Impact of COVID-19 on high-workload facilities: a case study of *Glossina palpalis gambiensis* productivity at the Insectarium in Bobo-Dioulasso, Burkina Faso.

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Abstract

In order to eradicate African animal trypanosomosis (AAT), various control strategies, including chemical and biological approaches, have been implemented. Among these strategies, the sterile insect technique (SIT) has proven to be more effective for disease control in the context of area-wide integrated pest management (AW-IPM). In this context, the Insectarium de Bobo-Dioulasso (IBD) was established to fulfil the demand for sterile male tsetse flies. However, the outbreak of the Covid-19 pandemic led to the implementation of restrictive measures at the IBD from April to November 2020. In this study, we assess the repercussions of these measures on tsetse fly mass rearing activities at the IBD, specifically their impact on environmental parameters, blood quantity and quality, colony size, as well as productivity of the two strains of *Glossina palpalis gambiensis*, namely CIRDES and SEIBERSDORF strains. In 2020, the data from the aforementioned variables was collected and subsequently subjected to analysis.

Restrictive measures due to Covid-19 pandemic did not have discernible adverse effects on environmental conditions of the mass rearing rooms. However, a reduction of the volume of collected and utilized blood was observed, leading to a reduction in the flies feeding frequency from four to three times a week. Consequently, pupal production decreased, colony size reduced in both strains and sterile male pupal shipments for the eradication program in Senegal were paused until the end of the pandemic. Based on these findings, precautionary measures have been delineated to tackle a similar crisis it was to arise in the future.

Keywords: Covid 19, *Glossina palpalis gambiensis*, Productivity, Mass rearing, Burkina Faso.

Résumé

Dans le but d'éradiquer la trypanosomose animale africaine diverses stratégies de contrôle incluant des approches chimiques et biologiques ont été proposées et mises en œuvre. Parmi ces stratégies, la technique de l'insecte stérile (TIS) s'est avérée plus efficace pour le contrôle de la maladie dans le contexte de la lutte intégrée. Dans ce contexte, l'Insectarium de Bobo-Dioulasso (IBD) a été créé pour répondre à la demande de mâles stériles de mouches tsé-tsé. Cependant, la crise sanitaire de la pandémie de la Covid-19 a engendré la mise en œuvre de mesures restrictives à l'IBD d'avril à novembre 2020. Dans cette étude, nous avons évalué les contraintes qu'imposent ces mesures à l'élevage de masse des glossines à l'IBD, notamment leur impact sur les paramètres environnementaux, la quantité et la qualité du sang collecté dans les abattoirs, la taille de la colonie et la productivité pour deux souches de *Glossina palpalis gambiensis*, à savoir les souches CIRDES et SEIBERSDORF. En 2020, les données des variables susmentionnées ont été collectées et ensuite soumises à l'analyse.

Les mesures restrictives dues à la Covid-19 n'ont pas d'effets négatifs perceptibles sur les conditions environnementales des salles d'élevage de masse. Cependant, une réduction du volume de sang collecté et utilisé a été observée, ce qui a entraîné une réduction de la fréquence d'alimentation des mouches de quatre à trois fois par semaine. En conséquence, la production de pupes a diminué, la taille des colonies a également diminue au niveau des deux souches et les envois de pupes mâles stériles pour le programme d'éradication au Sénégal ont été suspendues jusqu'à la fin de la pandémie. Sur la base de ces résultats, des mesures de précaution ont été définies pour faire face à d'éventuelles crises similaires à l'avenir.

Mots clés: Covid-19, *Glossina palpalis gambiensis*, Productivité, élevage en masse, Burkina Faso

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Introduction

Tsetse flies (Glossinidae: *Glossina*) represent the biological vectors of African trypanosomes, the pathogenic agents of sleeping sickness, also known as Human African Trypanosomiasis (HAT) in humans, and Nagana or African Animal Trypanosomiasis (AAT) in animals (Vreysen et al. 2013). AAT poses a severe threat to livestock, resulting in the deaths of approximately 3 million cattle, as well as significant losses among sheep and goats annually (FAO 2002). Tsetse flies are found in 38 sub-Saharan African countries, which cover more than 10 million square kilometres, thereby impeding the development of sustainable and productive agricultural systems (Hursey et Slingenbergh 1995; Swallow 1999). Annually, AAT leads to high mortality rates (ranging

from 10% to 20%) among livestock and a decline in calving rate (11% to 20%), meat production (5% to 30%), milk production (10% to 20%), and even cultivated area dedicated to beef production (33%) (Swallow 1997).

These losses are significantly high due to the fact that the distribution of tsetse flies encompasses some of the most fertile land, thereby constraining their use for agricultural purposes (De La Rocque et Cuisance 2005). Considering the food and economic challenges in Burkina Faso, it is crucial to enhance the health situation through the control of AAT and intensify both animal and agricultural productions. While AAT management could theoretically focus on controlling the parasite itself, this strategy is limited by widespread resistance to the most used trypanocidal drugs (Geerts et al. 2001; Delespaux et al. 2008) and the absence of effective preventative vaccines (Duvallet et al. 2003). Consequently, tsetse fly control remains the most economically efficient option for managing AAT (FAO 2002).

