



Potential distribution of *Musca domestica* in Jesús María Municipality, Aguascalientes, Mexico, based on climate change scenarios



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Abstract

The housefly *M. domestica* is a primary domestic pest responsible for food decomposition, and is a vector for more than 100 pathogens in humans and animals. Climate conditions including temperature and relative humidity influence *M. domestica* development and prevalence. As climate change advances control programs for this species will need to adapt to evolving conditions. A development assay was done of *M. domestica* at different temperatures and relative humidities to estimate its current potential incidence in Jesús María Municipality, Aguascalientes, Mexico. Local climate is temperate semi-dry (BS1k) with 16 to 18 °C annual average temperature and 500 to 600 mm annual average rainfall. In a completely randomized design, six treatments involving different temperatures and relative

humidities during the entire fly lifecycle were analyzed. Development conditions were ideal between 20 and 30 °C, conditions present in the study area between June and August. The CNRMCM5 (RCP 4.5) climate change model was used to predict extreme minimum temperatures in three time horizons: Short (2015-2039); Medium (2040-2060); and Long (2075-2090). Under the Medium and Long scenarios ideal development conditions could last as long as five months, representing a potential increase in the time *M. domestica* is present in the region, and in the duration of the public and animal health challenges it generates. The present results are important for planning future prevention, monitoring and control programs and strategies.

Key words: Housefly, Vector, Temperature, Relative humidity, Precipitation.

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Introduction

The housefly *Musca domestica* is a synanthropic insect in close association with humans and their environment. It is present wherever humans live, but is also associated with livestock such as poultry, cattle, horses and swine⁽¹⁾. It is therefore a potential disease vector for various diseases among humans and for zoonoses⁽²⁾. Prevention, monitoring and controlling *M. domestica* is vital because it is the principal domestic parasite responsible for food decomposition and a vector for more than 100 pathogens⁽³⁾. It can also propagate approximately thirty bacterial and protozoan diseases, although *M. domestica* can thrive without causing infection⁽⁴⁾. Controlling *M. domestica* is costly and ongoing; for example, an estimated 1.6 million dollars annually is spent in the United States of America on insecticides for control of this parasite on poultry farms⁽⁵⁾.

Survival in ectotherms such as flies is limited by temperature. They often remain exposed to extreme thermal variations in their natural habitat, especially during the summer months⁽⁶⁾. Optimum development of *M. domestica* occurs at about 25 °C⁽⁷⁾. Environmental factors such as temperature, precipitation, relative humidity and soil type and use directly affect *M. domestica* population dynamics⁽⁸⁾.

Livestock can exacerbate *M. domestica* presence and persistence. In 2015 the state of Aguascalientes, Mexico, had a dairy cattle population of approximately twenty thousand head⁽⁹⁾. Public health problems can emerge when dairy cattle production is in proximity to densely populated urban areas; for example, in livestock regions such as the Comarca Lagunera, in the states of Coahuila and Durango, and Jesús María Municipality in the state of Aguascalientes. *Musca domestica* can then effectively transmit myriad diseases from livestock to human populations, and extreme measures are required to control its propagation.

The present study objective was to evaluate the effects of variations in temperature and relative humidity on *M. domestica* population development in Jesús María Municipality, Aguascalientes, and estimate its potential distribution under climate change scenarios based on the CNRMCM5 (RCP 4.5) model for three periods: Near (2015-2039), Middle (2045-2069) and Long (2075-2099).

Material and methods

Development of *M. domestica* was evaluated under temperature and humidity conditions similar to the study area. Jesús María Municipality, Aguascalientes, has a temperate semi-dry (BS1k) climate with 16 to 18 °C annual average temperature and 500 to 600 mm annual average rainfall. Fly pupae for use as progenitors were collected from the livestock area of the Agricultural Sciences Center (Centro de Ciencias Agrícolas - CCA) of the Autonomous University of Aguascalientes (Universidad Autónoma de Aguascalientes-UAA). These were placed in stainless steel wire cages (30 x 30 x 30 cm), covered with 100% nylon fabric and incubated at 24 ± 2 °C in the Veterinary Clinic and Greenhouse Research Laboratory of the UAA. Once emerged the flies were fed a 10% sugar water solution in which pieces of cotton were saturated. The substrate for oviposition and larvae feeding was a mixture of wheat bran and water (70 %) or wheat bran, powdered milk and water (30 %). The resulting pupae were used in the evaluation of development under different temperatures and relative humidities (RH) done at the Laboratory of Natural Resources and Agrarian Systems Analysis of the CCA at UAA. Each pupa was placed in a one-ounce polypropylene container with lid to prevent copulation between females and males. After emergence they were sexed and placed in different cages (30 x 30 x 30 cm). Females and males were removed from these cages, three of each sex placed in stainless steel cages (size 10 x 10 x 10 cm), and these covered with nylon fabric. Each cage was subjected to one of six temperature/RH treatments (Table 1). Experimental design was completely random, with three replicates per

