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On Site Management of Agricultural Residue by Pelletization

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Abstract: Agricultural residue management is a major challenge due to the large quantity of crop residues generated during harvesting and the difficulties associated with their collection, transportation, storage, and utilization. Pelletization provides an effective method for converting loose agricultural residues into dense, uniform and easily transportable solid biofuel. Previous studies have investigated the effects of biomass moisture content, particle size, compression conditions, die speed, binders and machine operating parameters on pellet density, durability and energy consumption. Research on pellet-machine design has also demonstrated the potential for producing quality biomass pellets from different plant residues. However, conventional pelletization systems generally require the residues to be collected and transported to a separate processing facility. This project proposes an on-site agricultural residue management system in which a pelletizing unit is integrated with a harvesting machine. The proposed system aims to collect the residue generated during harvesting, process it through size reduction and conditioning, and immediately convert it into pellets at the field site. Such integration can reduce loose-residue handling, transportation requirements and residue accumulation in the field while improving the utilization of agricultural biomass as a renewable energy resource. The performance of the integrated system can be evaluated in terms of pellet production rate, specific energy consumption, pellet density, durability, moisture content, residue recovery efficiency and overall machine performance. The proposed approach provides a potential pathway toward decentralized and efficient management of agricultural residues through in-field pelletization.

Keywords— Agricultural residue management, Biomass pelletization, On-site pelletization, Integrated harvesting machine, In-field residue management, Agricultural waste, Biomass densification, Pellet machine, Crop residue collection, Pellet quality, Pellet durability, Specific energy consumption.

I. INTRODUCTION

Agricultural production generates large quantities of crop residues such as straw, stalks, husks, and other lignocellulosic materials. These residues are often left scattered in the field or are subjected to open burning, which can result in the loss of potentially useful biomass and contribute to environmental pollution. At the same time, the low bulk density of loose agricultural residues makes their collection, transportation, handling, and storage difficult and costly. Therefore, an efficient method for on-site management and utilization of agricultural residues is required. Pelletization is an effective densification technique for converting loose agricultural biomass into compact, uniform, and easily manageable fuel pellets. Previous studies have demonstrated that pellet quality and energy consumption are strongly influenced by important parameters such as moisture content, particle size, compression conditions, die speed, temperature, and the use of binders. Studies on biomass pelleting have also shown that appropriate operating conditions can improve pellet density, durability, and mechanical strength while reducing the specific energy required for pellet production [2]–[4]. More recent research has focused on the design and performance evaluation of biomass pelleting machines and the optimization of pellet manufacturing processes [14], [16].

However, conventional agricultural-residue management generally involves several separate operations. After harvesting, residues must be collected, gathered, transported, and subsequently processed at a centralized pelletization facility. This additional handling increases transportation requirements, labor, time, and energy consumption. Furthermore, loose residues occupy a large volume, making their transportation and storage inefficient. Although previous research has extensively investigated biomass densification and pellet-machine performance, the integration of residue collection and pelletization directly with the harvesting operation remains an important area for further development. The proposed project, "On-Site Management of Agricultural Residue by Pelletization," aims to address this issue by developing a pelletization unit integrated with a harvesting machine. The proposed system is intended to collect agricultural residues generated during harvesting and directly process them into compact biomass pellets at the field site. The integrated approach can reduce the need for separate residue collection and transportation while converting waste biomass into a useful and potentially marketable renewable-energy resource. The concept therefore combines harvesting, residue collection, size reduction/conditioning, and pelletization into a more continuous field operation.

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The performance of the proposed system can be evaluated based on parameters such as residue collection efficiency, pellet production rate, specific energy consumption, pellet density, pellet durability, moisture content, and overall machine efficiency. The studies by Tumuluru [3], Tumuluru et al. [4], Adapa et al. [2], and Ibrahim et al. [16] provide important technical foundations for selecting pelletization parameters and evaluating machine performance, while the broader densification studies [8], [10] provide the basis for understanding agricultural-residue utilization. By integrating pelletization with harvesting, the proposed system aims to provide a practical approach for in-field residue management, reduction of loose biomass handling, and decentralized production of biomass fuel pellets.