The control of AAT through area-wide integrated pest management (AW-IPM) approach, incorporating the sterile insect technique (SIT) component, has been effective in various regions. Notable successes were observed in Zanzibar against *Glossina austeni* (Vreysen et al. 2000), in Senegal against *Glossina palpalis gambiensis* (Vreysen et al. 2021; Pagabeleguem et al. 2015), in Burkina Faso against *Glossina morsitans submorsitans*, *G. palpalis gambiensis*, and *Glossina tachinoides* (Cuisance et al. 1984; Politzar et Cuisance 1984), and in Nigeria against *Glossina palpalis palpalis* (Takken et al. 1986).

However, the implementation of this technique requires several key steps, including mass rearing of the target species, followed by sterilization of the males using ionizing radiation. Subsequently, these sterile males are released in a sustained and sequential way within intervention zones. The mating between wild females and sterile males results in the absence of offspring, ultimately leading to a reduction in size of the targeted population and, in some cases, complete local eradication.

Under the framework of the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) (Kabayo 2002), the program of Burkina Faso, spanning from 2006 to 2013, achieved remarkable success by reducing *G. palpalis gambiensis* and *G. tachinoides* densities by approximately 83% to 92% across an area of 40,000 square kilometre. Additionally, during this period, the program of Burkina Faso established and equipped a mass-rearing facility known as the Insectarium de Bobo-Dioulasso (IBD) (Percoma et al. 2018). The primary objective of the IBD is to produce sterile males to support the effort of eradication program in Burkina Faso. Furthermore, strategically IBD is positioned to meet the demands of other PATTEC-affiliated campaigns in the sub-region countries that are implementing control strategies involving the sterile insect technique (SIT). Rearing activities at IBD started in June 2016 with *Glossina palpalis gambiensis*, and by week 42 of 2019, the colony had reached a size of approximately 617,600 females (Pagabeleguem et al. 2021).

The coronavirus disease of 2019 (Covid-19) was a global pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and has been spreading rapidly since its emergence in December 2019 (https://www.who.int/europe/emergencies/situations/covid-19). In Burkina Faso, the first Covid-19 case was reported on March 9, 2020 (Ndiaga 2020). In response to the confirmation of 40 cases on March 20, several protective measures were implemented to mitigate the spreading of the virus. These measures included the closure of airports and land borders, the imposition of a nationwide curfew, the shutdown of shopping centres, schools, restaurants and hotels, and restrictions on movement, along with city quarantines. Subsequently, work arrangements at IBD were restructured, with employees divided into two groups and subjected to shift rotations occurring 2 to 3 times a week instead of the previous 6-day workweek. The Covid-19 pandemic has had profound global impacts, affecting virtually all sectors (Willy et al. 2020). Like many other institutions, IBD was not immune to the effects of the pandemic. In this study, we assess the pandemic's impact on environmental conditions, the quantity of blood collected from slaughterhouses to feed the flies, and the productivity of the *Glossina palpalis gambiensis* colony at IBD during the Covid-19 global pandemic.

Materials and methods

Insectarium of Bobo-Dioulasso and daily routine activities

The study was carried out at the Insectarium de Bobo-Dioualasso (IBD), a specialized institute for mass-rearing of tsetse flies. It is a sub-regional facility located in Darsalamy, 15 km from Bobo-Dioulasso (11°03'32.4"N and 4°21'10.9"W), Burkina Faso.

Currently, two species are being mass-reared at the IBD namely: *G. palpalis gambiensis* and *G. morsitans submorsitans* (Pagabeleguem et al. 2021). The tsetse colonies are maintained at 24–25 °C and 75 ± 5 % RH with a 12:12 h light:dark photoperiod (Feldmann 1994; Pagabeleguem et al. 2023). Hobo U14-001 data loggers are placed inside the rooms and are programmed to display temperature and relative humidity every minute and to record data every 30 min.

Flies are separated the emergence day by sex using a 4 °C cold table and mated. The mating was performed into standard rearing cage in a ratio of 1 male to 3 females. The flies are fed four times a week for ten minutes (Monday, Tuesday, Thursday and Friday) using an in vitro silicone membrane system with the blood which was heated to 36–37 °C on controlled aluminium plates of the Tsetse Production Unit (TPU4) (Bauer et Wetzel 1976). The bovine blood is collected by technicians four times a week at the Bobo-Dioulasso slaughterhouse and once a month for ten days at the Ouagadougou slaughterhouse, frozen at -20 °C and irradiated with 1 kGy in a Co60 source of the FOSS 812 irradiator (Pagabeleguem et al. 2021). The blood quality is tested after irradiation through the microbial contamination value which is bacteriological cultures on agarose middle in petri dishes and incubate at 37 °C for 72 hours. A blood batch is considered to be of good quality when the count of microbial colonies is fewer than 10.

Pupae collection is done on a daily basis and are categorized as either normal or aborted L3 pupae 24 hours later. The normal pupae undergo weight measurement using an electronic balance with a sensitivity of 0.0001 mg and automatic calibration (specifically, the Sartorius MSE2 7S-000-DM Cubis Ultra model). Daily pupal production were meticulously documented, stratified by strain, and subsequently incubated under controlled conditions at 25 ± 1 °C with a relative humidity of 75 ± 5%.