treatment. A Tukey test was used to compare the means for the larvae count, pupae count, and fly emergence per cage variables ($\alpha= 0.005$). Statistical analyses were run using the STATISTICA® ver. 13 program.

Table 1: Temperature and relative humidity in *M. domestica* development treatments

Treatments	Temperature (°C)	Relative humidity (%)
T1	27.5 ± 2.5	90 - 95
T2	22.5 ± 2.5	60 - 65
T3	32.5 ± 2.5	20 - 25
T4	32.5 ± 2.5	35 - 40
T5	35	90
T6	32.5 ± 2.5	15 - 20

Data for maximum, minimum and mean temperature, as well as HR, for Jesús María municipality were acquired from the National Network of State Agroclimatological Stations (a.k.a., Agroclima)⁽¹⁰⁾ of the National Institute of Forestry, Agriculture and Livestock Research (Instituto Nacional de Investigación Forestal, Agrícola y Pecuaria - INIFAP). These were analyzed considering the *M. domestica* development variables and the species' possible infestation in the study area. Climate data were interpolated by the method based on inverse distance weighting (IDW), which has been described and applied previously^(11,12).

Geospatial processing first produced a raster image using the maximum and minimum temperatures as extreme values. The second product was an image classified based on changes in its properties in five classes associated with its distribution at the municipal level. The minimum temperature raster images were built based on the model created by the National Center for Meteorological Research (Centre National de Recherche Météorologique - CNRM), under the nomenclature CNRMCM5 (RCO 4.5)⁽¹³⁾, which formed part of the IPCC's 5th Climate Change Assessment Report⁽¹⁴⁾. After testing and rescaling from 0.5° x 0.5° (55 x 55 km, approximately) to 30" x 30" (926 x 926 m) for application in the Mexico, southern United States and Caribbean region, this and other models (GDFL-CM3, HADGEM2-ES, etc.) were downloaded from the webpage of the Atmospheric and Environmental Sciences Data Unit (Unidad de Informática para las Ciencias Atmosféricas y Ambientales - UNIATMOS) of the Atmospheric Sciences Center of the National Autonomous University of Mexico (Universidad Nacional Autónoma de México - UNAM)⁽¹⁵⁾. Using different modules of the ARCMAP 10.2.2® program (ESRI, Redlands,

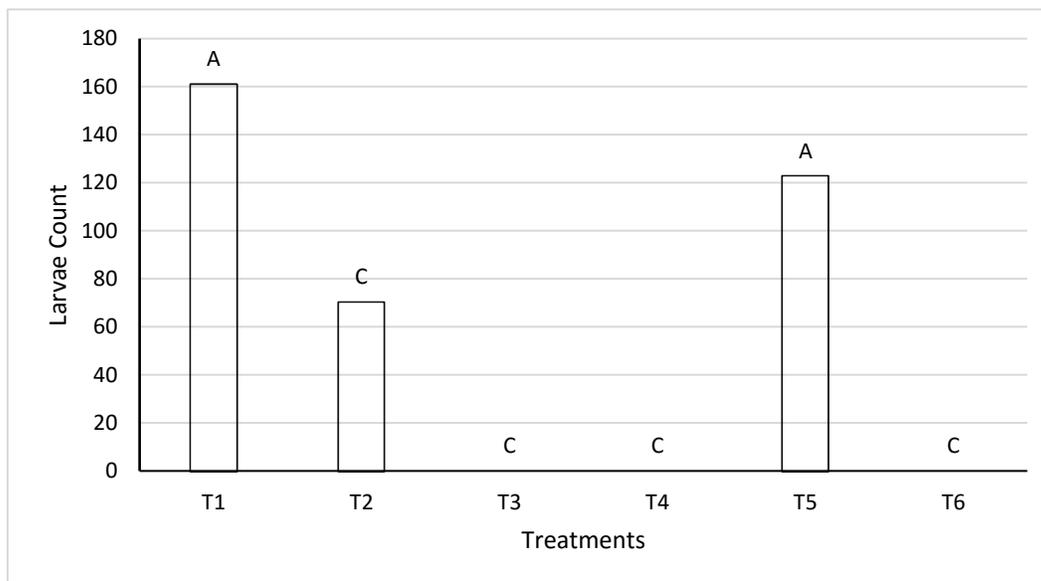
CA), the CNRMCM5 model was processed for three time horizons: Short (2015-2039), Medium (2045-2069) and Long (2075-2099).

