New World screwworm (Cochliomyia hominivorax) myiasis in feral swine of Uruguay: One Health and transboundary disease implications

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Research

Keywords: screwworm, myiasis, Cochliomyia hominivorax, invasive species, One Health, zoonosis, transboundary

Posted Date: August 4th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-52167/v1

Version of Record: A version of this preprint was published on January 7th, 2021. See the published version at https://doi.org/10.1186/s13071-020-04499-z.

Abstract

Background

Feral swine (*Sus scrofa*) are highly invasive and threaten animal and public health in the Americas. New World screwworm (*Cochliomyia hominivorax*) is listed by the World Organization for Animal Health as a notifiable infestation because myasis cases affect livestock, wildlife, and humans in endemic areas, and outbreaks can be of high socioeconomic consequence in regions where screwworm was eradicated. However, a knowledge gap exists on screwworm infestation of feral swine in South America where *C. hominivorax* is endemic. Here, we report infestation with *C. hominivorax* in feral swine harvested in the Department of Artigas where the Republic of Uruguay shares borders with Brazil and Argentina.

Methods

Myiasis caused by the larvae of *C. hominivorax* were identified in feral swine with the support and collaboration of a local feral swine hunting club over a three-year period in the Artigas Department of Uruguay. Harvested feral swine were examined for the presence of lesions where maggots causing the myiasis could be sampled and processed for taxonomic identification. The sites of myiasis on the body of infested feral swine and geospatial data for each case were recorded. Feral swine sex and relative size were registered along with ambient temperature and precipitation.

Results

Myiases caused by screwworms were recorded in 27 of 618 feral swine harvested. Cases detected in males over 40 kg were associated with wounds that, because of their location, were likely caused by aggressive dominance behavior between adult males. The overall prevalence of screwworm infestation in feral swine was associated with ambient temperature, but not precipitation. Case numbers peaked in the warmer spring and summer months.

Conclusion

This is the first report for South America of myasis caused by *C. hominivorax* in feral swine. In contrast to myasis in cattle that can reach deep into host tissues, screwworms in feral swine tended to cause superficial infestation. Feral swine present challenges to control screwworms in endemic areas. Screwworm populations maintained by feral swine may contribute to human cases in rural areas of Uruguay, which highlights the One Health importance of this invasive species-ectoparasite interaction.

Background

Interactions between invasive wildlife species and high consequence zoonotic parasites and vectors can have One Health and transboundary disease implications because of their multiplier effects on the health of human, domestic animal, and wildlife populations as well as the environment[1,2]. For example, feral swine (*Sus scrofa*) are highly invasive and threaten animal and public health in the Americas [3]. New World screwworm (*Cochliomyia hominivorax*) is listed by the World Organization for Animal Health as a notifiable infestation because myasis cases affect livestock and other domestic animal species, wildlife, and humans in endemic areas, and outbreaks can be of high socioeconomic consequence in regions of the American continent where this ectoparasite of warm blooded animals was eradicated [4,5]. Feral swine are known to host parasites and vectors of zoonotic importance in their invaded range. Although feral swine were known to be infested before the screwworm was eradicated from North and Central America [6], a knowledge gap existed for this invasive species in South America regarding cases of myiasis caused by *C. hominivorax*.

Screwworms were originally described infesting humans in 1858 [7], and remain endemic in South America where they cause myiasis regarded as a neglected zoonosis, affect domestic animals and wildlife, and inflict significant loss to livestock producers [8,9]. Similar conditions in the past triggered research in the United States (U.S.) that translated into the development sterile insect technique (SIT), which was applied areawide to eventually eliminate screwworms from North and Central America, and Puerto Rico [10]. Biotechnology-based SIT approaches are under development for sustainable operation of the screwworm barrier zone maintained on the border between Panama and Colombia through bilateral collaboration between the governments of Panama and the United States [11,12]. Screwworm control efforts related to animal health and production in countries of South America include monitoring and treatment of myiasis cases using insecticides when livestock are susceptible to infestation, such as in newborn navels, castrations, and other practices related to herd management and traceability [13]. In temperate regions of South America, additional protection from infestation can be achieved by planning livestock births, branding, castrations, or sheering to occur in months with lower screwworm abundance [14]. Surveillance in livestock is a key component of screwworm control but monitoring and reporting of myasis cases in wildlife is seldom practiced.

