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Mechanical preprocessing and black soldier fly (*Hermetia illucens*) larvae bioconversion of diaper waste: A scoping review with an illustrative prototype case study

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Abstract

Background: Disposal of single-use diapers is a growing solid waste issue because they are composed of a mix of composite materials, non-biodegradable, and have a high moisture and pathogen content. Although Black Soldier Fly (BSF, *Hermetia illucens*) larvae bioconversion is being increasingly proposed as sustainable biotechnology for valorisation of organic-fraction waste, diaper waste has a different composition compared to homogeneous feedstocks that most BSF studies have been performed on.

Objective: This scoping review aims to map the published evidence regarding the composition of diaper waste, environmental impacts, disposal practice, mechanical pre-treatment, and BSF bioconversion to characterize the extent and nature of evidence of combining mechanical shredding with larval bioconversion of diaper waste.

Methods: The literature search was carried out using a scoping review approach that involved identifying, charting, and thematically synthesising the literature on diaper waste management, shredding pre-treatment, and BSF larval bioconversion. The evidence is summarised and organised by themes and a prototype shredding-sterilising machine is provided as an operational example of the evidence gap identified.

Results: Based on the literature reviewed, diaper waste is found to be a very complex waste structurally, which is not suitable for direct biological treatment; mechanical shredding is well known as a pre-treatment technique in composting and anaerobic digestion, and BSF larvae is an efficient bioconverter for homogeneous organic wastes. No integrated experimental system was found that could integrate mechanical pre-treatment and BSF bioconversion for the diaper waste. An illustrative case study is presented, describing a combined shredding and steam-sterilising unit which would help to overcome this challenge by both decreasing particle size and controlling pathogens before larval feeding.

Conclusion: There is a definite gap in the research on the combination of mechanical pretreatment and biological conversion of diaper waste using BSF. These gaps can be filled by standardised and integrated experimental studies that quantify the effect of particle size reduction and pre-treatment on the larval performance, pathogen load and resource recovery.

Keywords: Diaper waste, Black Soldier Fly, *Hermetia illucens,* bioconversion, mechanical shredding, pre-treatment

1. Introduction

The solid-waste management problem of increasing amount of disposable diaper waste is among the more enduring problems that are present in the modern society. The reason the waste stream is challenging to deal with after it leaves the house is because diapers are a composite product of absorbent polymers, cellulose fibres, and a plastic film specifically designed for use and not for end-of-life recovery (Remla, Latha and Prince, 2025). Soiled diapers are unique, as they have a high moisture content, human waste-derived pathogens, and slowly degrading synthetic polymers - all of which traditional waste management solutions like landfilling and incineration struggle to manage, and that result in pollution and disproportionate greenhouse gas and municipal solid waste emissions (Loh *et al.*, 2025) [24, 17]. The problem is a multi-disciplinary one which has been gaining momentum in the field of research over the last few years, and it has been investigated unevenly along the waste-management pipeline.

One of the more promising methods of biological valorisation of organic wastes is through insect based bioconversion particularly with the Black Soldier Fly (*Hermetia illucens*) larvae (Hoque and Sultana, 2024). The BSF larvae are not selective feeders and can utilise a variety of organic waste materials to produce valuable larval biomass and nitrogen-rich excrement (frass) which is considered a circular-economy solution that not only reduces waste volume, but also produces a bio-organic protein and fertiliser co-product (Lim *et al.*, 2022). Most of the work undertaken to date to develop this technology, however, has been performed with comparatively homogenous feedstocks (food waste, animal manure, agriculture residues) with relatively predictable physicochemical properties and degradation pathways. Diaper waste doesn't have these properties. Structurally, it is quite different from the other substrates that have been the subject of much BSF literature, and it is well known that untreated diaper waste is too complex, in terms of both the layers of polypropylene non-woven sheets, cellulose fluff pulp, superabsorbent polymer, and polyethylene backing, and the contamination risk associated with it, to be suitable for direct feeding by larvae (Cohn, 2023) [10, 16, 9].