Results and discussion

Larvae development

Comparison of median number of larvae per treatment showed treatment one (T1) to have the highest number (161 larvae per cage) (Figure 1). Treatments T3, T4 and T6 produced no larvae due to temperature variability, since larval development depends on there being at least 8 °C^(16,17). *Musca domestica* larvae prefer to develop at 35 °C and high humidity, but when fully developed prefer 15 to 20 °C with low HR, and do not withstand temperatures above 45 °C⁽¹⁸⁾. In another study fly larva distribution was higher in manure at temperatures from 17 to 35 °C⁽¹⁹⁾.

Figure 1: Comparison of median *M. domestica* larvae count per treatment



*Different letters on different bars indicate significant difference ($P \leq 0.01$).

Treatment T5 had the highest larvae count with 122 larvae per cage. The discrepancy between these treatments was a lower initial temperature in T1 (25 to 30 °C for T1 vs 35 °C for T5)

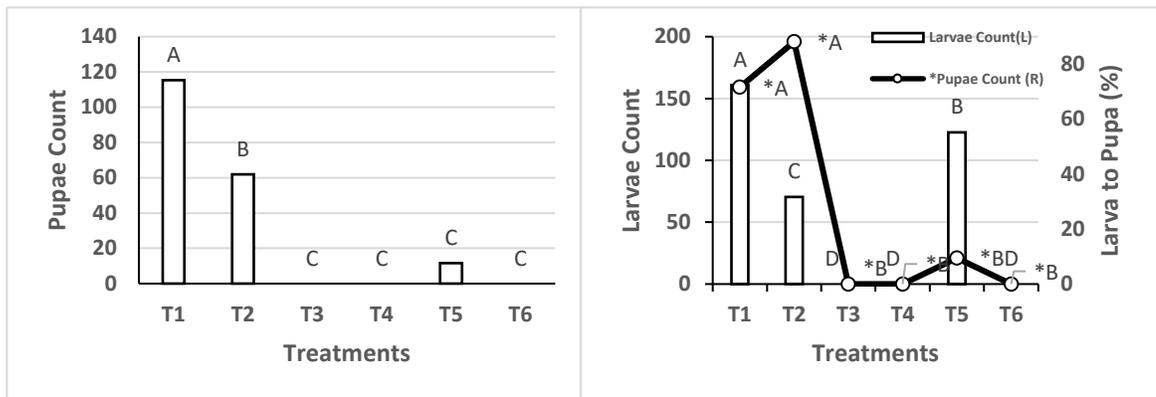
and constant RH in T5. Relative humidity (RH) determines larvae survival, since insufficient RH will dry them out, while excess moisture can cause them to drown⁽²⁰⁾.

Larvae to pupae development

Larvae were not present in treatments T3, T4 and T6 because initial conditions (>30 °C and low RH) did not allow for egg development. Maximum temperature for *M. domestica* oviposition is 25 to 30 °C, and eggs must remain moist or they will not hatch⁽²¹⁾.

Larvae did hatch in treatments T1, T2 and T5. Transition from larva to pupa was better in T1 than in the other treatments: an average of 115 pupae survived of the 160 larvae per cage. Treatment T2 had 62 pupae develop from 72 larvae per cage (Figure 2), and in T5 12 pupae survived from 122 larvae. The very low development rate in T5 and slightly lower rate in T1 may be due to the 90 % RH in both. In a previous study maximum larva mortality occurred at 100 % RH and temperatures higher than 30 °C⁽²²⁾. Pupae tolerate less moisture than larvae and can tolerate temperatures from 35 to 40 °C, but only for a minimum period of 3 to 4 d⁽¹⁸⁾. In the present study the pupae remained for sixteen days at temperatures as high as 35 °C. Temperature clearly affects survival in different stages of *M. domestica*. In one study it was found that at 48 °C for 15 min all lifecycle stages died, at 37 °C all stages survived for just over 4 h, and at 42 °C adults died after approximately one hour; pupae were found to resist temperatures of 44 to 46 °C⁽²³⁾. Exposure periods in this study were relatively short (a few hours at most), in contrast the periods used in the present study for the different treatments were until completion of the fly lifecycle, that is, from 19 to 22 d. An analysis of variance between treatments comparing larva to pupa transformation rates found T1 (74 %) and T2 (86 %) to have the best rates.