Tsetse fly strains

All experiments were carried out on *G. p. gambiensis* species fed *in vitro* on silicone membranes. At IBD, two strains of *G. palpalis gambiensis* are maintained according to their origin.

The CIRDES strain originates from the CIRDES (Centre International de Recherche-Développement sur l'Élevage en zone Subhumide) insectarium in Bobo-Dioulasso. This strain was established in Maisons-Alfort, France in 1972 using material collected in the field at Guinguette, near Bobo-Dioulasso, Burkina Faso. It was then transferred in 1975 to the Centre de Recherche et de Trypanosomiases Animales (CRTA), (CRTA is the former name of the CIRDES) (Sellin et al. 1979).

The SEIBERSDORF strain was initially established at the Insect Pest Control Laboratory (IPCL) of the joint FAO/IAEA division in Seibersdorf, Austria, in the year 2009. This strain was derived from a pool of 8,000 pupae originating from the CIRDES colony. The primary purpose behind establishing the SEIBERSDORF strain was akin to that of IBD, primarily to support the eradication initiative in the Niayes region of Senegal (Mutika et al. 2013).

Subsequently, in 2017, the IBD received a total of 64,213 pupae from the SEIBERSDORF colony. This influx of pupae prompted the establishment of a dedicated colony for mass production of the SEIBERSDORF strain at the IBD.

Data collection

Data collection was carried out on a weekly from January to November 2020 during the Covid 19 period. Data collected concerned environmental conditions, i.e. temperature and relative humidity, blood collection and use, colony size and female productivity. The data for the environmental parameters were recorded using the Hobo U14-001 data loggers. In the rearing room, four hobos (data logger) were installed, and weekly data were extracted for each hobo for further analysis. The quantity of blood collected at the slaughterhouse per outing and that used per feeding session were recorded. The quantity of blood used per feeding session were also recorded. The size of the colony were assessed after weekly mortality check, but also the new young tsetse flies that were added to the colony after the daily emergence, which also gave an idea of the pupal emergence rate. The pupae emergence rate is the total number of flies that emerged from the total number of pupae.

The number of normal pupae per day were assessed after collection of pupae from both strains. After collection, the larvae L3 and pupae were kept in a room in the above-mentioned standard conditions till they grew into pupae. A day following collection, the pupae were assessed, and the number of normal pupae and soft pupae were recorded according to the strain.

Data analysis

The data collected was entered into a database using Microsoft Excel 2016 software. The statistical analyses and the figures were performed with the R Software (version 4.0.3) (R Core Team 2019) using RStudio (RStudio, PBC. Boston, MA, USA, 2020). Descriptive statistics were used to determine the means and standard deviations of the data. Student's t tests were used to compare means. Correlation tests were used to study the relationship between variables. For the comparison of variables, every difference was considered significant if $p < 0.05$.

Results

Environmental parameters

During the year 2020, a significant variation of the temperature and the relative humidity was recorded from one week to the other ($\chi2 = 8.38$, df = 1, $p = 0.003$ for temperature and $\chi2 = 159.52$, df = 1, $p < 0.0001$ for the relative humidity) and room ($\chi2 = 426.87$, df = 2, $p < 0.0001$ for the temperature and $\chi2 = 187.89$, df = 2, $p < 0.0001$ for the relative humidity). However, the average temperature recorded during the period of Covid-19 (April to November 2020) was 25.09 ± 0.35 °C with a maximum and minimum of 25.86 °C and 24.55 °C respectively. The mean relative humidity recorded in rearing rooms were 77.66 ± 4.47 % with 61.03% as minimum and 78.19% as maximum. During the period of this study, the sawtooth variations in temperature and relative humidity from one week to another were observed, but remained within acceptable ranges (figures 1 and 2).

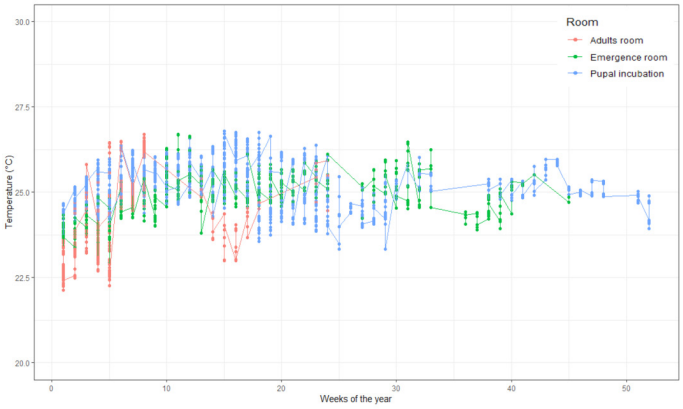

Figure 1: Temperature variations in the different rearing rooms during the period of this study