II. LITERATURE REVIEW

Agricultural residues have considerable potential as renewable biomass resources, and pelletization has been widely investigated as a method for converting loose residues into compact, useful solid fuels. Early research established the fundamentals of biomass densification, including binderless pelletization and the influence of feedstock characteristics on pellet formation [1]. Subsequent studies on corn stover and other agricultural residues demonstrated that moisture content, die configuration, compaction conditions, binders, and operating parameters significantly affect pellet density, durability, strength, and specific energy consumption [3], [4]. Research on rice-harvest residues and wheat straw confirmed the feasibility of producing pellets from different crop residues while emphasizing importance of feedstock preparation and pellet-quality assessment [6] .

Several studies have examined the broader economic, environmental, and energy potential of agricultural-residue pelletization. Economic assessments indicate that pelletization can create value from agricultural waste and support renewable-energy production, although transportation, processing energy, equipment cost, and feedstock availability influence overall feasibility [5], [12], [13]. Reviews of biomass densification have identified pelletization as an effective approach for improving biomass handling, storage, transportation, and utilization [8], [10], [18]. Recent research has also focused on process optimization, advanced pelletization techniques, and the design and performance assessment of biomass pellet machines [14], [16]. Despite these developments, most existing studies consider residue collection and pelletization as separate operations. Limited attention has been given to integrating residue collection and pelletization directly with harvesting equipment. Therefore, the proposed project aims to address this gap by developing an on-site agricultural-residue management system in which a pelletization unit is integrated with the harvesting machine, enabling residues to be collected and densified directly in the field while potentially reducing handling and transportation requirements [10], [14], [16], [18].

Based on the reviewed literature, the proposed project focuses on on-site management of agricultural residue through pelletization, with the pelletizing unit integrated directly with a harvesting machine. The system is intended to collect crop residues during harvesting and convert them into compact pellets at the field site. This approach addresses the problems of loose-residue handling and transportation while providing a pathway for the recovery and utilization of agricultural biomass as a renewable energy resource. The literature therefore provides a strong technical foundation for investigating the design, fabrication, and performance evaluation of an integrated harvesting and pelletization system.

In summary, the reviewed literature establishes that agricultural-residue pelletization is a technically feasible and promising method for converting low-density crop residues into valuable renewable biomass fuel. Previous studies have extensively investigated feedstock characteristics, moisture content, particle size, binders, compaction conditions, pellet quality, energy consumption, machine design, process optimization, and economic feasibility [1]–[18]. The research confirms that appropriate control of operating and material parameters is essential for achieving high-quality pellets with suitable density and durability while maintaining reasonable energy consumption [3], [4], [7].

Economic and techno-economic studies further indicate that pelletization can create value from agricultural residues, although collection, transportation, processing costs, and feedstock availability remain important challenges [5], [12], [13], [18]. Recent developments in pellet-machine design and optimization provide a strong foundation for developing improved biomass-processing systems [14], [16]. However, most existing approaches perform residue collection, transportation, and pelletization as separate operations. Therefore, a significant opportunity exists to integrate harvesting, residue collection, and pelletization into a single on-site system. The proposed project addresses this gap by developing an integrated harvesting-machine pelletizer for efficient, decentralized, and value-added agricultural-residue management.

III. RESEARCH GAPS OBSERVED

Based on the review of the 18 research papers, the following major research gaps have been identified:

1. Lack of integration with harvesting machines – Most existing studies investigate pelletization as a separate post-harvesting process rather than integrating it directly with harvesting equipment.
2. Separate residue collection and transportation – Existing systems generally require agricultural residues to be collected and transported before pelletization, increasing handling and transportation requirements.

3. Limited on-site pelletization research – There is comparatively limited research on converting agricultural residues into pellets directly in the field immediately after harvesting.
4. Feedstock variability – Agricultural residues vary significantly in moisture content, particle size, density, and composition, but integrated field systems need to handle these variations continuously.
5. Power and energy limitations – An integrated harvesting-pelletizing system must operate within the available power of the harvesting machine while maintaining acceptable pellet production and quality.
6. Continuous material feeding – Efficient transfer of irregular agricultural residue from the harvesting unit to the pelletizer without blockage or inconsistent feeding remains a technical challenge.
7. Limited performance evaluation of integrated systems – More research is required to simultaneously evaluate residue collection efficiency, pellet production rate, pellet quality, energy consumption, and overall machine efficiency.
8. Limited economic assessment of mobile systems – Although several studies examine the economics of pelletization, fewer studies evaluate the economic benefits of an integrated, mobile, field-based pelletization system.

The existing literature demonstrates significant progress in agricultural-residue pelletization, including feedstock preparation, densification, pellet quality, energy consumption, machine design, process optimization, and economic feasibility [1]–[18]. However, a clear research gap exists in the integration of harvesting, residue collection, and pelletization into a single field-based system. Most existing pelletization processes require residues to be collected, transported, and processed separately, which increases handling operations and transportation requirements for low-density biomass.

Furthermore, limited research has addressed the challenges of continuous residue feeding, variable moisture and particle size, power availability, and pellet-quality control under actual harvesting conditions. The economic benefits of reducing loose-residue transportation through on-site densification also require further investigation.

Therefore, there is a need to develop and evaluate an integrated harvesting-machine pelletization system capable of collecting agricultural residues and converting them into useful biomass pellets directly at the field site. The proposed research aims to address these gaps by evaluating residue collection efficiency, pellet production capacity, pellet quality, specific energy consumption, machine performance, and potential economic benefits of on-site agricultural-residue pelletization.

IV AGRICULTURAL RESIDUE PELLETIZATION TECHNOLOGY

Agricultural Residues as Biomass Feedstock

Agricultural residues are the organic materials remaining after the harvesting and processing of agricultural crops and represent an important source of renewable biomass. Common agricultural residues include rice straw, wheat straw, maize or corn stover, sugarcane residues, cotton stalks, groundnut shells, husks, and other crop residues. These materials generally have low bulk density, irregular shape, variable moisture content, and different physical and chemical characteristics depending on the crop, harvesting method, and field conditions. Their low density makes loose residues difficult to collect, handle, transport, and store efficiently.

Large quantities of agricultural residues may also remain scattered in fields after harvesting, creating difficulties in residue management. However, these residues contain organic matter and energy that can be recovered through suitable biomass-conversion technologies. Pelletization provides an opportunity to convert these low-density agricultural residues into compact and uniform biomass fuel. Therefore, proper utilization of agricultural residues can reduce waste while creating a useful renewable energy resource.

Agricultural Residue Collection During Harvesting

Agricultural residue is generated continuously during harvesting as straw, stalks, leaves, husks, and other plant materials are separated from the useful crop portion. In conventional agricultural operations, these residues may be left in the field, collected manually, baled, gathered using separate machinery, or transported to another location for further processing. Separate residue collection requires additional equipment, labor, time, and transportation.

The low bulk density and irregular distribution of loose residues can increase transportation requirements and make efficient collection difficult. Material losses may also occur during field collection, loading, unloading, and transportation. These limitations create a need for a more efficient method in which residue can be collected immediately during harvesting. On-site residue collection integrated with the harvesting machine can reduce separate handling operations and provide a continuous material flow toward the subsequent processing unit. This approach forms an important part of the proposed system for managing agricultural residue directly at the field site.

Biomass Densification and Pelletization

Biomass densification is the process of converting loose and low-density biomass into a compact form by applying mechanical force.

Densification reduces the volume occupied by biomass and improves its handling, transportation, storage, and utilization characteristics. Among various densification methods, pelletization is suitable for agricultural residues because it produces relatively uniform cylindrical or compact fuel particles using mechanical compression. During pelletization, prepared biomass is continuously fed into a die and compressed through mechanical action. The applied pressure forces the biomass particles together, while friction and heat generated during compression contribute to bonding and formation of a stable pellet. Pelletization can increase biomass bulk density, improve handling characteristics, and produce a more convenient form of solid biofuel compared with loose residues. For the proposed project, pelletization is selected because it can be incorporated into a harvesting-machine system to convert collected agricultural residue into a dense product directly at the site of generation.

Pelletization Process

The proposed on-site pelletization process consists of a continuous sequence beginning with harvesting and residue generation, followed by residue collection, size reduction, feeding, compression/pelletization, pellet cutting, and pellet collection. During harvesting, the crop is processed and the remaining agricultural residue is collected by the integrated collection mechanism. The collected material is then transferred toward the size-reduction unit, where large or irregular residue particles are reduced to a suitable size for efficient pelletization. The prepared biomass is subsequently conveyed into the feeding system, which supplies a controlled quantity of material to the pelletizing unit. Inside the pelletizer, the biomass is compressed through a die under mechanical pressure to form compact pellets. The continuous extruded material is then cut into suitable lengths, and the finished pellets are discharged and collected for storage, transportation, or further utilization. The efficiency of this sequence depends on maintaining continuous material flow and proper synchronization between the harvesting and pelletizing units.

Harvesting → Residue Collection → Size Reduction → Feeding → Compression/Pelletization → Pellet Cutting → Pellet Collection

Factors Affecting Pellet Quality

The quality and performance of biomass pellets are influenced by several material and operating parameters. Moisture content plays an important role because insufficient or excessive moisture can affect particle bonding, pellet strength, energy consumption, and durability. Particle size influences material flow and the ability of particles to form a compact structure during compression. Compression pressure directly affects densification and pellet strength, while die size and die geometry influence pellet dimensions, throughput, and compaction behavior. Die temperature can influence the bonding characteristics of biomass during compression. Feed rate affects the quantity of material entering the pelletizer and must be controlled to avoid overloading or insufficient feeding. Rotational speed influences material residence time, throughput, and energy consumption. The use of a suitable binder can improve pellet strength and durability for some types of agricultural residues. Residence time also affects the extent of compression and bonding within the die. Therefore, proper optimization of these parameters is essential for producing pellets with desirable density, durability, strength, and consistent quality while maintaining reasonable energy consumption.

Types of Pelletizing Machines

Different pelletizing machines are available depending on feedstock characteristics, production capacity, and application requirements. A flat-die pellet mill uses a flat perforated die with rollers that compress biomass through the die openings. It has a relatively simple construction and can be suitable for small- and medium-scale biomass applications. A ring-die pellet mill uses a rotating ring-shaped die and rollers to produce pellets at relatively high production capacities and is commonly associated with larger-scale pellet production. A roller-type pelletizer uses mechanical rollers to compress and densify biomass and can be adapted to different feedstock and operating conditions. A screw-type pelletizer uses a rotating screw to convey and compress biomass through a die, providing continuous material movement and compression. For an integrated harvesting-machine application, machine selection must consider available power, size, weight, production capacity, feedstock characteristics, energy consumption, maintenance requirements, and ease of integration. The selected pelletizing mechanism should be compact enough for field operation while maintaining sufficient capacity to process the residue generated during harvesting.

IV. VALUE CREATION OPPORTUNITIES

Based on the agricultural-residue pelletization studies you provided, the proposed system can create value by converting low-density crop residues generated during harvesting into a useful, dense, and potentially marketable biomass fuel. Pelletization improves the handling characteristics of agricultural residues and creates opportunities for resource recovery, energy generation, and economic utilization. The proposed integration of the pelletizing unit with the harvesting machine can further create value by performing residue collection and densification directly at the field site.

1. Production of Biomass Fuel Pellets

The primary value-creation opportunity is the conversion of agricultural residues such as straw, stalks, husks, and other crop residues into compact biomass fuel pellets.

Instead of treating residues as waste, the proposed system converts them into a standardized solid fuel that can be used for heating and other biomass-energy applications. Pelletization increases the density and improves the handling, storage, and transportation characteristics of loose agricultural biomass.

2. On-Site Residue Management

Integration of the pelletizer with the harvesting machine creates an opportunity for immediate field-level residue management. Residues can be collected and processed at the location where they are generated, reducing the need for separate residue collection and subsequent transportation to a centralized pelletization facility. This can make the residue-management chain more direct and potentially reduce handling requirements.

3. Reduction in Transportation and Handling

Loose agricultural residues occupy a relatively large volume because of their low bulk density. Converting the residue into pellets at the field site can reduce the volume that needs to be transported after harvesting. This creates value through potentially lower transportation requirements, handling operations, labor requirements, and associated costs. The economic importance of transportation and processing is also highlighted in the literature on agricultural-residue pelletization and techno-economic assessment.