Figure 2: Comparison of median *M. domestica* pupae count per treatment

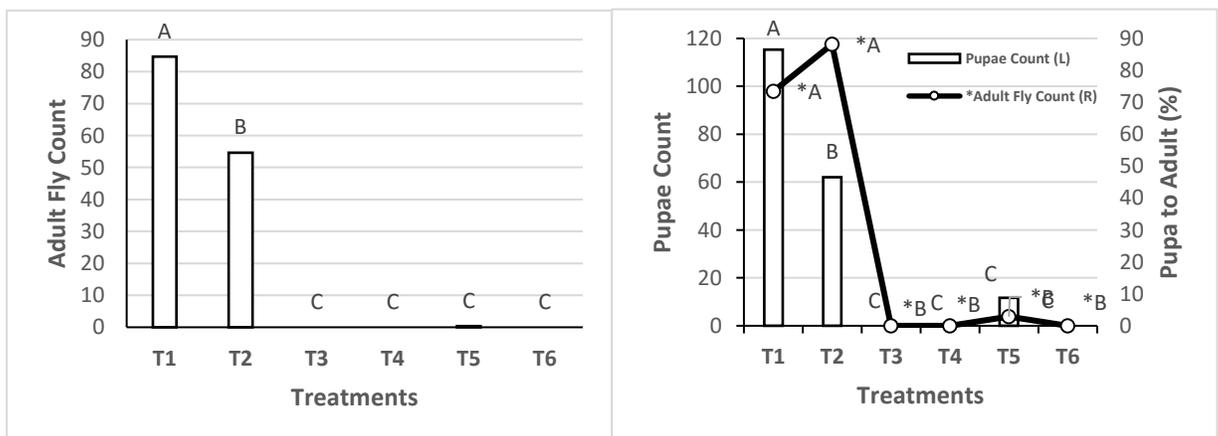


*Different letters on different bars indicate significant difference ($P \leq 0.01$).

Pupa to adult transition

Treatment 1 (T1) had the highest adult emergence per cage ($n = 85$), followed by T2 ($n = 54$) (Figure 3). This suggests that the ideal temperature for *M. domestica* development in the present study was 20 to 30 °C. This agrees with a previous study in which fly density was highest at an average temperature of 20 to 25 °C and no flies were present at temperatures higher than 45 °C or lower than 10 °C⁽¹⁷⁾. In another similar study the highest adult fly counts were observed at temperatures between 25 and 35 °C⁽²⁴⁾.

Figure 3: Comparison of median *M. domestica* adult fly count per treatment

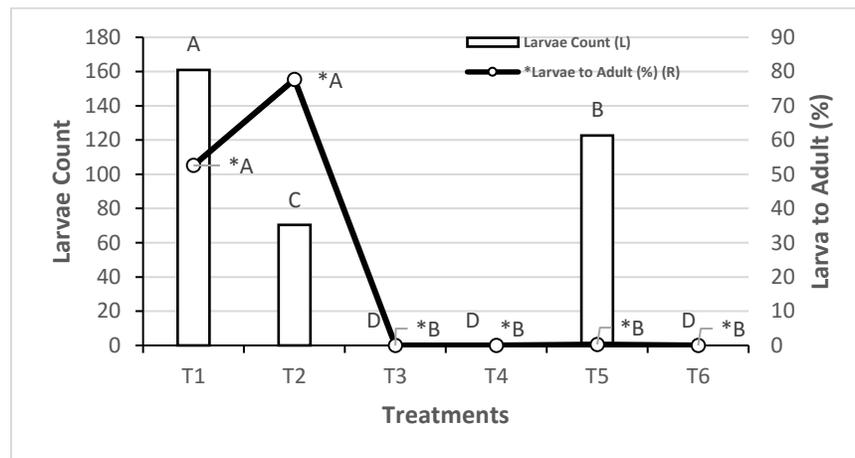


Treatment 2 (T2) had the highest pupa to adult transformation rate (84 %), followed by T1 (74 %). The $62.5 \pm 2.5\%$ RH used in T2 is near the 65 to 75 % RH reported as optimal for fly development⁽²²⁾, which is why this treatment exhibited a more consistent development rate among the different stages. In T5, counts for both pupae (n= 11) and adults (n= 1) were minimal (Figure 3).