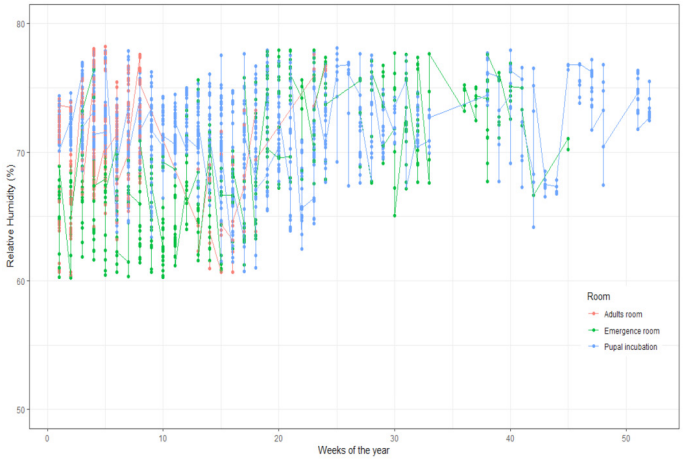

Figure 2: Relative humidity trend in the different rearing rooms during 2020

Impact on the quantity of blood collected

Tsetse flies are hematophagous insects and to ensure the maintenance of a tsetse mass rearing, it is essential to have a large quantity of high-quality blood. The colony at the IBD is maintained through permanent collection of bovine blood from local slaughterhouses, in particular Bobo-Dioulasso slaughterhouse. The quantity of blood collected in 2020 shown a monthly average of 804.6 litres, with a maximum collection in April (1,341 litres) and a minimum in November (463.5 litres) (Figure 3).

The quantity of blood used per month depended on the feeding frequency and the size of the colony. This quantity was high and almost constant from June onwards in November as compared to the other months, with the exception of March.

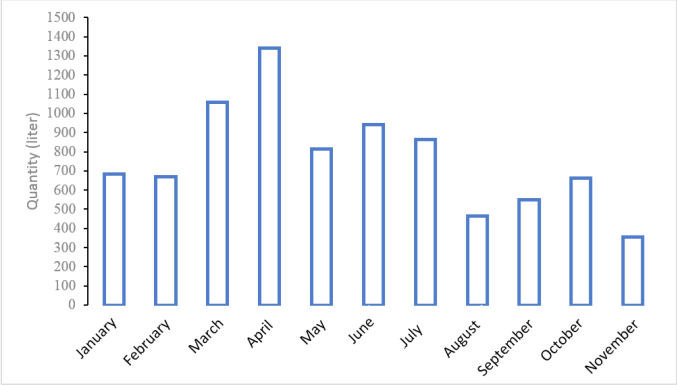

Figure 3: Quantity of bovine blood collected per month in 2020

Impact on the colony size

Assessing changes in colony size is essential for tsetse fly rearing. This gives an idea of possible variations over a year. During 2020, the size of the colony, which was essentially CIRDES and SEIBERSDORF strains, varied considerably. The colony size of both strains was almost constant from 1st to 17th week, but decreased between the 18th and 34th week, which is the period of the Covid-19 locked down (Figure 4).

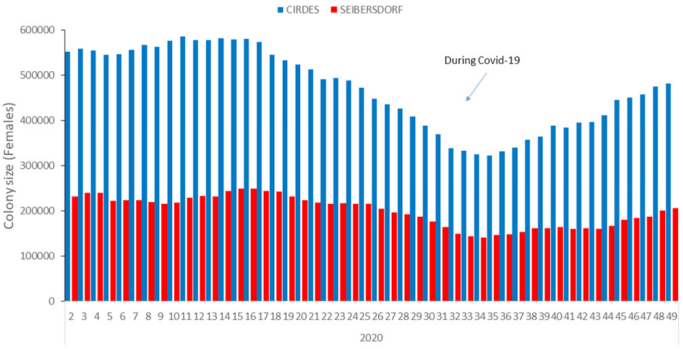

Figure 4: Evolution of the size of the two colonies in 2020

Impact on female productivity

Productivity is one of the most important factors to consider in tsetse fly mass-rearing. Productivity can be influenced by several factors, including environmental conditions, the state of the colony, the frequency of feeding and the quality of the blood provided. From week 1 to 9, normal colony pupae production increased in both CIRDES and SEIBERSDORF strains. From week 12 to 30, a significant decrease in pupae production was observed in both strains and production returned to normal after week 30 (Figure 5).

Production of soft pupae were observed over the period between week 12 and 14 and over the implementation period of Covid-19 measures (Figure 7). The results shown that the periods when the soft pupae were important, normal pupae production decreased, and vice versa. On average, 3,000 and 1,000 soft pupae were collected per week for the CIRDES and SEIBERSDORF strains, respectively (Figure 6).

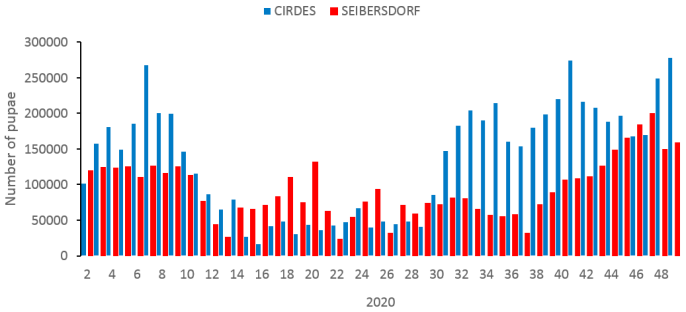

Figure 5: Production of normal pupae per week in the two colonies in 2020

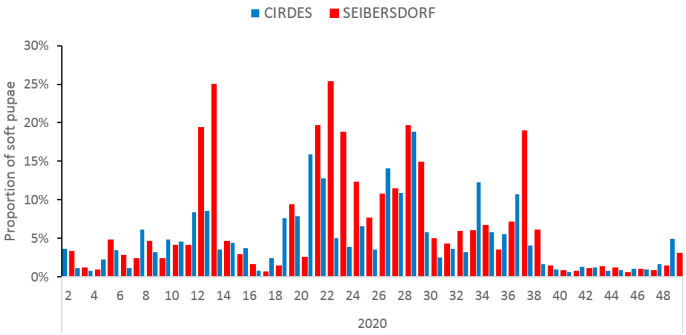

Figure 6: Production of soft pupae per week of the two colonies in 2020

Impact on adult emergence

The emergence of tsetse flies is essential for the renewal of the colony. It depends on environmental conditions, as well as the quality and quantity of pupae produced. Females emerge two to three days before males. Male emergence per week decreased from week 17 to week 35 for both strains, and then began to increase (Figure 7). During this period, an average of 27,500 and 10,000 females emerged per week for the CIRDES and SEIBERSDORF strains, respectively. (Figure 7).

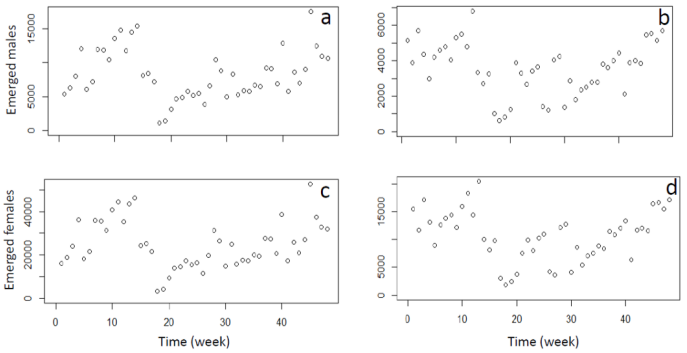

Figure 7: Impact on adult emergence. **a** males emerged for the CIRDES strain, **b** males emerged for the SEIBERSDORF strain, **c** females emerged for the CIRDES strain, **d** males emerged for the SEIBERSDORF strain.

Discussion

This study aimed to highlight the impact of the Covid-19

pandemic on Insectarium de Bobo-Dioulasso (IBD), engaged in mass rearing of tsetse flies for the sterile insect technique application in Africa and research programmes. The IBD was constructed as part of the first phase of PATTEC Burkina Faso (Percoma et al. 2018). The IBD-CETT's mission is to eradicate the tsetse fly to drive trypanosomosis out of Burkina Faso and the sub-region. The insectarium has a production capacity of 1,000,000 sterile males per week with the aim to support national and sub-regional control programmes. The recent programme supported in the sub-region contributed to the ongoing eradication of *Glossina palpalis gambiensis* in the Niayes region, Senegal (Vreysen et al. 2021), where since 2017, the IBD has supplied about 8.5 million sterile male *G. palpalis gambiensis* pupae in support of the Senegalese programme (Pagabeleguem et al. 2023).

The present study showed the impact of Covid-19 on the mass rearing of tsetse flies and the need to setting up a crisis response and management plan. In 2020, the recorded conditions in the breeding room, such as temperature and relative humidity, averaged 25.09 °C and 77.66 %, respectively. These recorded values are in line with Feldmann's (1994) norms for a tsetse breeding room as well as the recent environmental conditions assessed at IBD by Dera et al. (2023). This proves that, IBD has the equipment needed to maintain good environmental conditions in a tsetse rearing rooms and their maintenance is accurate. The rooms are equipped with air conditioners set to maintain the temperature at 25 ± 1 °C, humidifiers to maintain the relative humidity at 75 ± 5 %, and data loggers set to make simultaneous recordings of the room's humidity and temperature.

Covid-19 had an impact on the quantity of blood collected and used to feed the tsetse flies at the facility. First, there was a decrease in the quantity of blood collected, which could be explained by the COVID-19 restrictive measures, which led to a general lockdown, the IBD administration had to reduce the number of technicians involved in collection activities, as well as the frequency of collection. The number of cattle slaughtered each day also reduced, because many markets were closed due to the lockdown. As a result, led to an impact on the quantity of blood collected by the technicians in a collection session. The reduction in the quantity of blood collected had inevitably a negative impact on the quantity of blood used to feed the tsetse flies. There was a decrease from May to June, which corresponds to the start of the lockdown. As the quantity of blood was reduced, measures were taken by the administration to considerably reduce the quantity of blood required by reducing the frequency of feeding from 4 to 3 times a week, and by reducing the size of the colony in order to maintain it at a manageable size during the crisis. These measures have had a negative impact on the colony sizes of CIRDES and SEIBERSDORF strains, which have reduced considerably.

The decrease in the feeding frequency has undoubtedly led to a drop in the production of normal pupae in females and an increase in the production of soft pupae. These results corroborate the findings by Pagabeleguem et al. (2021) and Tsegaye et al. (2020) who observed also that only three blood meals per week affecting the mass rearing production (high mortality and low fecundity). Indeed, studies carried out at the Ethiopian Tsetse Eradication Project (STEP) facility on *Glossina palidipes* showed that the fecundity and survival of females were significantly lower under a feeding regime of three times a week than under a feeding regime of five times a week (Tsegaye et al. 2020). At the IBD, four blood meals per week have been administered to the all colonies since December 2018 (Pagabeleguem et al. 2021), however, Covid-19 restrictions again led to a reduction in feeding frequency to three, with the above-mentioned consequences for the colonies.

Normal pupae production by the CIRDES strain was almost double in comparison to of the SEIBERSDORF strain. Indeed, the CIRDES strain was the first to be established to the IBD at the start of rearing in 2016, with pupae from the CIRDES insectarium in the same locality in Bobo-Dioulasso. The SEIBERSDORF strain was therefore established from pupae received from the Insect Pest Control Laboratory (Seibersdorf, Austria) one year later. However, according to Toe et al. (2021), the SEIBERSDORF strain had better pupal productivity and survival than the CIRDES strain.

Under PATTEC initiative, the Government of Senegal initiated, tsetse flies eradication program in the Niayes area using area-wide integrated pest management approaches with the SIT component (Bouyer et al. 2010; Vreysen et al. 2021). For the SIT component, since 2017 an agreement was made with the IBD to mass-produce *G. palpalis gambiensis* in order to provide the Senegalese program with 50,000 sterile male pupae weekly (Pagabeleguem et al. 2021). The Covid-19 restrictions not only had an impact on the Senegalese project but also on the IBD financial capacities. With the reduction in colony size, the quantities of sterile pupae sent per week were considerably reduced, and worse, with the closure of the country borders, pupae delivery was interrupted.

In the absence of a significant correlation between production parameters and environmental factors, the decrease in the production of normal pupae and the increase in soft pupae may also be due to the quality of blood distributed to tsetse flies. To date, no data are available on the control of blood quality for drug residues. Previous studies has shown that antibiotic residues destroy intestinal and ovarian symbionts (*Wigglesworthia*, *Sodalis* and *Wolbachia*) (Itard et Bauer 1984), thus compromising the productivity and survival of female tsetse (Pais et al. 2008; Weiss et Aksoy 2011). It has been shown that female tsetse populations lacking *Wigglesworthia* become sterile and succumb rapidly to trypanosome infection, but this is not the case in males. Tsetse collection and feeding procedures can have a significant influence on the maintenance and production of female tsetse (FAO/IAEA 2006). In view of the above findings, measures must be taken to ensure good practices for the maintenance of a healthy tsetse colony. To achieve this, thorough testing must be carried out to ascertain the quality of the blood before feeding tsetse flies.

IBD is therefore obliged to collect as much blood as possible to be able to carry out various quality tests. This will also

make it possible to deal with any similar crisis, which almost halted the insectarium's activities, hence the negative impact on the colony.

Conclusion

The Covid-19 had a negative impact on various organisations around the world. The maintenance of the colony of the tsetse strains was affected by a decrease in the production of normal pupae and an increase in soft pupae, due to a reduction in the quantity and quality of blood distributed to the tsetse, combined with the reduced feeding frequency. To deal with similar crisis in the future, precautionary measures need to be taken by the IBD administration in collaboration with partners as the IBD plays a key role in the programme to eradicate animal trypanosomiasis and the tsetse fly in West African countries,.

Conflict of Interest

The authors declare that they have no competing interests

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References

Bauer, B., et H. Wetzel. 1976. « A New Membrane for Feeding *Glossina Morsitans* Westw. (Diptera, Glossinidae) ». *Bulletin of Entomological Research* 65 (4): 563-65. https://doi.org/10.1017/S0007485300006246.

Bouyer, Jérémy, Sophie Ravel, Laure Guerrini, Jean-Pierre Dujardin, Issa Sidibé, Marc J.B. Vreysen, Philippe Solano, et Thierry De Meeûs. 2010. « Population Structure of *Glossina Palpalis Gambiensis* (Diptera: Glossinidae) between River Basins in Burkina Faso: Consequences for Area-Wide Integrated Pest Management ». *Infection, Genetics and Evolution* 10 (2): 321-28. https://doi.org/10.1016/j.meegid.2009.12.009.

Cuisance, D, H Politzar, P Mérot, et I Tamboura. 1984. « Les lâchers de mâles irradiés dans la campagne de lutte intégrée contre les glossines dans la zone pastorale de Sidéradougou, Burkina Faso ». *Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux* 37 (4): 449-67.

De La Rocque, S, et D Cuisance. 2005. « La tsé-tsé : une mouche singulière et dangereuse ». *Insecte numéro* 136 (1): 27-31.

Delespaux, Vincent, Hunduma Dinka, Justin Masumu, Peter Van den Bossche, et Stanny Geerts. 2008. « Five-Fold Increase in *Trypanosoma Congolense* Isolates Resistant to Diminazene Aceturate over a Seven-Year Period in Eastern Zambia ». *Drug Resistance Updates* 11 (6): 205-9. https://doi.org/10.1016/j.drup.2008.10.002.

Dera, Kiswend-Sida Mikhailou, Bénéwendé Aristide Kaboré, Soumaïla Pagabeleguem, Abdoul Aziz Ouedraogo, Ange Irénée Toé, Mamadou Ira, Adrien Marie Gaston Belem, et Gisèle Marie Sophie Ouedraogo/Sanou. 2023. « Influence of Environmental Conditions on Mass Rearing Parameters of Tsetse Flies at the Bobo-Dioulasso Insectary (Burkina Faso): Retrospective Study ». *International Journal of Biological and Chemical Sciences* 17 (3): 1020-32. https://doi.org/10.4314/ijbcs.v17i3.21.

Duvallet, G., J. L. Frezil, et J. Itard. 2003. « Trypanosomoses : agents pathogènes ». In *Principales maladies infectieuses et parasitaires du bétail : Europe et régions chaudes : 1. Généralités, maladies virales : 2. Maladies bactériennes, mycoses, maladies parasitaires*, par P.C. Lefèvre, J Blancou, et R. Chermette, Editions Médicales Internationales, 1617-25. Cachan : Tec et Doc. Paris, France. https://www.documentation.ird.fr/hor/fdi:010031357.

FAO. 2002. « Twenty-second regional conference for Africa: Programme against African Trypanosomiasis (PAAT), Cairo, Egypt, 4-8 February 2002 ». ARC/02/REP. Cairo, Egypt.

FAO/IAEA. 2006. *Standard operating procedures for mass-rearing tsetse flies*. Vienna, Austria: IAEA. http://www-naweb.iaea.org/nafa/ipc/public/Tsetse_Rearing_SOP_web.pdf.

Feldmann, U. 1994. « Guidelines for the rearing of tsetse flies using the membrane feeding technique ». In *Techniques of insect rearing for the development of integrated pest and vector management strategies*, édité par J P R Ochieng'-Odero, 449-71. Nairobi, Kenya: ICIPE Science Press.

Geerts, S, P H Holmes, M C Eisler, et O Diall. 2001. « African Bovine Trypanosomiasis: The Problem of Drug Resistance ». *Trends in Parasitology* 17 (1): 25-28. https://doi.org/10.1016/S1471-4922(00)01827-4.

Hursey, B S, et J Slingenbergh. 1995. « The tsetse fly and its effects on agriculture in sub-saharan Africa ». *World Animal Review* 2: 67-73.

Itard, J., et B. Bauer. 1984. « Elevage des glossines. Synthèse ». *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux* 37 (N° spécial): 143-75.

Kabayo, John P. 2002. « Aiming to eliminate tsetse from Africa ». *Trends in parasitology* 18 (11): 473-75.

Mutika, G. N., Idrissa Kabore, Momar T. Seck, Baba Sall, Jérémy Bouyer, Andrew G. Parker, et Marc J.B. Vreysen. 2013. « Mating Performance of *Glossina Palpalis Gambiensis* Strains from Burkina Faso, Mali, and Senegal ». *Entomologia Experimentalis et Applicata* 146 (1): 177-85. https://doi.org/10.1111/j.1570-7458.2012.01305.x.

Ndiaga, Thiam. 2020. « Burkina Faso Confirms First Cases of Coronavirus ». World reppoter (Reuters). 22 mars 2020. https://www.usnews.com/news/world/articles/2020-03-09/burkina-faso-confirms-first-cases-of-coronavirus.

Pagabeleguem, Soumaïla, Oumar Koughuindida, Ernest Wendemanegde Salou, Geoffrey Gimonneau, Ange Irénée Toé, Bénéwendé Aristide Kaboré, Kiswend-sida Mikhailou Dera, et al. 2023. « Gamma-Radiation of *Glossina Palpalis Gambiensis* Revisited: Effect on Fertility and Mating Competitiveness ». *Parasite* 30: 8. https://doi.org/10.1051/parasite/2023009.

Pagabeleguem, Soumaïla, Momar T. Seck, Baba Sall, Marc J.B. Vreysen, Geoffrey Gimonneau, Assane G. Fall, Mireille

Bassene, et al. 2015. « Long Distance Transport of Irradiated Male *Glossina Palpalis Gambiensis* Pupae and Its Impact on Sterile Male Yield ». *Parasites & Vectors* 8 (1): 259. https://doi.org/10.1186/s13071-015-0869-3.

Pagabeleguem, Soumaïla, Ange Irénée Toé, Sié Hermann Pooda, Kiswendsida Mikhailou Dera, Abdou Salam Belem, Adrien Marie Gaston Belem, Gisèle Marie Sophie Ouedraogo/Sanou, et al. 2021. « Optimizing the feeding frequency to maximize the production of sterile males in tsetse mass-rearing colonies ». *PLOS ONE* 16 (1): e0245503. https://doi.org/10.1371/journal.pone.0245503.

Pais, R., C. Lohs, Y. Wu, J. Wang, et S. Aksoy. 2008. « The obligate mutualist *Wigglesworthia glossinidia* influences reproduction, digestion, and immunity processes of its host, the tsetse fly ». *Applied and Environmental Microbiology* 74 (19): 5965-74. https://doi.org/10.1128/AEM.00741-08.

Percoma, Lassané, Adama Sow, Soumaïla Pagabeleguem, Ahmadou H. Dicko, Oumarou Serdebéogo, Mariam Ouédraogo, Jean-Baptiste Rayaissé, Jérémy Bouyer, Adrien M. G. Belem, et Issa Sidibé. 2018. « Impact of an integrated control campaign on tsetse populations in Burkina Faso ». *Parasites & Vectors* 11 (1): 270. https://doi.org/10.1186/s13071-017-2609-3.

Politzar, H, et D Cuisance. 1984. « An integrated campaign against riverine tsetse flies *Glossina palpalis gambiensis* and *Glossina tachinoides* by trapping and the release of sterile males. » *Insect science and application* 5: 439-42.

R Core Team. 2019. *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. Vienna, Austria. http://www.r-project.org/index.html.

Sellin, E., G. Bourdoiseau, Dominique Cuisance, Jacques Février, et H. Politzar. 1979. « Effets sur *Glossina palpalis gambiensis* de substances médicamenteuses administrées au lapin hôte-nourricier. Deuxième partie ». *Revue d'élevage et de médecine vétérinaire des pays tropicaux* 32 (mars): 267. https://doi.org/10.19182/remvt.8152.

Swallow, B M. 1997. « Impacts of trypanosomosis on African agriculture: Programme against African trypanosomosis (PAAT) ». Maputo, Mozambique: PAAT.

Swallow, Brent M. 1999. « Impacts of trypanosomiasis on African agriculture ». *Rome: FAO*. http://www.fao.org/waicent/FAOINFO/Agricult/AGAInfo/programmes/en/paat/documents/papers/Paper_1999.pdf.

Takken, V., M. A. Oladunmade, L. Dengwat, H. U. Feldmann, J. A. Onah, S. O. Tenabe, et H. J. Hamann. 1986. « The eradication of *Glossina palpalis palpalis* (Robineau-Desvoidy) (Diptera: Glossinidae) using traps, insecticide-impregnated targets and the sterile insect technique in central Nigeria ». *Bulletin of Entomological Research* 76 (02): 275. https://doi.org/10.1017/S0007485300014747.

Tsegaye, Mintesnot, Behablom Meharenet, Tekaligni Desta, Bekele Lema, Tazezew Desalegni, et Dessalew Shitu. 2020. « Feeding Frequency and its Related Effect on Productivity and Survival Rate of *Glossina Pallidipes* in Kality Tsetse Mass Rearing and Production Center for the Purpose of Sterile Insect Technique (SIT) ». *Biomedical Journal of Scientific & Technical Research* 28 (1): 21313-23. https://doi.org/10.26717/BJSTR.2020.28.004604.

Vreysen, Marc J.B., Khalfan M. Saleh, Mashavu Y. Ali, Abdulla M. Abdulla, Zeng-Rong Zhu, Kassim G. Juma, Arnold V. Dyck, Atway R. Msangi, Paul A. Mkonyi, et Udo Feldmann. 2000. « *Glossina Austeni* (Diptera: Glossinidae) Eradicated on the Island of Unguja, Zanzibar, Using the Sterile Insect Technique ». *Journal of Economic Entomology* 93 (1): 123-35. https://doi.org/10.1603/0022-0493-93.1.123.

Vreysen, Marc J.B., M. Seck, Baba Sall, Abdou Mbaye, M. Bassene, Assane Fall, M. Lo, et Jérémy Bouyer. 2021. « Area-Wide Integrated Management of a *Glossina palpalis gambiensis* Population from the Niayes Area of Senegal: A Review of Operational Research in Support of a Phased Conditional Approach ». In *Area-Wide Integrated Pest Management: Development and Field Application*, par J. Hendrichs, R. Pereira, et M. J. B. Vreysen, 275-303. Boca Raton, Florida, USA: CRC Press.

Vreysen, Marc J.B., Momar T. Seck, Baba Sall, et Jérémy Bouyer. 2013. « Tsetse Flies: Their Biology and Control Using Area-Wide Integrated Pest Management Approaches ». *Journal of Invertebrate Pathology* 112: 15-25. https://doi.org/10.1016/j.jip.2012.07.026.

Weiss, Brian, et Serap Aksoy. 2011. « Microbiome Influences on Insect Host Vector Competence ». *Trends in Parasitology* 27 (11): 514-22. https://doi.org/10.1016/j.pt.2011.05.001.

Willy, Daniel Kyalo, Yacouba Diallo, Hippolyte Affognon, Francis Nang'ayo, Michael Waithaka, et Tesfamicheal Wossen. 2020. « COVID-19 Pandemic in Africa: Impacts on Agriculture and Emerging Policy Responses for Adaptation and Resilience Building. » Working paper WP01/2020. The Technologies for African AgriculturalTransformation (TAAT) Policy Compact. https://www.aatf-africa.org/wp-content/uploads/2021/02/TAAT-Policy-Working-Paper-on-COVID19_FINAL-for-Dissemination_May-2020.pdf.