Mechanical pre-treatment, especially shredding, is an old approach to make the heterogeneous waste streams more suitable for further biological treatment or recycling. Shredding has been observed to have beneficial effects such as decreasing particle size, increasing surface area for microbial or enzymatic reactions and homogenous mixed feedstocks when used in composting, anaerobic digestion and plastics-recycling applications (Brewster *et al.*, 2022). However, mechanical pre-treatment of diaper waste before feeding by the larvae is relatively less explored in the BSF literature, and a prototype diaper-shredding machine has been proposed as one way forward to fill the gap by enhancing uniformity of the substrates and accessibility to the larvae before bioconversion (Lim *et al.*, 2022) [5, 16].

The aim of this review was therefore to map and synthesize the existing evidence on the various segments of this problem, such as the composition of diaper waste and its environmental impacts, current practice and mechanical pre-treatment technology, and the BSF larval bioconversion, as well as identify how much of the various segments have been studied together as an integrated system. Due to the aim of the scoping review, to describe the range, spread and development of the evidence base, and not to combine and analyse quantitative outcomes from a limited number of similar studies, a scoping review approach was chosen instead of a systematic review. Considering the relative lack of literature that brings together mechanical preprocessing with BSF bioconversion, this review also presents as an illustrative case study, the design rationale for a prototype having two processes shredding and steam-sterilising for a diaper-derived substrate.

2. Methods

2.1 Review Approach

This manuscript is presented in the format of a scoping review, which is suitable for a topic that is new and may involve a variety of study designs and/or is too diverse for an evaluation of the methodological quality of a narrow selection of similar studies. What is understood about the composition, generation and environmental effects of diaper waste? (ii) What strategies might reduce the environmental effects of diaper waste?What strategies can be used to mitigate the environmental impacts of diaper waste? (iii) What are potential solutions for the environmental impacts of diaper waste? and (iv) What are the methods for tracking the impacts of diaper waste? (ii) What are the current practices for disposal/management of this waste stream? (iii) What are the evidences for mechanical shredding as a pre-treatment strategy in organic and plastic waste system? (iv) How do we know BSF can bioconvert organic wastes and how has this knowledge been extended to diaper or diaper like heterogeneous substrates?

2.2 Eligibility and Source Material

Sources used included peer-reviewed journal articles, book chapters, and conference proceedings that included information on one or more of the following: composition and management of diaper or sanitary waste; environmental or public health impacts of diaper waste; mechanical shredding or comminution of diaper waste as a waste pre-treatment method; or BSF (*Hermetia illucens*) larval rearing, feeding, or performance during bioconversion. The evidence base synthesised in this review was limited to a specific literature set that was identified during the applied engineering study, and possibly not a full systematic search of all electronic databases (this scope and implications are discussed in the limitations section).

2.3 Charting and Synthesis

The sources were classified into thematic groups to cover the different aspects of the diaper to bio conversion pathway namely waste characterisation, environmental and health impacts, disposal practice, mechanical pre-treatment and BSF bioconversion performance and determinants. Findings from the themes within each theme were aligned descriptively on a chart and then summarized narratively that highlighted areas of consensus, conflicts, and, importantly, gaps that where the themes within themes had not yet been explored together. This charting process directly led to a description of the integration gap (Section 4) which directly influenced the creation of an illustrative prototype case study (Section 5) of how this gap could be addressed in practice.

3. Results: Thematic Synthesis of the Literature

3.1 Diaper Waste Composition and the Basis of Its Persistence

Disposable diapers are not a single material, they are a composite product, and this gives a clue to why they are not degraded, nor are they easily recycled. A typical diaper is made up of a non-woven polypropylene top sheet, an absorbent core made of fluff pulp and superabsorbent polymer, a polyethylene back sheet, and a variety of elastics and adhesives, which make the diaper extremely resistant to biodegradation and this multi-material construction, explains Remla, Latha and Prince 2025, contributes to the non-biodegradable fraction of household and municipal solid waste. The superabsorbent polymer material is designed to absorb large amounts of liquid, which makes used diapers even more absorbent than the majority of other household waste items, making them more challenging to manage, transport, and treat if moisture content is an important parameter (Czarnecka *et al.*, 2022) [7].