Larva to adult transition

Larva to adult development was highest in T2 (73 %), followed by T1 (55 %)(Figure 4).

Figure 4: *Musca domestica* larva counts and larva to adult transition rates



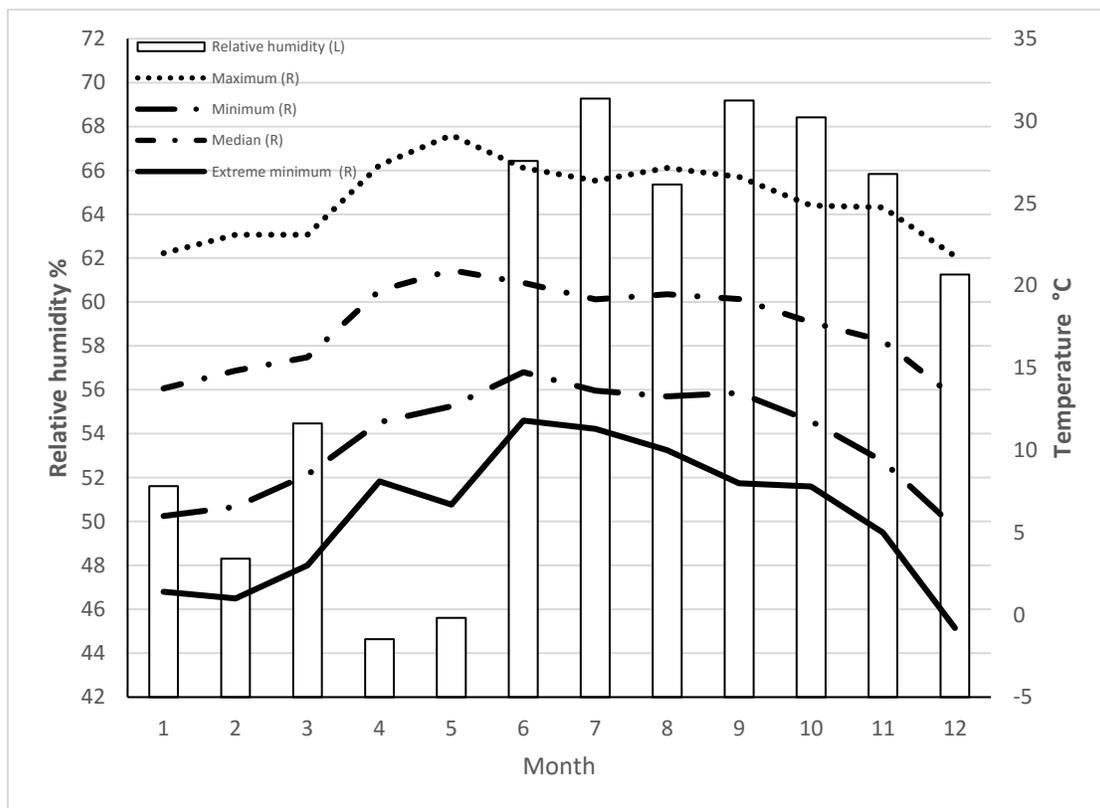
*Different letters on different bars indicate significant difference ($P \leq 0.01$).

Role of temperature and relative humidity in *M. domestica* development

An analysis was done incorporating temperature and RH data for Jesús María municipality in 2015, *M. domestica* frequency, and the experimental results. Population increase was highest in June (extreme minimum= 11.8 °C) to August (extreme minimum= 10 °C)(Figure 5). The latter temperature is the lower limit for egg hatching and at which adults can barely

fly⁽¹⁷⁾; it can be inferred that little copulation occurs. Oviposition generally does not happen below 15 °C⁽¹⁸⁾, which is probably why *M. domestica* populations are lower in April and May than in warmer months. This data agrees with reports of higher activity in this species at milder temperatures (30 to 33 °C) and low RH, and lower activity at very high temperatures and high RH^(17,25). In another study in which temperature remained nearly constant year round fly abundance was only influenced by changes in rainfall and RH⁽²⁴⁾. A study done in horse farms also found that temperature and RH affected fly populations, causing them to grow in the spring when temperatures rise and decrease in autumn when temperatures fall⁽²⁶⁾. Temperature is known to influence daytime *M. domestica* physical activity. As temperature increases (10 to 30-35 °C) during the day so does activity, and consequently pathogen dispersion and transmission, but when it surpasses 35 °C activity decreases notably⁽²⁷⁾. This species therefore has a wide temperature range within which to function, which is important information when designing disease outbreak prevention measures.