Wildlife involvement in endemic areas maintains screwworm populations that also affect humans and livestock. Prior to eradication the United States it was estimated that up to 2-3% of wild animals could be infested with screwworms in endemic regions [15]. White-tailed deer die-offs in parts of the U.S. were associated with myiasis before screwworm eradication [16,17]. It has also been argued that the disappearance of the screwworm as a natural wildlife population control is part of the reason white-tailed deer populations exploded in those parts of the United States [16]. In the 1950s, screwworm infestations were reported in feral swine in the state of Florida, U.S.A., and control of the swine populations was considered a priority to be able to reduce the screwworm incidence in the deer herd [6]. The importance of wildlife as a host for screwworm was highlighted during the outbreak in the Florida Keys of the U.S.A. in 2016, which resulted in the death of 135 endangered key deer [18]. Therefore, surveillance for myiasis cases in wildlife species including invasive feral swine could enhance the efficiency of areawide screwworm management programs [19].

In 1982, feral swine were officially declared a national pest in Uruguay after they were introduced to the country at the beginning of the last century for hunting purposes [20]. Females are capable of producing up to two litters of 4-5 piglets each year that can reach sexual maturity in less than one year, a reproductive output four times greater than white-tailed deer [21]. As it is the case in other parts of their invaded range, feral swine also cause extensive damage to agriculture, critical infrastructure, and private property, as well as being a public safety hazard in Uruguay [22,23]. Organized hunting in Uruguay helps control feral swine and under the proper sanitary conditions provides economic opportunities to hunters and farmers. Research on the causes of myiasis in feral swine was listed as part of the activities needed to inform plans to develop a screwworm control program in Uruguay [24].

This study is the result of a public-private partnership involving an interdisciplinary project on feral swine led by the Colleges of Sciences and Veterinary Medicine of the University of the Republic of Uruguay in collaboration with the National Association of Hunters in Uruguay, and other regional feral swine hunting and control associations called ProJAB for its acronym in Spanish. In particular, myiasis cases in feral swine reported by members of the Association for the Control of Feral Swine (ACJA) in the Province of Artigas provided the opportunity to investigate if screwworms were involved. The support and involvement of hunters and associated groups proved invaluable to obtain data on screwworm cases in feral swine of Uruguay and stresses the impact that citizen science can have on pest management programs [25,26].

Methods

Feral swine were harvested over a three-year period (May 2017 to April 2020) by members of the ACJA, which operate in the Artigas and northern Salto departments (Figure 1; total sampling data is available in Additional file 1). The hunters used several methods including dogs, firearms and cage traps. Upon capture, the feral swine were euthanized, geo-referenced and inspected to assess the general state of health and the presence of parasites (ticks, lice, dipteran larvae) as part of a comprehensive study to assess zoonosis. Size and sex were recorded for all animals, with size being categorized as <20 kg, 20-40 kg or large >40 kg. The site of larval infestation, larval instar, and predicted source of wound were also recorded when dipteran larvae were present. The larvae were stored in 70% ethanol for transport to the laboratory where they were identified to species using a stereoscope (4x and 10x magnification). Identification of *C. hominivorax* larvae was based on tracheole color, spine structure and distribution, and oral hooks [27] (Figure 2A).

The map of hunted feral swine and myiases cases was created using the ArcGIS online application. Monthly average temperature and total precipitation data was obtained from the Artigas meteorological station (Inumet.gub.uy) and accessed through Weather Underground (www.wunderground.com) and is provided in Additional file 2. Statistical analysis were conducted in the R statistical environment (v3.5.1;[28]). The Fisher's exact test was used to test for nonrandom associations between sex and size with myiasis. Linear regressions were used to in correlations between myiases and temperature and precipitation. Differences in hunting pressure by month was conducted using analysis of variance.

Results

A total of 618 feral swine were examined during the study period, of which 27 were infested with dipteran larvae (Figure 1, Table 1). Animal size, sex, location of capture, and area of body infested for the 27 feral swine with myiasis is reported in Additional file 3. Microscopic examination of the larvae revealed all cases of myiasis were due to infestation by *C. hominivorax*. The number of infested males was significantly greater than expected by random chance ($p = 0.0027$), with 20 of 282 males with NWS compared to seven of 336 females. In addition, the number of large adults was greater than expected ($p = 1.095e-06$), with 26 of 332 large adults having NWS compared to only 1 of 286 small/medium. These data suggest there is a greater prevalence of NWS infestation in large adults, especially, large adult males.

Myiasis was found in 12 areas broadly distributed across the body (Table 2). Despite these infestations, the hogs showed no signs of severe morbidity due to the myiasis and were otherwise healthy. In some cases, the site of myiasis was covered in mud to a greater extent than the rest of the body, thus their wallowing behavior could provide some protection by limiting the severity of infestation.

The hunters participating in this study proposed sources of wound resulting in myiasis (Table 3). Across all samples, the majority of proposed wounds were the result of interspecies aggression (15 of 27), primarily between males (13 of 20). The second leading cause of myiasis was non-lethal bullet wounds (5 of 27). The only juvenile pig collected with myiasis had the infection in the umbilical cord.

Average percent of feral swine harvested with myiases reported are shown in Figure 3. The number of harvested hogs was consistent between months ($F_{11,25} = 1.483$, $p = 0.20$) with an average 16.73 ± 8.81 hogs harvested per month. The number of myiases reported were not correlated to the number of harvested hogs ($R^2 = .090$, $p = 0.1785$), indicating sampling depth was able to capture accurate myiasis rates. Cases of myiasis were highest in spring months, September to December (6.71% hogs with myiasis), and lowest in winter, July and August (1.09% hogs with myiasis). The highest percent of myiasis cases were reported in December (12.9%) and the lowest in June with no cases of myiasis. Total monthly myiasis cases were correlated to monthly average temperate with cases increasing with increasing average monthly high ($R^2 = 0.4384$, $p < 0.001$) and low ($R^2 = 0.1016$, $p = 0.031$) temperatures. Total monthly precipitation did not correlate to the presence of myiases ($R^2 = 0.0043$, $p = 0.289$).

Discussion

To the authors' knowledge, this is the first of epidemiological report of screwworm myiasis in feral swine from South America. Myiasis cases in feral swine were reported by hunters in the Artigas and Salto provinces of Uruguay between April 2017 and April 2020. Of the 618 swine examined, 27 were infested with maggots. Screwworm infestation prevalence (4.36%) in feral swine was relatively higher than the estimated 2-3% in wildlife reported by Lindquist (1937), and lower than the >5% recorded in domestic pigs in Yucatan, Mexico [29]. The prevalence reported here is similar to that in sheep (5.7%) and cattle (3.4%) in Uruguay [24].

Screwworm cases were detected primarily in large male feral swine, and primarily in wounds that the hunters suspected as being the result of fighting between males. Dominance behavior in swine includes the males lining up facing each other and pushing at the shoulders, which can leave large lacerations due to their tusks and biting the neck, ears, and face (Figure 2B)[30]. These opportunities to lay eggs were exploited by screwworm female flies because 41% of the myiases occurred in those body parts of the host. Wound infestation in males associated with lesions resulting from feral swine infighting was also reported to be common in before screwworm eradication Florida was accomplished [6].

Genital myiases in post-birthing females and in juvenile navels are very common in livestock and a primary concern to ranchers. Of the feral swine harvested in this study, only one female with genital myiasis and one juvenile male with naval myiasis were observed. It is possible that in feral swine these are not common sources of myiases, or that these were not commonly observed because they lead to mortality. Navel myiases may have also been underreported, as more adult animals were harvested.

Hunters who participated in this study reported that, although myiases are common in feral swine, they did not observe myiases causing serious morbidity or mortality (A typical myiasis in feral swine is shown in Figure 2B). Physically, feral swine have thick skin that could inhibit the formation of myiasis and be inhospitable to screwworm larvae. Additionally, male swine develop thick layers of skin and cartilage near the shoulder, called shields [20], which protect males during dominance fights and may also inhibit screwworm development (Figure 2C,D). Feral swine behavior may also prevent or treat myiases. Wallowing has many benefits to the animal including thermal regulation, UV protection, and protecting against ectoparasites and biting flies [31]. Screwworm larvae in a myiasis are surrounded by fluid but they must have exposure to air through their terminal spiracles, thus coating a myiasis in mud or water could suffocate larvae [32]. Coating a wound in mud could also prevent release of odors that attract gravid female screwworm flies to a wound and stimulate oviposition. Feral swine also exhibit a rubbing behavior associated with wallowing that could remove unhatched egg masses or larvae close to the surface. They also soak or swim in water, behaviors that have been observed in deer to help clean myiases [15]. Thus, it is possible feral hogs also intentionally soak to remove screwworm larvae.

Feral swine that survive infestation could play an important role in the dissemination of screwworm. Their home range can be over 400 ha and feral swine movement is not inhibited by rivers [33]. It was reported during this study that during some hunting operations in parts of Artigas Department where the Cuareim river serves as the international boundary, feral swine escaped by jumping and swimming to the bank of the river on the Brazilian side of the border. It is probable that screwworm infestations acquired in Uruguay, Argentina, or Brazil could be carried to a bordering country where the larvae would crawl off and pupate. This presents the potential for a transboundary zoonotic disease issue. The results from this study highlight the ability of feral swine in South America to maintain screwworm populations. If one of these nations were to begin a control or eradication program, feral swine would be a source for re-infestation.

Cooperation with local hunters through ProJAB enabled records of screwworm infestation in feral swine, which stresses how research and extension efforts facilitate collaboration between groups that deal with issues at the livestock-wildlife interface. This public-private partnership also involves education of the hunters on practical aspects of veterinary public health to mitigate risks associated with exposure to zoonoses harbored by feral swine in Uruguay [20]. Hunters were made aware of measures to avoid the dispersal of screwworms and to manage the risk of human and domestic animal exposure to infestation. Hunting feral swine often occurs at night and the hunters transport the harvested animals to their homes and leave them hanging until morning when they are cleaned and processed. During this time the 3rd instar larvae would be able to crawl off and pupate near the homes of the hunters increasing the presence of screwworm adults in the vicinity of the hunters' homes. In Uruguay, up to 818 human cases of screwworm myiasis can be recorded annually with the majority of cases affecting rural populations [24]. This stresses the One Health relevance of screwworm myiasis, which in the region is considered a neglected zoonosis [34].

All the larvae collected from the myiasis cases in feral swine were identified as *C. hominivorax*, with no secondary species present. Screwworm cases reportedly contain larvae of species in the families Calliphoridae, Sarcophagidae, and Muscidae that cause secondary myiasis [35]. In myiases with secondary species, the primary screwworm *C. hominivorax* is found feeding on living tissues while the secondary species are at the wound periphery consuming necrotic tissues. The absence of secondary fly larvae in infested feral swine could be due to the same factors mentioned previously for the low mortality associated with myiases. If myiases are not persistent and tissues do not become necrotic, the development of secondary infestation would be unlikely.

Seasonal changes in temperature and precipitation have been correlated with screwworm prevalence. However, the patterns are dependent on local climates and should not be generalized. Screwworm infestation in this study correlated with higher monthly average temperatures, and fewer cases were detected in winter months with low temperatures. These observations are similar to the seasonal variations in screwworm prevalence in the United States prior to eradication [36]. An increase in infestations associated with higher temperature is concerning because it has been estimated that current global change trends could result in an increase in temperatures in Uruguay of up to 3 degrees Celsius by 2100 [37]. Under this scenario that has been contemplated for other parts of the American continent [38], the risk for screwworm infestation could extend in the year thereby reducing the efficacy of seasonal birthing currently practiced by livestock producers in parts of Uruguay with a more temperate climate to reduce screwworm cases. The apparent seasonality of myiases in feral swine mirrors prevalence patterns in livestock, which suggests that screwworms could persist in the environment by infesting feral swine alone in in Uruguay, which was documented in Florida before population control of feral swine and screwworm eradication took place. Total monthly precipitation was not correlated to myiases prevalence as has been seen in screwworm surveys in tropical countries such as Panama or the Caribbean [39,40]. However, the risk for screwworm outbreaks where domestic pigs and feral swine are present must be noted. One pet pig was infested during the 2016 outbreak in Florida [18], and feral swine also thrive in Panama where the screwworm barrier zone exist to prevent the reinvasion of Central and North America through the continental mainland [41].

Conclusion

Efforts to manage screwworm populations need to include surveillance of myiasis in feral swine where these two high consequence pests of zoonotic importance coexist. Feral swine in Uruguay were documented to be a common screwworm host. Moreover, feral swine appear to be resilient to screwworm infestation, unlike the key deer in southern Florida. Although precautions are taken to reduce screwworm cases in livestock, the invasive feral swine in Uruguay apparently can maintain screwworm populations that can serve as a source of infestation in livestock and humans. This situation and the public-private partnership with hunters in Uruguay that facilitated this research project emphasize the relevance of taking the One Health approach to deal with invasive species and transboundary zoonotic diseases.

Abbreviations

ACJA: Asociación de Controladores de Jabali de Artigas

C. hominivorax: *Cochliomyia hominivorax*

NWS: New World screwworm

PROJAB:

UV: ultraviolet

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analyzed during this study are included in this published article and its additional information files.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported through funding from USDA-ARS project 3094-32000-038-00D.

Authors' contributions

BPL, APA, and PVH conducted statistical tests and drafted the manuscript. MA, GC, SM collected and identified the specimens. All authors contributed to editing and content of the manuscript.

Acknowledgements

We thank the Asociación de Controladores de Jabali de Artigas (ACJA) for evaluating the harvested feral swine for myiasis, sending larvae for microscopic examination, and providing the coordinates for the harvest sites. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. The USDA is an equal opportunity provider and employer.

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Tables

Table 1. Size, sex and number of feral swine examined in the study.

Size and sex	No. examined	No. w/ myiasis
Females (>40 kg)	167	7
Males (>40 kg)	165	19
Females (20-40 kg)	122	0
Males (20-40 kg)	71	0
Females (<20 kg)	47	0
Males (<20 kg)	46	1

Table 2. Locations of myiasis on the hog body.

Myiasis site	Male	Female	Total
Shoulder	4 (20%)	1 (14%)	5 (19%)
Loin	2 (10%)	1 (14%)	3 (11%)
Eye	1 (5%)	0 (0%)	1 (4%)
Nose	1 (5%)	0 (0%)	1 (4%)
Head	2 (10%)	0 (0%)	2 (7%)
Umbilical	1 (5%)	0 (0%)	1 (4%)
Neck	2 (10%)	0 (0%)	2 (7%)
Leg	0 (0%)	1 (14%)	1 (4%)
Hind Leg	1 (5%)	0 (0%)	1 (4%)
Flank	1 (5%)	2 (29%)	3 (11%)
Genitals	1 (5%)	1 (14%)	2 (7%)
Ribs	3 (15%)	0 (0%)	3 (11%)

Table 3. Predicted sources of wounds resulting in myiasis.

Wound Source	Male	Female	Total
Bullet	3 (15.0%)	2 (28.6%)	5 (18.5%)
Fight between hogs	13 (65.0%)	2 (28.6%)	15 (55.6%)
Fight with dogs	0 (0.0%)	2 (28.6%)	2 (7.4%)
Umbilical	1 (5.0%)	0 (0.0%)	1 (3.7%)
Vegetation	1 (5.0%)	1 (14.3%)	2 (7.4%)
Barbed wire	2 (10.0%)	0 (0.0%)	2 (7.4%)

Figures

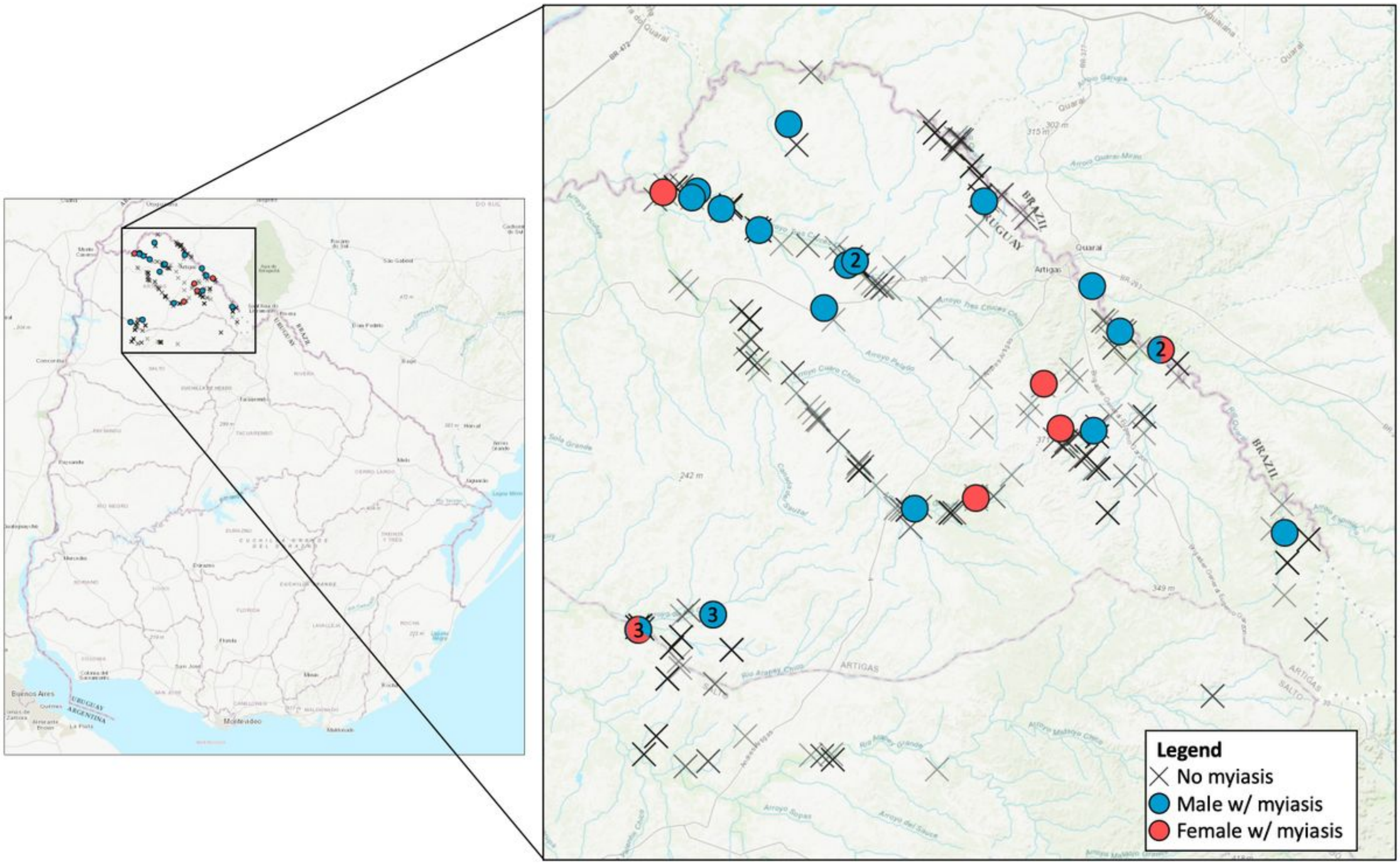

Figure 1

Map of Uruguay with the sampling area in Artigas and Salto along the Brazilian border expanded. Locations of swine capture sites are shown as having or not having myiasis. Darker X's indicate multiple swine sampled in at that site. Sites with more than one myiasis case have the total number of cases in the circle, and sex ratio is shown as a pie chart.