With the increasing urbanisation and evolving childcare trends, the consumption of diapers has risen, leading to a higher share of this composite, moisture-absorbing material in the municipal waste stream (Mukherjee, 2025). Adults incontinence waste is another, increasing, waste stream, and data suggests that in some high-income environments, incontinence waste from adults is growing faster than from infants, and is now beyond the scope of child care only (Brewster *et al.*, 2022) [20, 5].

3.2 Effects on the environment and recovery of natural resources

The environmental argument to take action on diaper waste is two-fold, related to the persistence of the waste after landfill and the fact that little of the value of the waste is captured via traditional end-of-life options. The plastic parts of the diapers do not break down environmentally, but fragment slowly, and like the other single-use plastics in the environment, contribute to the overall plastic pollution found in waste streams more broadly (Khoaele *et al.*, 2023). In cases where there is degradation, even that of a diaper product that is labeled as biodegradable, it is often partial and is significantly affected by the general composition of the waste matrix in which the product is found (Czarnecka *et al.*, 2022). The fragmentation of such plastic waste creates microplastic and nanoplastic particles that have been found to disrupt ecological processes in some cases as far removed from the waste of the diaper as interactions between plants and pollinators, which shows how the diaper is part of a much larger, and growingly known, environmental concern of plastic waste (Shah *et al.*, 2023). Concurrently, the literature on resource recovery more and more calls for a recycling approach that is not just about waste, but the use of waste as an underutilized feedstock: open-loop recycling of diaper waste, and upcycling of soiled diaper material through insect bioconversion, highlights the organic and energetic value that is embedded in the waste but simply discarded in the waste bin (Lim *et al.*, 2022; Loh *et al.*, 2025) [15, 7, 25, 16, 17].

3.3 Current Disposal and Management Practice

There is an apparent lack of resources compared to the magnitude of the problem associated with diaper waste management as described throughout the literature, especially outside of a high-income context. Due to the significant differences in physical and hygienic properties of diaper waste, source separation from the general municipal solid waste stream is not common and, in the absence of source separation, diaper material is collected and processed, if at all, alongside the rest of municipal solid waste (MSW) (Hoque and Sultana, 2024). There are two general categories of alternatives to the undifferentiated landfilling: material recovery and substitution. Technical feasibility of material-recovery approaches, such as the open-loop recycling of diaper components to secondary products, has been reported, but to date they rely on more infrastructure and processing costs that restrict their use in other systems, except those that are well-resourced (Lim *et al.*, 2022). Substitution approaches attempt to tackle part of the problem at the design stage, but they come with feasibility challenges relating to cost, performance and consumer acceptance, in addition to not removing the need for an end-of-life treatment pathway for the substituted diapers that are still in use (Mulungo and Gumede, 2025) [10, 16, 21]. Other behavioural interventions that goal to lessen plastic content or promote more sustainable disposal practices have been examined, emphasizing that the resolution of the diaper waste issue is not simply a technical one but additionally relies on the habits and incentives of households (Allison *et al.*, 2026).

Against this background, the COVID-19 literature on solid waste management in general emphasised the rapid increase of the hygiene-related waste streams of sanitary and protective products, and how these waste streams can overload the existing waste collection and treatment systems, which further reinforces the need for targeting specific waste streams for pre-treatment and valorisation actions instead of general municipal waste streams (Jebaranjitham *et al.*, 2022) [1, 14].

3.4 Mechanical Shredding as a Pre-treatment Strategy

Mechanical shredding, referred to in the broader waste-management literature as comminution, is one of the most consistently described pre-treatment methods, and its role is similar for the various types of waste: to decrease the particle size, to increase the surface area of the particles, and to make an otherwise heterogeneous feedstock more homogeneous. The design of shredders has been studied over and over again in plastics recycling, and size reduction is an integral process in nearly all the subsequent sorting and reprocessing operations (Wong *et al.*, 2022). Other recent evaluations of shredder technology for solid waste processing have confirmed that the performance of shredders in terms of throughput, energy consumption, and particle size distribution produced is significantly influenced by various design parameters such as the design of blades, feed handling systems, and the speed of the shafts, which are all dependent on the specific solid waste stream being processed (Sharma, Washimkar and Belkhode, 2025). Shredding has also been directly used in extraction and recovery of materials of biological origin, and particle size reduction was found to be directly beneficial to the efficiency of the subsequent extraction steps, underlining the more general principle that surface area enhancement by mechanical pre-treatment is generally beneficial to the efficiency of any biological or chemical process that follows it (Baldassini *et al.*, 2025).

Mechanical degradation strategies are emerging as one of several complementary methods required to significantly increase the degradation of polymers, in particular biodegradable ones, and are especially well established in the context of polymer breakdown for some components in diapers where the most direct approach is to shred the polymer (Bher, Cho and Auras, 2023). This confirms that simply shredding is not enough to make composite diaper material degradation resistant, but that shredding is a preparatory treatment that enhances the degradation resistance of the subsequent biological or chemical treatments. The field applications of organic waste shredders, such as purpose-built shredders for institutional and small-scale waste-management applications, have demonstrated the maturity and versatility of the shredding technology for its use on waste streams outside of the conventional municipal solid waste categories (MSW) (Muttaqin *et al.*, 2025) [28, 26, 2, 3, 22].

3.5 Organic Waste Bioconverter using Black Soldier Fly Larvae (BSFL)

Black Soldier Fly larvae have been a biological means of two main value streams of larval biomass, which can be processed into a protein-rich material to be used downstream, and frass, a nutrient-rich by-product that can be used as an organic fertiliser. Unlike simple composting, BSF bioconversion reduces the amount of organic waste they are fed to a significant extent, while also reducing pathogenic and competing microorganisms in the substrate, making BSF bioconversion unique (Su *et al.*, 2026). This is one of the main reasons why BSF technology is proposed to be used in general for organic waste management, even for waste streams that carry a risk for hygiene like diaper material (Rehman *et al.*, 2023).

However, the performance of BSF larvae is not the same in all substrates. Substrate composition has been found to have measurable effects on larval growth and development, even relatively subtle ones, such as the sugar content of a substrate, which can affect substrate temperature and can also have an effect on the dynamics of growth in the larvae during the process of bioconversion, as has been demonstrated (Fuhrmann *et al.*, 2026). Similarly, substrates with high content of phenolic compounds, which are derived from agro-industrial residues, also generate detectable variations in larvae composition and development from other more traditional substrates, thus demonstrating that BSF performance is not a one-size fits all (Ionica *et al.*, 2026). The sensitivity of substrates is echoed by other studies that investigate BSF as a means to valorise agricultural and animal wastes, which also highlight that the efficiency and safety of the bioconversion process depend on more than just the BSF, but also on the characteristics of the substrate (Iskakov and Sugirbay, 2023).

It has also been proven empirically that BSF can have other applications, not just animal feed, as demonstrated by the use of BSF-derived product as ingredients in extruded food products, which shows potential for commercialization of BSF-derived biomass beyond animal feed (Iñaki *et al.*, 2022). Frass and bioconverted material from agro-waste substrates (e.g., olive pomace) have been evaluated for soil application and found to pose low soil hazard in general, which reinforces the potential of BSF bioconversion residues to be safely recycled for agricultural production if the input material is well characterised and regulated (Mostafaie *et al.*, 2025) [27, 23, 8, 12, 13, 11, 19].

3.6 Particle Size, Pre-treatment, and Larval Performance

In addition to the substrate factors known to affect BSF performance, particle size has a special place among those parameters since it is one of the few parameters which can be directly modified by mechanical pretreatment in addition to the selection of feedstock. Smaller and more uniform particle size is associated with improved feeding efficiency (and conversion performance) by providing increased feeding surface area for the larva as well as uniformity of moisture and texture in the substrate. This is in line with the general pre-treatment literature, which indicates that mechanically treating a heterogeneous material before biological treatment (microbial or larval) has a significant impact on the yield of biogas and digestate quality, thus explaining the general principle of mechanically treating a heterogeneous substrate before microbial or larval biological treatment, and the transfer is obviously logical to the BSF field.

Substrate accessibility is not the only issue under consideration for interaction between mechanical pre-treatment and biological performance. Another possible change in feeding behaviour would be due to changes in particle size and substrate structure, which has been observed in insect systems with altered substrates or plastic-contaminated substrates where the larval gut microbiota composition changed significantly as a function of the physical and chemical nature of the ingested substrate (Misser *et al.*, 2025). The results are also significant for diaper waste as a source of substrates because they are inherently plastic, and indicate that the impact of mechanical pre-treatment on BSF performance with diaper waste cannot be assumed to be the same as purified organic substrates, without an empirical investigation [18].

4. Synthesis: The Integration Gap

When considered collectively, the aforementioned themes present a pipeline with documented evidence for each stage; however, when the feedstock is diaper waste, the stages have not always been examined in tandem. The composition and environmental impacts of diaper waste have been established (Remla, Latha and Prince, 2025; Khoaele *et al.*, 2023). Mechanical shredding is a well-characterised and mature pre-treatment technology in other waste streams such as plastics recycling and biomass extraction (Wong *et al.*, 2022; Baldassini *et al.*, 2025). The BSF larvae are an efficient organic waste bioconverter and their performance is influenced by the substrate composition and particle size (Su *et al.*, 2026; Fuhrmann *et al.*, 2026). There is a lack of literature that directly correlates a specific mechanical pre-treatment step (done in a controlled manner) to diaper waste and its effect on BSF larval feeding efficiency, survival, development time, and the safety of the biomass and frass.

For three reasons this gap is important. The first is that pre-treatment parameters that would work for food waste or manure are not easily transferable to diaper waste, since the polypropylene and superabsorbent polymer components react to mechanical stress differently from any organic material, for example (Bher, Cho and Auras, 2023). Second, unlike most conventional BSF feedstocks, the potential for the pathogens to be a hygiene concern adds urgency to the need for proper pre-treatment, meaning that pathogen reduction is a co-equal design goal for any pre-treatment system that will be used with diaper waste. Third, the scalability of BSF based diaper waste treatment has not been proven when used in combination with a mechanical-biological system, as mechanical pre-treatment systems and BSF rearing systems have each been scaled in other contexts [24, 15, 28, 2, 27, 8, 3].

5. Illustrative Case Study: A Prototype Shredding-Sterilising Unit for Diaper Waste Preprocessing.

In order to make the point of how the integration gap identified above could be achieved in practice, the design rationale of a prototype machine is presented that was developed specifically for combining mechanical shredding with thermal sterilisation as a combined pre-treatment before BSF larval feeding. This case study is offered as an example of the design logic working out the reviewed literature into an operational system and is not a validated performance trial, the numbers below are design specifications not experimental results.

5.1 Design Rationale

This unit, known as diaper conditioning and pre-treatment (DCP), was designed to address two needs identified in the literature synthesis above: particle size reduction, which is needed to make the diaper waste as uniform as possible, to allow easy access of the larvae as per shredding pre-treatment principles (Wong *et al.*, 2022; Sharma, Washimkar and Belkhode, 2025), and pathogen control, which is necessary as a hygiene risk is associated with the diaper waste before reaching the larval rearing stage. These functions are combined in one machine because the mechanical/hygienic conditioning is treated as a co-equal, simultaneous design goal for this waste stream and not as two sequential processes [28, 26].

5.2 Functional Description
The DCP machine has a mechanical shredding unit combined with an LPG-fired steam-heated mixing unit. A 1,5 hp electric motor powering a shredding shaft with circular blades and spacers, which mesh with a stationary set of semi-circular counter-blades in the shredding chamber, is used to shred the diaper material into a particle size range suggested in composting and bioconversion pre-treatment literature as 10 to 25 mm, to meet a balance between the energy put in and the surface area required for rapid heat penetration and subsequent biological accessibility (Haug, 2018) [9]. A bevel gear arrangement is used to convey the drive from the shredding shaft to a vertical mixing shaft including inclined stirrer blades in two layers within a mixing bowl located below the outlet to the shredding chamber. The heat from an LPG burner preheats a water reservoir under the mixing bowl, and the steam from this water reservoir is used to sterilise the shredded material as it is mixed. The length of the time the material spends being sterilised depends upon the rate at which heat is supplied to the mixing unit.
The functional design considerations discussed are consistent with a traditional machine design and include feed-handling and shredding performance, steam heating and thermal processing control, safety and regulatory compliance unique to steam-fired machines, energy efficiency, and manufacture and maintainability, including the use of common off-the-shelf components for modular assembly and field repair.

5.3 Conceptual Design Selection
Three conceptual designs were compared and assessed based on a predetermined set of criteria: Fabrication cost, ease of operation, ease of maintenance, shredding capacity, mixing and heating efficiency, and ergonomics with a weighted scoring matrix, a three point scale, was used to evaluate each. This concept selection method mirrors conventional engineering design process when interpreting qualitative design priorities, including several ones such as cost, maintainability, modularity, which are also echoed in the general shredder-technology literature about the practical deployability of waste-processing machines in less well-resourced environments (Muttaqin *et al.*, 2025), with a single comparable score across competing design options [22].

Table 1: Concept evaluation parameters and scoring criteria for the DCP machine design

Parameter	Score 3	Score 2	Score 1
Cost of fabrication	≤ GH¢7,500	GH¢7,600-8,000	≥ GH¢8,500
Ease of operation	Easy	Moderate	Difficult
Ease of maintenance	Easy	Moderate	Difficult
Shredding capacity	High	Medium	Low
Mixing and heating efficiency	Most efficient	Efficient	Less efficient
Ergonomics	Excellent	Acceptable	Needs improvement

5.4 Structural and Mechanical Design Basis
Standard mechanical-engineering relationships were used to size the selected design. The volume of the hopper was obtained by summing the volumes of a rectangular base section and a trapezoidal upper transition section (around 0.0134 m^3 or 13.4 litres). Shaft power requirements were estimated using the relation between shredding force, angular velocity and shaft radius, while the shredding force was related to the mass of the blades, angular velocity and radius of rotation. The diameter of the shafts was calculated based on maximum shear stress theory, which is the appropriate one for shafts that are subjected to combined bending and torsional loadings, in line with the loading conditions of the shredding and stirring shafts of this design. To ensure that the proposed structural design was able to withstand operating loads without failure, a finite element analysis of these components was performed in Autodesk Inventor following a structured sequence of steps that included creating the model, assigning materials, defining constraints, applying loads, generating a mesh, simulating the design, and reviewing the results.

5.5 Operational Role within a BSF Bioconversion Pipeline
So far as the pipeline this review has synthesized goes, the DCP machine itself is seen as the pre-treatment step, prior to the introduction of BSF larval feeding, where diaper waste is shredded to obtain the required particle size, sterilised with the built-in steam system, and discharged as a substrate or mixed into it for BSF larval feeding. This positioning directly translates the gap outlined in Section 4, as it is, to the authors' knowledge, one of the first integrated mechanical/thermal pre-treatment systems that are specifically designed for diaper waste and are intended to be followed by a BSF bioconversion process, rather than be adapted to a different waste stream.

5.6 Status of the Study
The purpose of this study is to make clear what it demonstrates and does not demonstrate. The mechanical and structural design of the prototype has been stated and, in accordance with the project documentation, the prototype has been manufactured and assembled. Not yet developed, and therefore not covered in this specific review, is a full quantitative performance test that correlates the pre-treated product of this particular machine with measurable BSF larval growth and survival, feed conversion, and pathogen reduction and frass quality. The case study is provided here as a concrete example of the mechanical-biological integration that is discussed throughout the literature reviewed and is not intended as an indication that this integration gap is closed.

6. Discussion
This review aimed to trace the evidence base through the various stages of the diaper-waste-to-bioconversion value chain and has identified a body of literature which is fairly well developed but still quite disjointed. The diaper waste composition and its environmental impact has well-

documented (Remla, Latha and Prince, 2025; Khoaele *et al.*, 2023; Shah et al, 2023). Documentation of material-recovery and behavioural-intervention approaches to disposal and management practice for this waste stream is inconsistent, with some evidence of resource, but none of it is resourced (Lim *et al.*, 2022; Mulungo and Gumede, 2025; Allison *et al.*, 2026). It is certain that mechanical shredding is an effective pre-treatment technology, and there are a considerable volume of evidence from plastics recycling, biomass extraction and general pre-treatment of solid waste in the form of shredders (Wong *et al.*, 2022; Baldassini *et al.*, 2025; Sharma, Washimkar and Belkhode, 2025). Likewise, BSF larvae have been well documented as an organic-waste bioconverter and there are many studies on the sensitivity of BSF larval performance to substrates (Su *et al.*, 2026; Fuhrmann *et al.*, 2026; Ionica *et al.*, 2026; Iskakov and Sugirbay, 2023).

An integrated experimental assessment of mechanical pre-treatment, such as shredding and sterilisation, of diaper waste and quantified BSF larval bioconversion outcomes is however not reported anywhere of the reviewed literature. It is not a lack of interest, but is indicative of the two aspects of the problem mechanical waste engineering and insect-based bioconversion being largely separate research traditions that have yet to be integrated for this specific, hygiene-focused, structurally diverse waste material. There are parallels in the literature review that suggest potential mechanisms by which mechanical pre-treatment might affect BSF performance on diaper-derived substrates: pre-treatment by bio-physical before anaerobic digestion (Boarino *et al.*, 2024); and substrate-driven shifts in insect gut microbiota under altered or contaminated feed conditions (Misser *et al.*, 2025), both of which do not directly test that interaction.

The prototype case study in Section 5 provides one practical solution to this challenge: a single integrated machine to achieve both particle-size reduction and thermal sterilisation, designed and structurally tested using typical mechanical engineering procedures and informed by the particle-size targets taken from the composting and pre-treatment literature (Haug, 2018). Including it in this review does not replace the need for controlled experimental performance data as indicated by the literature synthesis, but rather is presented to prove feasibility of design. The following logical step from this review is the creation of the missing data: a controlled trial quantifying effect of different shredding and sterilisation parameters on BSF growth, survival, feed conversion, pathogen indicators and frass and biomass quality, when using diaper waste as feedstock for BSF, either in its sole or combined use with conventional organic feedstock.

In the practical sense, closing this gap is far from academic completion. Moreover, if the mechanically pre-treated waste can be proven to be suitable for BSF bioconversion at an acceptable safety factor, it will provide a lower-cost biological alternative to landfilling or incineration for municipalities or waste managers, especially ones lacking established segregated diaper collection and advanced recycling infrastructure, with the added benefit of recovering value from the waste in the form of larval protein biomass and organic fertilisers. This would help to better integrate diaper waste management with the circular economy approach used in other organic waste streams in the literature reviewed here (Su *et al.*, 2026; Mostafaie *et al.*, 2025) [24, 15, 25, 16, 21, 1, 28, 2, 26, 27, 8, 12, 13, 4, 18, 9, 27, 19].

7. Limitations

There are some limitations in this review that must be taken into account in interpreting the results. First, this is a scoping review, not a systematic review, as it combines a bounded and specific set of literature, rather than the result of a systematic, multi-database search with formal duplicate screening and quality appraisal, meaning that the conclusions drawn in the themes should be understood as a map of the evidence landscape rather than an exhaustive census of it; Secondly, the prototype design described in the case study in Section 5 is not a replicated or independently tested system; the mechanical parameters discussed as optimal for diaper-waste shredding should not be considered to represent a standard set of values for use with other shredding applications. Third, the review does not have any quantitative bioconversion performance data on diaper-derived substrates (such as larval weight gain, feed conversion ratio, or pathogen reduction results), because no completed BSF feeding trial with this particular pre-treated substrate was found for inclusion; this is not a deficiency in the methodology or framework of the review, but rather the main finding on which the review is focused. This type of information should be added in future updates of this review.

8. Conclusion

This scoping review traced the published evidence to understand the composition of diaper waste, its impact, current disposal practices, mechanical shredding as a pre-treatment method, and BSF larval bioconversion of organic waste. While each of these themes has been well reported in isolation, no study was found that integrated mechanical pre-treatment with quantified BSF bioconversion performance of diaper wastes in particular. This is a clear and actionable evidence gap. The combined shredding and steam-sterilising unit designed here, based on standard mechanical design principles and targets for particle sizes determined from the composting literature, is an example of a mechanism that can be mechanically designed to integrate the two processes. However, it requires careful experimental studies to take the pre-treated diaper waste through to measured outcomes of larval performance, safety and resource-recovery to realize its potential. Such studies would be able to resolve the evidence gap identified here, and help to clarify if BSF-based bioconversion is a viable, scalable, and safe waste-management option for mechanically pre-treated diaper waste.

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