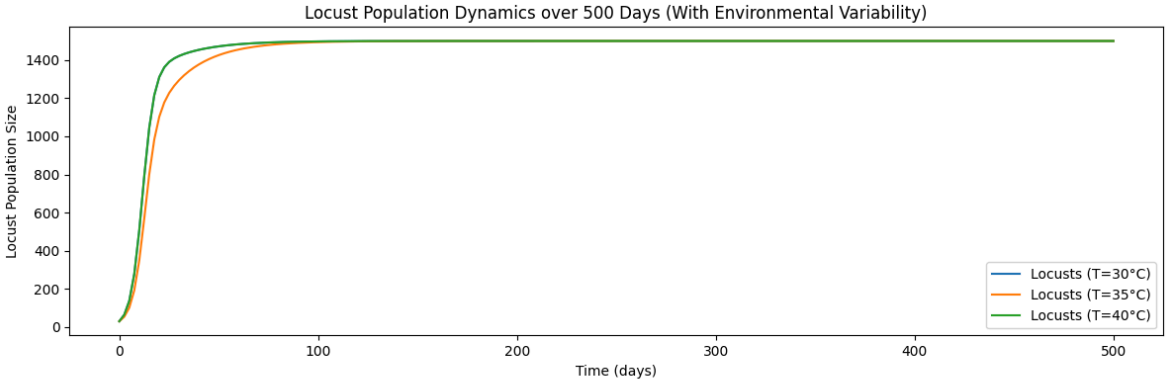
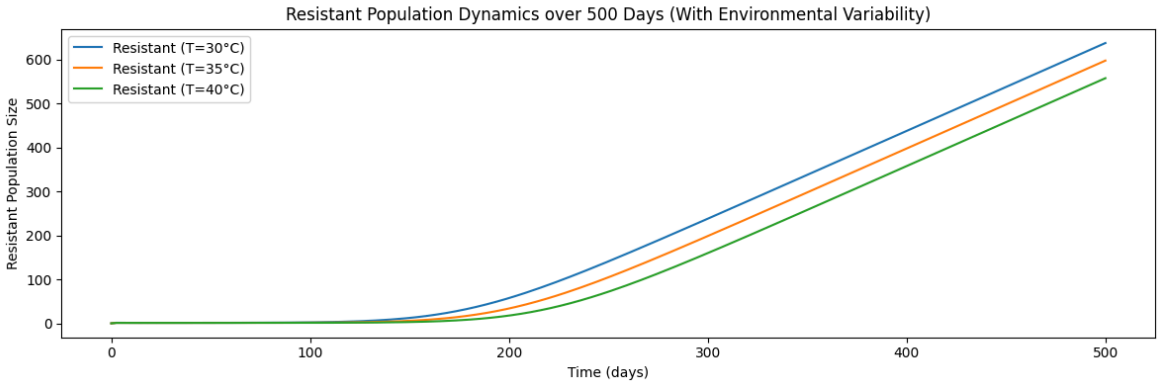






```
Final populations after 400 days:
At 30°C: Locust population = 1500.00, Resistant population = 437.50
At 35°C: Locust population = 1500.00, Resistant population = 397.51
At 40°C: Locust population = 1500.00, Resistant population = 357.52
```






```
Final populations after 500 days:
At 30°C: Locust population = 1500.00, Resistant population = 637.49
At 35°C: Locust population = 1500.00, Resistant population = 597.49
At 40°C: Locust population = 1500.00, Resistant population = 557.49
```

In [ ]: