A brief review of forensically important flesh flies (Diptera: Sarcophagidae)

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ABSTRACT
Forensic entomology could provide valuable data for the minimum postmortem interval (PMImin) estimation and other relevant information, such as causes and circumstances of death. Some representatives of flesh flies are one of the dominant necrophagous insects during early stages of decomposition, demonstrating unique biological characteristics compared with other necrophagous flies. Moreover, they lead to global health concerns as carriers of various pathogenic micro-organisms, and dominantly result in the traumatic myiasis. Thus, sarcophagid flies are considered important in decomposition processes for PMImin estimation. However, the utility of sarcophagid flies has been seriously hampered by limited ecological, biological and taxonomic knowledge of them. The aim of this paper is to provide a brief review on the species, distribution and biological habit of forensically important sarcophagid flies. In addition, the relation between traumatic myiasis and flesh flies, molecular identification methods and developmental pattern of flesh flies are summarized.

Introduction
The correct sampling, measuring and subsequent interpretation of the insects found on decomposed remains would provide valuable information in forensic science, such as the minimum postmortem interval (PMImin), the causes and circumstances of the death, toxification and human DNA from the gut of the larvae [1,2]. By determining the developmental stage of necrophagous insects colonized on decomposed remains and the initial colonization timeframes, the PMImin estimation for decomposed corpses is relatively accurate [3]. The common necrophagous insects are Diptera order, mainly including Sarcophagidae, Calliphoridae and Muscidae family, which are critically important in forensic investigations [4–6].

Sarcophagid flies (known as flesh flies) visiting a corpse mostly belong to the synanthropic dement of subtropical or even tropical origin, which constitute a part of the insect faunal succession representing actually the first and very important destruction stage responsible for the essential decomposition [7–9]. Nevertheless, compared with other fly species, sarcophagids have unique characteristics facilitating the estimation of PMImin. First, many flesh flies are well known for adopting the reproductive strategy of ovoviviparity (or ovolarviparity); they deposit maggots directly on a corpse instead of eggs [4,9,10]. Second, they are more observable than others because of the larger size [5,7,11]. Third, sarcophagid flies are more active in various decay stages of corpses [6,8,12]. Moreover, they may play important role in decomposition of buried carrion since they are more efficient colonizers for these types of substrates than blowflies [13,14].

As mentioned above, sarcophagid flies should be widely applied to estimate the PML whereas in forensic investigations, it is severely limited by the insufficientness of systematic studies on the taxonomic features and inadequate documentation of their thermobiological histories. Establishment of detailed database on the flesh flies is vitally important. Hence, the aim of this review is to provide a comprehensive review on the species and distribution of sarcophagid species in forensic investigations, especially in indoor cases. Besides, reports of traumatic myiasis caused by sarcophagid species, the effect of drugs on the growth rates of flesh flies, species identification and the developmental pattern of flesh flies are summarized.

Species diversity and distribution of flesh flies
Sarcophagid flies distribute worldwide, and consist of more than 100 genera and 2 600 species, among which approximately 800 species belong to the genus Sarcophaga [5,7,8,11,15,16]. Since the dominant species vary significantly with geographic region and climate [10], insect faunal succession on decaying carcasses concerning flesh flies were currently performed, e.g. in Finland, Switzerland, Portugal, Germany, Poland, Spain, Italy,
The geographic region or biogeoclimatic zone has a major impact on the species of insects existed on a corpse. For instance, *Sarcophaga africa* (Wiedemann), *Sarcophaga argyrostoma* (Robineau-Desvoidy), *Sarcophaga caerulescens* Zetterstedt, *Sarcophaga dux* Thomson, *Sarcophaga melanura* Meigen and *Sarcophaga similis* Meade are dominant species in Europe (e.g. Finland, Switzerland, Germany, Spain and Poland) [10,17–20]. The species of *Sarcophaga peregrina* (Robineau-Desvoidy), *Sarcophaga ruficornis* (Fabricius) and *Sarcophaga taenionota* Wiedemann are widely distributed in China and Malaysia [12,21–26]. *Sarcophaga albiceps* Meigen is extensively found in Asia (e.g. China, India and Malaysia) [9,12,22,26], and Europe (e.g. Germany and Poland) [10,17]. *Sarcophaga crassipalpis* Macquart is widespread in Spain, Australia and China. *Wohlfahrtia nuba* (Wiedemann) is frequently recorded in the Middle East (e.g. Egypt and Kuwait) [27,28]. Moreover, a new record of *Sarcophaga caullertata* Pandelle was identified at preimaginal stages collected in autopsies performed in Spain, which is reported for the first time in human corpses [29]. The detailed summary is shown in Table 1.

The diversity and abundance of biases towards flesh flies may be explained by habitat preferences, as they are strongly synanthropic [10,17]. Fremdt and Amendt [17] demonstrated that *Sarcophaga subvicina* Baranov, and *Sarcophaga variegata* (Scopoli) could serve as indicators of urban habitats during summer and *S. albiceps* as indicator of rural habitats in Frankfurt, Germany. A significant association of *S. caerulescens* with rural habitats as well as *S. similis* with urban habitats was observed [17]. Geographical region has obvious influence on arrival time of different species of insects, suggesting that data generated in one region or biogeoclimatic zone cannot be used as a direct reference to estimate the PMI in a different region. It is recommended that databases should be developed for every biogeoclimatic zone in which insects are used to estimate the time of colonization.

**Effect of indoor environment on flesh flies**

Flesh flies were widely reported to colonize on indoor corpses, which may be due to the special biological features [30,46–48]. In recent years, flesh flies were frequently found to invade corpses in indoor cases, which were mainly reported in Japan, Southern Finland, Switzerland, Spain, Australia, Brazil, United States, Malaysia, Italy, Poland and China. In Switzerland, *S. caerulescens*, *S. similis* and *S. africa* have been reported to be the dominant species colonizing on the corpses in indoor cases, and *S. argyrostoma* was commonly found indoors during summer [19]. Meanwhile, the involvement of *S. argyrostoma* in indoor cases has also been reported in Poland [49]. In Italy, *S. africa* was also recorded in indoor cases [45]. However, it should be treated with caution when estimating the *PMI_{min}* according to the developmental data of the larvae of *S. africa* on human corpses, as it is well known that this fly prefers to larviposit of faeces [50]. Moreover, *S. caerulescens* was dominant species found in indoor corpses in Finland [39]. In conclusion, *S. peregrina*, *S. ruficornis* and *S. (Liosarcophaga) tibialis* Macquart were often reported in China, Spain and Australia, respectively [20,24,26]. *Sarcophaga crassipalpis* and *Sarcophaga impatiens* Walker were also found to colonize on the corpses at the earliest stage of decomposition in Australia [24].

Additionally, Syamsa et al. [43] reported the occurrence of flesh flies at higher altitudes. Unfortunately, the authors failed to identify them to the species level because of insufficient taxonomical studies regarding the larvae of this taxon. In summary, more than 10 common species of flesh flies typically colonize on indoor cadavers, including *S. africa*, *S. argyrostoma*, *S. caerulescens*, *S. crassipalpis*, *S. peregrina*, *S. ruficornis*, *S. similis*, etc. (Table 1). Even so, the insufficient taxonomic and developmental data of flesh flies severely limit their application in the PMI estimation compared with blowflies.

**Influence of drugs on flesh flies**

Certain cases of drug-related deaths occurred in concealed places, particularly for solitary victims. The cadavers are usually found at the later stages of decomposition. Although it is difficult to estimate the PMI according to the postmortem phenomena, forensic entomology has unique advantages in such cases [51–59], whereas, if the effects of drugs on the developmental pattern of flies are not taken into account, misestimate of PMI might occur. Therefore, knowledge of various drugs on the development of immature carrion-breeding insects could be potentially valuable in redefining the PMI estimation, which involves deducing minimum and maximum PMI [60].

Drugs can affect the developmental pattern of flesh flies, potentially leading to the misestimation of PMI. As early as 1989–1991, Goff et al. [55,56] reported that cocaine and heroin residues and metabolites accelerated the development of the larvae of *S. peregrina*. Later, Goff et al. [57,61] reported again that higher concentrations of methamphetamine (‘ice’) accelerated the development of *S. ruficornis*, and lower concentrations of 3, 4-methylenedioxymethamphetamine (MDMA) delayed the larval development of the same species. Whereas, puparial durations of *S. ruficornis* were significantly longer for the colonizers fed on tissues from the rabbits receiving the high concentrations of amitryptiline and phencyclidine [58,59]. These effects could potentially lengthen the PMI estimation.
Table 1. The common species and distribution of forensically important flesh flies.

| No | Species                        | Location                          | Animal model          | Habitat                          | Date of collection | References |
|----|--------------------------------|-----------------------------------|-----------------------|----------------------------------|--------------------|------------|
| 1  | Boettcherisca higlondica       | Malaysia (Pahang)                 | Rabbits              | Highland                         | Unstated           | [12]       |
| 2  | Blaesoxipha plinthoppyga       | USA (Idaho)                       | Human                | Mountain                         | August 2002       | [30]       |
| 3  | Liocarcophaga babiyari         | Saudi Arabia (Al-Baha)            | Rabbits              | Mountain                         | Unstated           | [31]       |
| 4  | Oxysarcodesia intero           | Brazil (Maranhão)                 | Baited traps         | Outdoor                          | 2009–2012          | [32]       |
| 5  | Oxysarcodesia rograndensisis  | Brazil (Pernambuco)               | Human                | Rural                            | 2008               | [34]       |
| 6  | Oxysarcodesia thorax           | Brazil (Maranhão)                 | Baited traps         | Outdoor                          | 2009–2012          | [32]       |
| 7  | Peckia chrysostoma             | Brazil (Pernambuco)               | Male cadaver         | Indoor                           | July 2012          | [36]       |
| 8  | Peckia (Squamatodes) ingens    | Brazil                             | Baited traps         | Outdoor                          | 2009–2012          | [32]       |
| 9  | Peckia (Sarcodesia) lambens    | Brazil                             | Baited traps         | Outdoor                          | 2009–2012          | [32]       |
| 10 | Ravinia belforti (Prado & Fonseca) | Brazil (Pernambuco)               | Human corpse         | Rural                            | 2008               | [34]       |
| 11 | Ravinia pernix (Harris)        | Saudi Arabia (Riyadh)             | Rabbits              | Agricultural/desert/urban area   | June 2014          | [37]       |
| 12 | Sarcophaga aegyptiaca "Salem"  | Egypt (El-Qalyubiya)              | Rabbit               | House                            | August–September 2008 | [27]       |
| 13 | Sarcophaga albiceps Meigen     | China (Zhongshan)                 | Pigs                 | Outdoor                          | December 2003–October 2004 | [22]       |
| 14 | Sarcophaga afric "(Wiedemann)  | Switzerland (canton de Vaud)      | Human                | Indoor                           | Unstated           | [19]       |
| 15 | Sarcophaga angrostroma "(Robineau-Desvoidy)" | Switzerland (canton de Vaud) | Human               | Indoor                           | Unstated           | [19]       |
| 16 | Sarcophaga caerulescens "Zetterstedt" | Southern Finland (Turku) | Human               | Indoor                           | Unstated           | [39]       |
| 17 | Sarcophaga carnaria (Linnaeus) | Germany (Frankfurt)               | Baited traps         | Rural                            | September 2008–May 2011 | [17]       |
| 18 | Sarcophaga crassipes "Macquart" | Spain (Alcala de Henares)         | Man, pig and rabbit  | Forest                           | September 2006     | [20]       |
| 19 | Sarcophaga culellata Pandelle   | Switzerland (canton de Vaud)      | Human                | Outdoor                          | Unstated           | [19]       |
| 20 | Sarcophaga dux Thomson         | India (Punjab)                    | Mutton               | Wooden platform                  | September 2005     | [38]       |
| 21 | Sarcophaga hirtipes Wiedemann  | India (Punjab)                    | Rabbits              | Agricultural/desert/urban area   | June 2014          | [37]       |

(continued)
up to 70 h [58]. In South Africa, Musvasva et al. [53] demonstrated that the larvae of *S. tibialis* exposed to the hydrocortisone and sodium methohexital took significantly longer time to reach pupation compared with those in the control while the larvae exposed to sodium methohexital passed through pupation significantly faster than those in the control. Yet, no systematic relationship was found between drug concentration and developmental time of larvae or pupae. The total developmental period from hatching to eclosion did not differ after drug treatments, implying that estimation of the PMI based on the emergence of adult flies will not be affected by the involvement of these drugs in a case. On the other hand, anomalous pupation spans might indicate the presence of barbiturates. Recently in China, Zhang et al. [62] explored that the larvae of *S. crassipalpis* grew faster with the increased concentration of morphine hydrochloride. Moreover, Goff et al. [55,56,58] also emphasized the need for studies on the effects of more drugs on the development of various species of necrophagous flies. Thus, further analyses involving different fly species, drug types, concentrations and means of administration should be undertaken to establish a systematic database in support of criminal investigations.

Besides, sarcophagids and their remains could be used for entomological toxicology (entomotoxicology) analyses. Entomotoxicology is the science studies the potential use of insects for detecting drugs or other toxic substances that may not be measurable in decomposing tissues. Necrophagous insects, feeding on the decomposing remains, accumulate toxins present in their food

Table 1. (Continued)

| No  | Species                   | Location                        | Animal model | Habitat                     | Date of collection          | References |
|-----|---------------------------|---------------------------------|--------------|-----------------------------|-----------------------------|------------|
| 22  | *Sarcophaga impatiens* Walker | Australia (Queensland)          | Human        | Indoor                      | December 2011–January 2014  | [24]       |
| 23  | *Sarcophaga melanura* Meigen | Poland (Alcalá de Henares)      | Pig          | Forest and grassland        | October 2005–September 2006 | [10]       |
|     |                           | Spain (Alcalá de Henares)       | Carrion-baited traps | Periurban                  | Unstated                   |            |
| 24  | *Sarcophaga peregrina* (Robineau-Desvoidy) | China                          | Human, Man, pig and rabbit | River, Forest          | July 2010–August 2013       |            |
|     |                           |                                |              |                             | Unstated                   |            |
| 25  | *Sarcophaga praealatrix* Walker | Australia (Queensland)          | Human        | Grassland                   | 2011–2012                   |            |
| 26  | *Sarcophaga princeps* Wiedemann | Malaysia                      | Human, Rabbits | Outdoor                    | July 2007–July 2010         |            |
|     |                           |                                |              |                             | Unstated                   |            |
| 27  | *Sarcophaga ruficornis* (Fabricius) | Australia (Queensland)     | Human        | Indoor                      | December 2011–January 2014  | [24]       |
|     |                           |                                |              |                             | Unstated                   |            |
| 28  | *Sarcophaga similis* Meade | Switzerland (canton de Vaud)    | Human        | Indoor                      | Unstated                   | [19]       |
|     |                           | Poland (Biedrasko)             | Pigs         | Grassland                   | Unstated                   | [34]       |
|     |                           | Germany (Frankfurt)           | Baited traps | Urban                      | Unstated                   | [17]       |
| 29  | *Sarcophaga subvicina* Baranov | Germany (Frankfurt)          | Baited traps | Rural                      | September 2008–May 2011    |            |
| 30  | *Sarcophaga taenionota* Wiedemann | China (Zongshan)          | Pigs         | Outdoor                     | December 2003–October 2004 | [22]       |
| 31  | *Sarcophaga tibialis* Macquart | Malaysia (Pahang)         | Rabbits      | Rural/highland              | Unstated                   | [12]       |
|     |                           | Spain (Alcalá de Henares)     | Carrion-baited traps | Indoor                   | Unstated                   |            |
| 32  | *Sarcophaga variegata* (Scopoli) | Germany (Frankfurt)         | Baited traps | Rural                      | September 2008–May 2011    | [17]       |
| 33  | *Sarcophaga spp.*         | Malaysia                       | Human        | Indoor (high-rise buildings) | 2009–2010                   | [42]       |
|     |                           |                                |              | Indoor                      | July 2007–July 2010         | [25]       |
|     |                           |                                |              | Indoor                      | 2015                       |            |
|     |                           |                                |              | Indoor                      | January 2010–December 2013 | [44]       |
| 34  | *Tricharca occidua* (Fabricius) | Italy (Tuscany)              | Baited traps | Indoor                      | 2009–2010                   | [45]       |
| 35  | *Wohlfahrtia nube* (Wiedemann) | Kuwait                        | Rabbits      | Outdoor                     | 2009                       | [28]       |

The common species and distribution of flesh flies with indoor activity habits.
substances. These insects, in some cases, provide a more reliable and sensitive result than traditional analytical methods dealing with decomposed tissues [52].

**Relation between traumatic myiasis and flesh flies**

Myiasis is the invasion of tissues and organs both in humans and animals by dint of the larvae of sarcosaphrophagous flies. Those larvae feed on the host tissues, body fluids, or ingested food as parasites in the skin, subcutaneous tissues, mouth, stomach, eyes, nose, ears, intestines, urinogenital system, and other soft tissues of humans and warm-blooded vertebrate animals [63]. Relevant cases were mainly reported in Europe and Asia at present. In humans and animals, sarcophagid species have been reported to cause myiasis in ophthalmic, nasal, urinogenital, aural, cutaneous, oral and gastrointestinal cases [64–89]. Accordingly, it is crucial to exclude traumatic myiasis in the PMI estimation based on the development of sarcosaphrophagous flies [63]. Investigations illustrated that the most common species causing traumatic myiasis is Wohlfahrtia magnifica Schiner, Wohlfarth’s wound myiasis fly, the third of the most important obligatory traumatic myiasis agents [63,90]. Besides, the common sarcophagid species causing myiasis also includes S. africana, S. argyrostoma, S. crassipalpis and S. ruficornis.

Traumatic myiasis caused by sarcophagid species is extensively reported as the consequence of ignorance and can be used as an indicator of wound care neglect, either by oneself or by the nurses [63]. Obviously, criminal investigations require more researches involving various fly species and means of administration to establish a systematic database.

**Species identification of flesh flies**

Although the species of sarcophagids can be identified by their morphological characteristics of male terminalia, they present as being very numerous and diverse [10,91,92]. Thus, species identification based on morphological methods requires specialized taxonomic knowledge, only a few specialists are able to identify larvae of forensically relevant insects to species level [13,93]. To implement the use of sarcophagids for PMI estimation, a method for easy and accurate species-level identification at any life stage is required. DNA-based method is an alternative method proposed to identify species credibly and rapidly with lower requirement of sample preservation. DNA sequence data would serve as standards for further analysis [94]. Phylogenies also improve the understanding of the taxonomy and systematics of flesh flies [95–99].

At present, the partial genes of mitochondrial genome have been broadly applied to the species-level identification, mainly including the different fragments of Cytochrome c oxidase subunit I (COI) gene [94,95,100–115], in addition to the Cytochrome c oxidase subunit II (COII) gene [108–113], 16S ribosomal RNA (16S rRNA) [108–119], 12S ribosomal RNA (12S rRNA) [119], the nicotinamide adenine dinucleotide (NADH) dehydrogenase subunit 5 [108,109], the ribosomal internal transcribed spacer regions [119,120] and the nuclear period and 28S rRNA genes [111,112] (Table 2). Although these markers could be potentially served as discriminatory tools in identification of forensically important flesh flies, available gene sequences are deficient in the species-level identification of Sarcophagidae on GenBank databases, such as a flaw of insufficient discrimination power in utility of short gene fragments. The use of complete gene remains time-consuming and has a higher requirement for the preservation quality of specimens [104]. Until recently, a set of 4-SNP marker system has been developed for the identification of forensically important sarcophagid flies using the Pyrosequencing (PSQ) method, which showed high discriminating power, specificity of PCR amplification and particular advantages for degraded insect samples [121].

Due to the recent burst of development in forensic sciences, new court criteria require the evaluation of scientific evidence prior to its submission to the court [122]. Limitation of individual gene for species identification has been illustrated by recent studies [111,123]. Combined use of multiple genes is more valuable for evolutionary analysis and closely related species. To raise the identification efficiency of certain genes, the molecular markers still require further screening and optimization. Meanwhile, it is necessary to explore accurate, rapid and reliable species determination methods that are relatively insensitive to sample preservation so as to improve the application of flesh flies in forensic investigations.

**Developmental pattern of flesh flies**

Generally, the developmental pattern of flesh flies is in a predictable manner under controlled temperature [93]. To ensure accurate PMImin estimation, it is particularly important to collect precise basic data on the developmental pattern of flesh flies [124]. In 1994, Amoudi et al. [125] explored that the developmental time of S. ruficornis at constant temperatures varying from 13 °C to 37 °C, indicating that the optimal temperature in terms of rapid development, low mortality and greatest weight was from 22 °C to 28 °C. In 1998, Byrd and Butler [126] reported that the developmental durations from first instar to adult for the larva and pupa of S. haemorrhoidalis (Fallen) ranged from 252 h to 802 h under cyclic temperatures with means of 15.6 °C, 21.1 °C, 26.7 °C and 35 °C, and a constant temperature of 25 °C. In 2002, Grassberger and Reiter [127] studied the total developmental time of S. argyrostoma from larviposition to adult...
emergence was from (54.9 ± 1.45) to (14.9 ± 0.4) days reared at six constant temperature regimes (8 °C–35 °C), respectively. Moreover, the minimum development threshold for total immature development is 7.4 °C. In 2014, Mariana et al. [128] explored the rates of development, viability and survival of immature *S. rufigenus* and *Microcerella halli* (Engel) that were reared at different temperatures, demonstrating that the range of optimum temperature for *S. rufigenus* was between 20 °C and 35 °C, and that for *M. halli* was between 20 °C and 25 °C. Furthermore, for both species, the longest time of developmental duration was at the lowest temperature, and the survival rate was lower at extreme temperatures (10 °C and 35 °C). In 2017, Wang et al. [129] reported that the developmental durations of *S. peregrina* at seven constant temperatures (16 °C–34 °C) ranged from (1.064.7 ± 34.8) to (258.0 ± 3.5) h. Moreover, the developmental threshold temperature of *S. peregrina* was (10.87 ± 0.49) °C, and the thermal summation constant was (5 809.7 ± 291.4) degree days. In the same year, Yang et al. [130] investigated the development patterns of *S. similis* which was reared at nine constant temperatures ranging from 15 °C to 35 °C (Table 3).

In conclusion, the developmental duration of *S. rufigenus* from Central Arabian Peninsula is longer than that from south-eastern Brazil even at the same

| No | DNA region | Amplified fragment length (bp) | Primer ID and sequences | Collection location | References |
|----|------------|--------------------------------|-------------------------|---------------------|------------|
| 1  | COI        | 783                            | Unstated                | USA                 | [94]       |
| 2  | COI        | 278                            | C1-J-2495: 5'-CAGCTACATTATGAGCTTTAGG-3' | Australia           | [95]       |
| 3  | COI        | 304                            | C1-N-2800: 5'-CATTICAGCTGTGAAGACTC-3' | Japan               | [108]      |
| 4  | COI        | 658                            | 5'-CAGCTACATTATGAGCTTTAGG-3' | Japan               | [108]      |
| 5  | COI        | 304                            | 5'-CATTICAGCTGTGAAGACTC-3' | China and Egypt     | [103]      |
| 6  | COI        | 127/658                        | TY-J-1460: TACAATTTATGCTAAACTTCAGTCATCT-3' | West Europe         | [104]      |
| 7  | COI        | 272/173                        | 5'-CAGATCGAATTTAATATACCTC-3' | Egypt and China     | [105]      |
| 8  | COI        | 465                            | 5'-CAGCTACATTATGAGCTTTAGG-3' | Thailand            | [112]      |
| 9  | COI        | 400                            | 5'-CATTICAGCTGTGAAGACTC-3' | Brazil              | [107]      |
| 10 | COI + NDS  | 296 ± 386                      | COI: 5'-CAGCTACATTATGAGCTTTAGG-3' | Germany             | [108]      |
| 11 | COI + 16S rDNA | 278 ± 289                   | COI: 5'-CATTICAGCTGTGAAGACTC-3' | China               | [110]      |
| 12 | COI + period | 700 ± 678                     | COI: 5'-CATTICAGCTGTGAAGACTC-3' | China               | [111]      |
| 13 | COI + 28S rDNA | Unstated                     | 5'-CATTICAGCTGTGAAGACTC-3' | Thailand            | [112]      |
| 14 | COI        | 189                            | 5'-CAGCTACATTATGAGCTTTAGG-3' | China               | [116]      |
| 15 | COI        | 635                            | 5'-CAGCTACATTATGAGCTTTAGG-3' | Egypt and China     | [117]      |
| 16 | COI + 16S rDNA | 637 ± 555                   | 5'-CAGCTACATTATGAGCTTTAGG-3' | China               | [118]      |
| 17 | COI + COI  | 2300                           | TY-J-1460: TACAATTTATGCTAAACTTCAGTC-3' | Malaysia           | [111]      |
| 18 | COI + COI  | 1300                           | TY-J-1460: TACAATTTATGCTAAACTTCAGTC-3' | Malaysia           | [114]      |
| 19 | 125 and 16S rDNA + ITS | 1172 + 1500                   | 5'-CAGCTACATTATGAGCTTTAGG-3' | Egypt and China     | [115]      |
| 20 | ITS2       | Unstated                       | mtD-33F: 5'-ATGTTTATGTTAAACAGGCC-3' | Malaysia           | [119]      |
| 21 | MtSNP markers | <150                      | 5'-CAGCTACATTATGAGCTTTAGG-3' | China               | [120]      |

**Table 2.** DNA-based identification of forensically important Sarcophagid flies.

In conclusion, the developmental duration of *S. rufigenus* from Central Arabian Peninsula is longer than that from south-eastern Brazil even at the same...
Temperature [125,128]. At the constant temperature of 25 °C, the developmental duration of *S. ruficornis* is distinctly longer than that of *S. similis* [125,130]. Accordingly, the developmental durations of flesh flies should be related to the diversity of geography and climate in addition to the temperature and species. Therefore, further analysis of the developmental pattern of flesh flies at various temperatures in different geographic locations could improve the value of flesh flies in forensic investigations.

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### Compliance with Ethical Standards

This article does not contain any studies with human participants or animals performed by any of the authors.

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References

[1] Manhoff DT, Hood I, Caputo F, et al. Cocaine in decomposed human remains. J Forensic Sci. 1991;36:1732–1735.

[2] Wells JD, Introna FJ, Di Vella G, et al. Human and insect mitochondrial DNA analysis from maggots. J Forensic Sci. 2001;46:685–687.

[3] Amendt J. Forensic entomology. Forensic Sci Res. 2017. DOI:10.1080/20961790.2017.1403081

[4] Byrd JH, Castner JL. Forensic entomology – the utility of arthropods in legal investigation. 2nd ed. Boca Raton (FL): CRC Press; 2010.

[5] Cai JF. Forensic entomology. Beijing: People’s Medical Publishing House; 2015.

[6] Anderson G, VanLaerhoven SL. Initial studies on insect succession on carrion in Southwestern British Columbia. J Forensic Sci. 1996;41:617–625.

[7] Pape T. Catalogue of the Sarcophagidae of the world (Insecta: Diptera). Florida, Gainesville: Associated Publishers. Mem Entomol Inter. 1996:8:1–558.

[8] Povolny D, Verves YG. The flesh-flies of central Europe (Insecta, Diptera, Sarcophagidae). Spixiana Suppl. 1997:24:1–260.

[9] Singh D, Bharti M. Some notes on the nocturnal larvae of species of Sarcophaga (Diptera: Sarcophagidae). Forensic Sci Int. 2008;177:19–20.

[10] Szpila K, Mądra A, Jarmusz M, et al. Flesh flies (Diptera: Sarcophagidae) colonizing large carcasses in central Europe. Parasitol Res. 2015;114:2341–2348.

[11] Tomberlin JK, Benbow ME. Forensic entomology international dimensions and frontiers. Boca Raton (FL): CRC Press; 2015.

[12] Silahuddin SA, Latif B, Kurahashi H, et al. The Importance of habitat in the ecology of decomposition on rabbit carcasses in Malaysia: implications in forensic entomology. J Med Entomol. 2015:52:9–23.

[13] Szpila K, Voss JG, Pape T. A new dipteran forensic indicator in buried bodies. Med Vet Entomol. 2010;24:278–283.

[14] Pastula EC, Merritt RW. Insect arrival pattern and succession on buried carrion in Michigan. J Med Entomol. 2013;50:432–439.

[15] Hu C. Forensic entomology. Chongqing: Chongqing Publishing House; 2000.

[16] Chen LS. The necrophagous flies of China (Insecta, Diptera). Vol. 9, Guizhou, Guiyang: Guizhou Publishing Group; 2013.

[17] Fremdt H, Amendt J. Species composition of forensically important blow flies (Diptera: Calliphoridae) and flesh flies (Diptera: Sarcophagidae) through space and time. Forensic Sci Int. 2014;236:1–9.

[18] Matuszewski S, Frątczak K, Konwerski S, et al. Effect of body mass and clothing on carrion entomofauna. Int J Legal Med. 2016;130:221–232.

[19] Cherix D, Wyss C, Pape T. Occurrences of flesh flies (Diptera: Sarcophagidae) on human cadavers in Switzerland, and their importance as forensic indicators. Forensic Sci Int. 2012;220:1–3.

[20] Baz A, Botías C, Martíneva D, et al. Preliminary data on carrion insects in urban (indoor and outdoor) and periurban environments in central Spain. Forensic Sci Int. 2014;248:41–47.

[21] Wang Y, Ma MY, Jiang XY, et al. Insect succession on remains of human and animals in Shenzhen, China. Forensic Sci Int. 2017;271:75–86.

[22] Wang J, Li Z, Chen Y, et al. The succession and development of insects on pig carcasses and their significances in estimating PMI in south China. Forensic Sci Int. 2008;179:11–18.

[23] Liu Y, Chen Y, Guo Y, et al. Estimation of post-mortem interval for a drowning case by using flies (Diptera) in Central-South China: implications for forensic entomology. Rom J Leg Med. 2013;21:293–298.

[24] Farrell JF, Whittington AE, Zalucki MP. A review of necrophagous insects colonising human and animal cadavers in south-east Queensland, Australia. Forensic Sci Int. 2015;257:149–154.

[25] Kumara TK, Disney RH, Abu HA, et al. Occurrence of oriental flies associated with indoor and outdoor human remains in the tropical climate of north Malaysia. J Vector Ecol. 2012;37:62–68.

[26] Chen LS. Experimental study on postmortem interval with the invasion of sarcosaphagous insects on cadavers in different environments. Chin J Forensic Med. 2000;15:157–160.

[27] Abd El-bar MM, Sawaby RF. A preliminary investigation of insect colonization and succession on remains of rabbits treated with an organophosphate insecticide in El-Qalyubiyah Governorate of Egypt. Forensic Sci Int. 2011;208:26–30.

[28] Al-Meshah H, Moffatt C, El-Azazy OM, et al. The decomposition of rabbit carcasses and associated necrophagous Diptera in Kuwait. Forensic Sci Int. 2012;217:27–31.

[29] Velásquez Y, Magaña C, Martínez-Sánchez A, et al. Diptera of forensic importance in the Iberian Peninsula: larval identification key. Med Vet Entomol. 2010;24:293–308.

[30] Wells JD, Smith JL. First report of Blaesoxipha plinthopyga (Diptera: Sarcophagidae) from a human corpse in the U.S.A. and a new state geographic record based on specimen genotype. J Forensic Sci. 2013;58:1378–1380.

[31] Abouzied EM. Insect colonization and succession on rabbit carcasses in southwestern mountains of the kingdom of Saudi Arabia. J Med Entomol. 2014;51:1168–1174.

[32] de Sousa JR, Carvalho-Filho Fda S, Esposito MC. Distribution and abundance of necrophagous flies (Diptera: Calliphoridae and Sarcophagidae) in Maranhão, Northeastern Brazil. J Insect Sci. 2013;15:15:15.

[33] Vasconcelos SD, Cruz TM, Salgado RL, et al. Diptera associated with a decomposing animal carcass in a rainforest fragment in Brazil: notes on the early arrival and colonization by necrophagous species. J Insect Sci. 2013;13:14:45.

[34] Oliveira TC, Vasconcelos SD. Insects (Diptera) associated with cadavers at the Institute of Legal Medicine in Pernambuco, Brazil: implications for forensic entomology. Forensic Sci Int. 2010;198:97–102.

[35] de Souza CR, Von Zuben CJ. Synanthropy of Sarcophagidae (Diptera) in southeastern Brazil. Neotrop Entomol. 2016;45:637–641.
(Sarcophagidae) as colonizers of a human corpse. Int J Legal Med. 2014;128:229–233.

[37] Mashaly AM. Entomoфаunal succession patterns on burnt and unburnt rabbit carrion. J Med Entomol. 2016;53:296–303.

[38] Bharti M, Singh D. Insect faunal succession on decaying rabbit carcasses in Punjab. India J Forensic Sci. 2003;48:1133–1143.

[39] Pohjoismäki JL, Karahunen PJ, Goebeler S, et al. Indoors forensic entomology: colonization of human remains in closed environments by specific species of sarcosaprophagous flies. Forensic Sci Int. 2010;199:38–42.

[40] Toukairin Y, Arai T, Hoshi T, et al. The geographical distribution of fly larvae on corpses in Saitama Prefecture in Japan during the summer season. Leg Med (Tokyo). 2017;24:75–77.

[41] Sukontason K, Bunchu N, Chaiwong T, et al. Forensic entomology and the estimation of the minimum time since death in indoor cases. J Forensic Sci. 2015;60:525–531.

[42] Syamsa RA, Ahmad FM, Marwi MA, et al. An analysis of forensic entomological specimens by Universiti Kebangsaan Malaysia. Med J Malaysia. 2010;65:192–195.

[43] Syamsa RA, Oscar B, Zuhra RM, et al. Forensic entomology of high-rise buildings in Malaysia: three case reports. Trop Biomed. 2015;32:291.

[44] Syamsa RA, Oscar B, Ahmad FM, et al. Comparative fly species composition on indoor and outdoor forensic cases in Malaysia. J Forensic Leg Med. 2017;45:41–46.

[45] Bugelli V, Forni D, Bassi LA, et al. Forensic entomology and the estimation of the minimum time since death in indoor cases. J Forensic Sci. 2015;60:525–531.

[46] Goff ML. Comparison of insect species associated with decomposing remains recovered inside dwellings and outdoors on the island of Oahu, Hawaii. J Forensic Sci. 1991;36:748–753.

[47] Ren LP, Deng HX, Dong SZ, et al. Survey of indoor sarcosaprophagous insects. Trop Biomed. 2017;34:284–294.

[48] Frost CL, Braig HR, Amendt J, et al. Indoor arthropods of forensic importance: insects associated with indoor decomposition and mites as indoor markers. In: Amendt J, Goff ML, Campobasso CP, Grassberger M, editors. Current concepts in forensic entomology. Dordrecht: Springer; 2010. p. 93–108.

[49] Draber-Monko A, Malewski T, Pomorski J, et al. On the morphology mitochondrial DNA barcoding of the flesh fly Sarcophaga (Liopygia) argyrostoma (Robineau-Desvoidy, 1830) (Diptera: Sarcophagidae) an important species in forensic entomology. Ann Zool. 2009;59:465–493.

[50] Banzinger H, Pape T. Flowers, faeces and cadavers: natural feeding and laying habits of flesh flies in Thailand (Diptera: Sarcophagidae, Sarcophaga spp.). J Nat Hist. 2004;38:1677–1694.

[51] Beyer JC, Enos WF, Stajic M. Drug identification through analyses of maggots. J Forensic Sci. 1980;25:411–412.

[52] Magni PA, Pacini T, Pazzi M, et al. Development of a GC-MS method for methamphetamine detection in Calliphora vomitoria L. (Diptera: Calliphoridae). Forensic Sci Int. 2014;241:96–101.

[53] Musvasva E, Williams KA, Muller WJ, et al. Preliminary observations on the effects of hydrocortisone and sodium methoxetinal on development of Sarcophaga (Carrnea) tibialis Macquart (Diptera: Sarcophagidae), and implications for estimating post mortem interval. Forensic Sci Int. 2001;120:37–41.

[54] Wilson Z, Hubbard S, Pounder DJ. Drug analysis in fly larvae Am. J Foren Med Pathol. 1993;14:118–120.

[55] Goff ML, Omori AI, Goodbrod JR. Effects of cocaine in tissues on the development rate of Boetettcherisca peregrina (Diptera: Sarcophagidae). J Med Entomol. 1989;26:91–93.

[56] Goff ML, Brown WA, Hewadikaram KA, et al. Effects of heroin in decomposing tissues on the developmental rate of Boetettcherisca peregrina (Diptera: Sarcophagidae) and implications of this effect on estimation of post mortem intervals using arthropod developmental patterns. J Forensic Sci. 1991;36:537–542.

[57] Goff ML, Brown WA, Omori AI. Preliminary observations of the effect of methamphetamine in decomposing tissues on the development rate of Parasarca phaga ruficornis (Diptera: Sarcophagidae) and implications of this effect on the estimations of postmortem intervals. J Forensic Sci. 1992;37:867–872.

[58] Goff ML, Brown WA, Omori AI, et al. Preliminary observations of the effects of amitriptyline in decomposing tissues on the development of Parasarca phaga ruficornis (Diptera: Sarcophagidae) and implications of this effect to estimation of post mortem interval. J Forensic Sci. 1993;38:316–322.

[59] Goff ML, Brown WA, Omori AI, et al. Preliminary observations of the effects of phencyclidine in decomposing tissues on the development of Parasarca phaga ruficornis (Diptera: Sarcophagidae). J Forensic Sci. 1994;39:123–128.

[60] Cats EP. Problems in estimating the post mortem interval in death investigations. J Agirc Entomol. 1992;24:25–255.

[61] Goff ML, Miller ML, Paulson JD, et al. Effects of 3,4-methylenedioxymethamphetamine in decomposing tissues on the development of Parasarca phaga ruficornis (Diptera: Sarcophagidae) and detection of the drug in post mortem blood, liver tissue, larvae and puparia. J Forensic Sci. 1997;42:276–280.

[62] Zhang N, Niu XL, Liang J, et al. Effect of morphine hydrochloride on grow accumulated degree hour and cephalopharyngeal skeleton of the larvae of Sarcophaga crassipalpis under natural condition. Acad J Second Mil Med Univ. 2013;36:1202–1206.

[63] Hall MJ, Wall RL, Stevens JR. Traumatic myiasis: a neglected disease in a changing world. Annu Rev Entomol. 2016;61:159–176.

[64] Pezzi M, Whitmore D, Chicca M, et al. Traumatic myiasis caused by an association of Sarcophaga tibia lis (Diptera: Sarcophagidae) and Lucilia sericata (Diptera: Calliphoridae) in a domestic cat in Italy. Korean J Parasitol. 2015;53:471–475.

[65] Severini F, Nocita E, Tosini F. Myiasis of the Tracheostomy wound caused by Sarcophaga (Liopygia) argyrostoma (Diptera: Sarcophagidae): molecular identification based on the mitochondrial cytochrome c oxidase I gene. J Med Entomol. 2015;52:123–130.

[66] Graffi S, Peretz A, Wilamowski A, et al. External Ophthalmomyiasis caused by a rare infesting larva, Sarcophaga argyrostoma. Case Rep Ophthalmol Med. 2013;3:850–865.
Burgess I, Spraggs PD. Myiasis due to *Parasarcophaga argyrostomum*—first recorded case in Britain. Clin Exp Dermatol. 1992;17:263.

Gaglio G, Brianti E, Abbene S, et al. Genital myiasis caused by *Wohlfahertia magnifica* (Diptera: Sarcophagidae) in Sicily (Italy). Parasitol Res. 2011;109:1471–1471.

Rafinnejad A, Akbarzadeh K, Rassi Y, et al. Traumatic myiasis agents in Iran with introducing of new dominant species, *Wohlfahertia magnifica* (Diptera: Sarcophagidae). Asian Pac J Trop Biomed. 2014;4:451–455.

Alizadeh M. A review of myiasis in Iran and a new nosocomial case from Tehran, Iran. 2014;8:124–131.

Giangaspero A, Traversa D, Trentini R, et al. Traumatic myiasis by *wohlfahertia magnifica* in Italy. Vet Parasitol. 2011;175:109–112.

Derraik JG, Heath AC, Rademaker M. Human myiasis caused by *Phormia regina* (Diptera: Muscidae). J Med Entomol. 2010;47:487–498.

Harvey ML, Dadour IR, Gaudieri S. Mitochondrial gene subunit I (*C19orf12*) in *Lucilia sericata* (Diptera: Calliphoridae) of forensic importance. Forensic Sci Int. 2001;131:134–147.

Wells JD, Pape T, Sperling FA. DNA-based identification of *Oestrus sp.* (Diptera: Sarcophagidae) in livestock. Med Vet Entomol. 2009;1:80–85.

Boscarelli A, Levi Sandri GB. Periungual myiasis mimicking an ingrown toenail. Transl Pediatrics. 2016;5:95–96.

Titgui H, Bouazzazari A, Agoumi A. Human auricular myiasis caused by *Wohlfahertia magnifica* (Diptera: Sarcophagidae): about three observations in Morocco. Bull Soc Pathol Exot. 2007;100:61–64.

Ferraz AC, Proença B, Gadelha BQ, et al. First record of human myiasis caused by association of the species *Chrysomya megacephala* (Diptera: Calliphoridae), *Sarcophaga (Liopygia) ruficornis* (Diptera: Sarcophagidae), and *Musca domestica* (Diptera: Muscidae). J Med Entomol. 2010;47:487–490.

Nazni WA, Jeffery J, Lee HL, et al. Nosocomial nasal myiasis in an intensive care unit. Malays J Pathol. 2011;33:53–56.

Chaiwong T, Temeiam N, Limpavithayakul M, et al. Aural myiasis caused by *Parasarcophaga (Liosarcophaga) dux* (Thomson) in Thailand. Trop Biomed. 2014;31:496–498.

Maleki RN, Shayeghi M, Najibi B, et al. Infantile nosocomial myiasis in Iran. J Arthropod Borne Dis. 2012;6:156–163.

Braverman I, Dano I, Saah D, et al. Aural myiasis caused by flesh fly larva, *Sarcophaga haemorrhoidalis*. Am J Otolaryng. 1994;23:204–205.

Abdel-Hafeez EH, Mohamed RM, Belal US, et al. Human wound myiasis caused by *Phormia regina* and *Sarcophaga haemorrhoidalis* in Minia Governorate, Egypt. Parasitol Res. 2015;114:3703–3709.

Dutto M, Bertero M. Traumatic myiasis from *Sarcophaga (Berecaea) cruzentata* Meigen, 1826 (Diptera, Sarcophagidae) in a hospital environment: reporting of a clinical case following polytrauma. J Prev Med Hyg. 2010;51:50–52.

Uni S, Shinozaga S, Nishio Y, et al. Ophthalmomyiasis caused by *Sarcophaga cressipalpis* (Diptera: Sarcophagidae) in a hospital patient. J Med Entomol. 1999;36:906–908.

Hiraoka H, Ozawa T, Sowa-Osako J, et al. Repeated myiasis in a female vulgar squamous cell carcinoma caused by *Lucilia sericata* and *Sarcophaga cressipalpis*. J Dermatol. 2015;42:840–841.

Chigusa Y, Tanaka K, Yokoi H, et al. Two cases of otomyiasis caused by *Sarcophaga peregrina* and *S. similis* (Diptera: Sarcophagidae). Med Entomol Zool. 1994;45:153–157.

Türk M, Afşar İ, Özbel Y, et al. A case of nasosmyiasis whose agent was *Sarcophaga sp.*. Turk J Pathol. 2006;30:330–332.

Aldemir OS, Şimşek E. The first case of otomyiasis caused by *Sarcophaga spp.* (Diptera: Sarcophagidae) larvae in a goose in the world. Turk J Pathol. 2014;38:211–213.

Ahmad AK, Abdel-Hafeez EH, Madiha M, et al. Gastrointestinal myiasis by larvae of *Sarcophaga sp.* and *Oestrus sp.* in Egypt: report of cases, and endoscopical and morphological studies. Korean J Parasitol. 2011;49:51–57.

Dutto M, Bertero M. Cutaneous superficial myiasis: report of a rare nosocomial parasitic disease caused by *Sarcophaga spp.* (Diptera, Sarcophagidae). Cent Eur J Public Health. 2011;19:232–234.

Szpila K, Hall MJ, Wardhana AH, et al. Morphology of the first instar larva of obligatory traumatic myiasis agents (Diptera: Calliphoridae, Sarcophagidae). Parasitol Res. 2014;113:1629–1640.

Ubéro-Pascal N, Paños A, García MD, et al. Micromorphology of immature stages of *Sarcophaga* (Liopygia) *caulellata* Pandelé, 1896 (Diptera: Sarcophagidae), a forensically important fly. Micros Res Tech. 2015;78:148–172.

Szpila K, Richet R, Pape T. Third instar larvae of flesh flies (Diptera: Sarcophagidae) of forensic importance: critical review of characters and key for European species. Parasitol Res. 2015;114:2279–2289.

Amendt J, Richards CS, Campobasso CP, et al. Forensic entomology: applications and limitations. Forensic Sci Med Pathol. 2011;7:379–392.

Wells JD, Pape T, Sperling FA. DNA-based identification and molecular systematics of forensically important *Sarcophagidae* (Diptera). J Forensic Sci. 2001;46:1098–1102.

Harvey ML, Dadour IR, Gaudieri S. Mitochondrial DNA cytochrome oxidase I gene: potential for distinction between immature stages of some forensically important fly species (Diptera) in western Australia. Forensic Sci Int. 2001;131:134–139.

Piwczyński M, Szpila K, Grzywacz A, et al. A large-scale molecular phylogeny of flesh flies (Diptera: Sarcophagidae). Syst Entomol. 2014;39:783–799.

Buenaventura E, Whitmore D, Pape T. Molecular phylogeny of the hyperdiverse genus *Sarcophaga* (Diptera: Sarcophagidae), and comparison between algorithms for identification of rogue taxa. Cladistics. 2016;2:1–25.

Piwczyński M, Pape T, Deja-Sikora E, et al. Molecular phylogeny of mitogenome-intraspecies (Diptera: Sarcophagidae): implications for classification, systematics and evolution of larval feeding strategies. Mol Phylogenet Evol. 2017;116:49–60.
Meiklejohn KA, Wallman JF, Dowton M. DNA-based identification of forensically important Australian Sarcophagidae (Diptera). Int J Med Leg. 2011;125:27–32.

Meiklejohn KA, Wallman JF, Dowton M. DNA barcoding identifies all immature life stages of a forensically important flesh fly (Diptera: Sarcophagidae). J Forensic Sci. 2013;58:184–187.

Aly SM, Wen J. Applicability of partial characterization of cytochrome oxidase I in identification of forensically important flies (Diptera) from China and Egypt. Parasitol Res. 2013;112:2667–2674.

Jordans K, Sonet G, Richet R, et al. Identification of forensically important Sarcophaga species (Diptera: Sarcophagidae) using the mitochondrial COI gene. Int J Legal Med. 2013;127:491–504.

Aly SM. Reliability of long vs short coi markers in identification of forensically important sarcophagid flies (Diptera: Sarcophagidae) in China. J Forensic Sci. 2011;56:1534–1540.

Guo Y, Cai J, Chang Y, et al. Identification of forensically important sarcophagid flies (Diptera: Sarcophagidae) based on mitochondrial COI gene in China. Trop Biomed. 2011;28:1497–1501.

Aly SM, Cai JF, Xiong F, et al. The utility of mitochondrial DNA fragments for genetic identification of forensically important sarcophagid flies (Diptera: Sarcophagidae) in China. Trop Biomed. 2012;29:51–60.

Roziah A, Tan SH, Lee HL, et al. Mitochondrial and nuclear DNA for identification of forensically important flesh flies (Sarcophagidae: Boettcherisca Spp.). Entomol Ornith Herpetol. 2015;4:163.

Zhang CQ, Fu XL, Yang X, et al. Application of mtTSNp marker for genetic identification of forensically important Sarcophagidae flies (Diptera: Sarcophagidae) in China. Forensic Sci Int-Gen Suppl. 2015;5:240–242.

Baqué M, Amendt J. Strengthen forensic entomology in court—the need for data exploration and the validation of a generalized additive mixed model. Int J Legal Med. 2013;127:213–223.

Roe AD, Sperling FAH. Patterns of evolution of mitochondrial cytochrome c oxidase I and II DNA and implications for DNA barcoding. Mol PhylogeNet. 2007:44:325–345.

Brown K, Thorne A, Harvey M. Calliphora vicina (Diptera: Calliphoridae) pupae: a timeline of external morphological development and a new age and PMI estimation tool. Int J Legal Med. 2015;129:835–850.

Amoudi MA, Diab EM, Abou-Fannah SS. Development rate and mortality of immature Parasarcophaga (Liopygia) ruficornis (Diptera: Sarcophagidae) at constant laboratory temperatures. J Med Entomol. 1994:31:168–170.

Byrd JH, Butler JF. Effects of temperature on Sarcophaga haemorrhoidalis (Diptera: Sarcophagidae) development. J Med Entomol. 1998;35:694–698.

Grasserberger M, Reiter C. Effect of temperature on development of Liopygia (= Sarcophaga) argyrostoma (Robineau-Desvoidy) (Diptera: Sarcophagidae) and its forensic implications. J Forensic Sci. 2002;47:1332–1336.

Nassu MP, Thyssen PJ, Linhares AX. Developmental rate of immatures of two fly species of forensic importance: Sarcophaga (Liopygia) ruficornis and Microcerella hallii (Diptera: Sarcophagidae). Parasitol Res. 2014;113:217–222.

Wang Y, Wang JF, Zhang YN, et al. Forensically important Boettcherisca peregrina (Diptera: Sarcophagidae) in China: development pattern and significance for estimating postmortem interval. J Med Entomol. 2017;54:1491–1497.

Yang L, Wang Y, Li L, et al. Temperature-dependent development of Parasarcophaga similis (Meade 1876) and its significance in estimating postmortem interval. J Forensic Sci. 2017;62:1234–1243.

Mulleri PR, Marliuis JC, Abalay FH. Two species of Microcerella (Diptera: Sarcophagidae) found in highland arid landscapes of Argentina, during forensic studies. J Med Entomol. 2012;49:183–191.

Bonacci T, Silvia G, Berardo C, et al. The flesh fly Sarcophaga (Liopygia) crassipalpis Macquart 1839 as an invader of a corpse in Calabria (southern Italy). J Forensic Sci Criminol. 1987:1:1–5.