Figure 5: Temperature and relative humidity in Jesús María Municipality in 2015



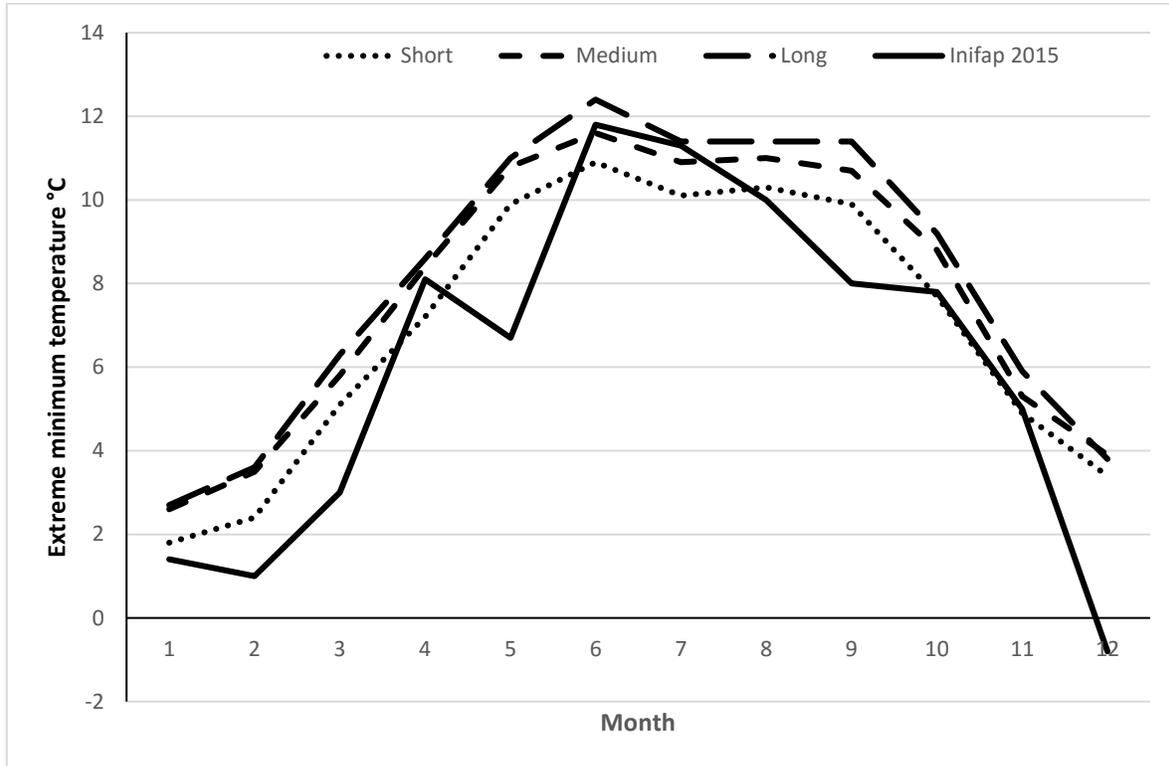
Source: Red Nacional de Estaciones Estatales Agroclimatológicas, Agroclima (INIFAP).

Minimum temperature projection model

Prediction of future extreme minimum temperatures in Jesús María Municipality can indicate when *M. domestica* could have ideal development conditions. The experimental results demonstrated that temperature is the most significant parameter influencing mortality in this species⁽²²⁾, while RH was important in regulating the viability of different stages within a moderate temperature range.

In the Short time horizon model, current conditions are predicted to remain relatively unchanged and *M. domestica* development will peak from June to August. Under the Medium and Long horizon models favorable development conditions will exist for a total of five months, from May to September (Figure 6). These projections will also depend on other factors such as wind, food availability, light and RH in the region. If these scenarios hold true, *M. domestica* populations will remain stable until 2039, but could then increase due to the longer periods apt for development. A similar prediction has been made for the United Kingdom, for which climate change scenarios predict increases of up to 244 % in the fly population in the summer months by 2080⁽²⁸⁾.

Figure 6: Extreme minimum temperatures in Jesús María Municipality in 2015, and its projection over three time horizons: Short, 2015-2039; Medium, 2045-2069; and Long, 2075-2099



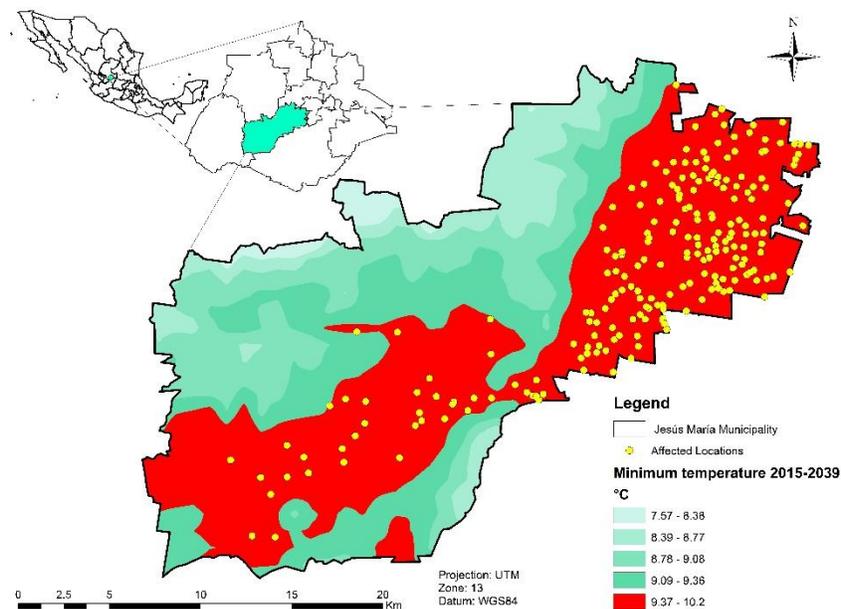
Source: ⁽¹⁵⁾ and Red Nacional de Estaciones Estatales Agroclimatológicas, Agroclima INIFAP.

This predictive information can help in planning control programs during more favorable fly development periods. Reducing *M. domestica* proliferation can help to avoid negative effects on livestock farms, reduce food contamination in the food industry and lower disease occurrence in human populations. The species' high reproductive potential requires effective and timely control practices to protect human and animal health⁽²⁹⁾. Control measures in developed countries have been established, especially for agriculture and the dairy industry, control agents have been formulated, and they are applied in both urban and rural areas⁽¹⁾. If insecticide is to be used, the present data can help to program application schedules and efficacy. It must be considered that these projections do not take into account biotic factors such as predators and parasitoids that could arise in coming years⁽²⁸⁾.

Prediction of temperature ranges in Jesús María Municipality over the Short horizon shows that approximately 100,000 inhabitants in the municipality's 235 settlements⁽³⁰⁾ could be affected by increased *M. domestica* populations (Figure 7). The problem could be most acute

in the map's red-toned areas where most of the population is concentrated (219 villages; 99,046 inhabitants). *Musca domestica* is often associated with livestock and household waste disposal facilities, since accumulation of organic matter provides appropriate breeding conditions⁽²⁸⁾. It also prefers to feed on decomposing vegetal and animal matter, which puts it in contact with the pathogenic organisms present in human garbage and animal waste, making it a disease vector for humans and animals⁽³¹⁾.

Figure 7: Distribution of average annual minimum temperature in Short horizon (2015-2039) in Jesús María Municipality)



Conclusions and implications

Under the experimental conditions *M. domestica* development was ideal between 20 and 30 °C, a temperature range that currently occurs in the study area for three months a year (June to August). Predictive analysis of regional climate suggested that this species will be favored by longer periods of ideal temperatures in the Medium and Long horizons; these will probably stretch over the five months from May to September. Longer periods with apt conditions for *M. domestica* development could exacerbate contamination problems in livestock and agricultural production and the food industry, and promote the spread of

diseases among animal and human populations. Almost all the populated areas in Jesús María Municipality will experience this climate change, highlighting the need to consider it when designing monitoring and control programs.

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