Figure 2

Images of A) representative screwworm larvae samples, B) myiasis of a feral swine, C) male shoulder shield that had the tusks of another male broken off and embedded, and D) shoulder shield from a large male split to show the thickness (approximately 5-6cm).

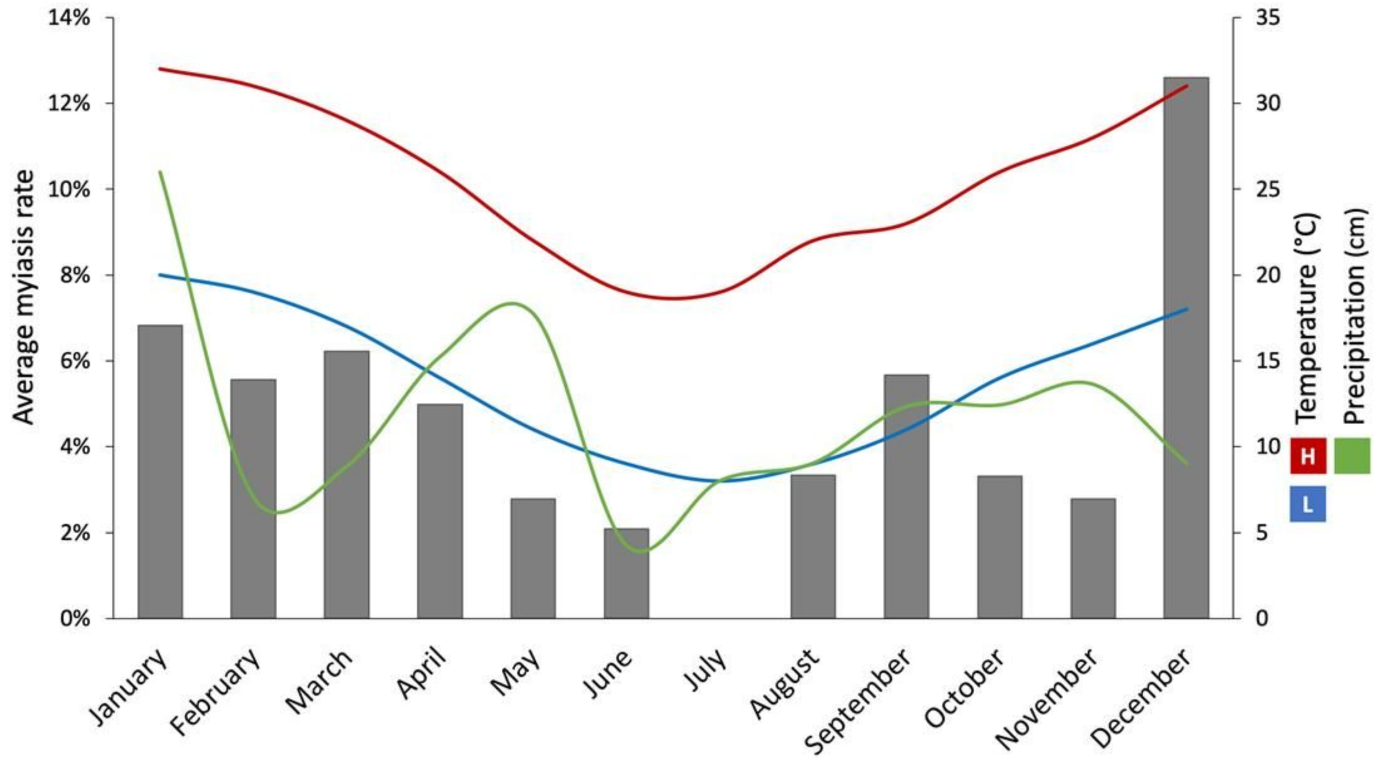

Figure 3

Average rate of myiases in harvested hogs presented as bars with scale on the left axis. Average monthly high and low temperatures and average total precipitation during the study period are presented on the right axis.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.xls
- Additionalfile2.xls
- Additonalfile3.xls
- graphabst.jpg