4. Additional Income Opportunity for Farmers

Agricultural residues that have limited value in their loose form can become a saleable biomass product after pelletization. The production of pellets can therefore provide an additional value stream from crop residues. Instead of considering residue removal only as a cost or disposal activity, farmers or agricultural service providers could potentially recover economic value from the biomass through pellet production.

5. Improved Utilization of Agricultural Biomass

The proposed system promotes the valorization of agricultural residues by treating them as a resource rather than waste. Agricultural biomass that might otherwise remain unused can be converted into a useful energy product. This contributes to more efficient utilization of locally available biomass resources and supports the broader concept of sustainable biomass energy production.

6. Reduction of Field Residue Accumulation

On-site collection and pelletization can reduce the quantity of loose residues remaining in the field after harvesting. This creates an opportunity for better field cleanliness and more organized residue management. Where residues would otherwise be burned or disposed of, their recovery for pellet production can provide an alternative utilization pathway.

7. Renewable Energy Generation

Agricultural-residue pellets can serve as a renewable solid-biomass fuel, providing an alternative to some conventional fossil-based fuels in suitable applications. The literature demonstrates the potential of agricultural residues for solid biofuel production and highlights pelletization as a method for improving biomass utilization.

8. Creation of Rural Employment and Business Opportunities

A field-based pelletization system can create opportunities for local biomass collection, machine operation, pellet production, transportation, storage, and marketing. This is particularly relevant in agricultural regions where crop residues are generated seasonally. A mobile integrated system could potentially support decentralized biomass-fuel production rather than depending entirely on large centralized processing facilities.

9. Value Creation Through Improved Pellet Quality

Appropriate control of moisture content, particle size, compaction conditions, die speed, and other operating parameters can improve pellet density, durability, and mechanical strength. Better-quality pellets are easier to handle and store and can have greater usefulness as a solid fuel. Therefore, optimizing the integrated machine can create additional value by producing pellets with consistent physical characteristics.

10. Energy and Process Efficiency

The literature shows that pelletization performance is closely associated with specific energy consumption and operating conditions. Designing the integrated system to use the available harvesting-machine power efficiently can create value by reducing the energy required per unit of pellet produced. This is particularly important because the pelletizer will be mechanically integrated with the harvesting machine and therefore must operate within its available power capacity.

V. COMPARATIVE ANALYSIS

Agricultural residues can be managed through several approaches, including leaving the residues in the field, conventional collection and transportation, centralized pelletization, and on-site pelletization. Conventional residue management is simple but provides limited value from the biomass and may require additional operations for collection or disposal. Centralized pelletization can produce high-quality pellets under controlled processing conditions, but the loose residues must first be collected and transported to the pellet-production facility. This increases the handling and transportation requirements because agricultural residues generally have low bulk density. In contrast, on-site pelletization converts the residue into dense pellets close to the point where it is generated, reducing the need to transport large quantities of loose biomass.

The proposed system provides a further improvement by integrating the pelletizing unit directly with the harvesting machine. During harvesting, the agricultural residue can

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be collected and continuously transferred to the pelletization unit, where it is processed into compact pellets. This eliminates or reduces the requirement for a separate residue-collection operation and allows the residue to be managed immediately at the field site. Compared with conventional centralized systems, the integrated approach has the potential to reduce loose-residue handling, transportation volume, labor requirements, and post-harvest residue accumulation. However, the integrated system requires careful consideration of available machine power, feed rate, pelletizer capacity, machine dimensions, residue flow, and synchronization between harvesting and pellet production.

From the technical perspective, centralized pelletization provides better control over feedstock preparation, moisture content, particle size, compression, and operating conditions. The proposed on-site system must operate under changing field conditions, where agricultural residues may vary in moisture content, particle size, density, and composition. Therefore, suitable conditioning and feeding mechanisms are required to maintain consistent pellet production. Important performance parameters include pellet production rate, pellet density, durability, moisture content, specific energy consumption, and residue recovery efficiency.

From the economic perspective, centralized pelletization requires transportation of loose agricultural residues from the field to the processing facility. Since loose biomass has low bulk density, transportation can represent an important part of the overall handling process. On-site pelletization can increase the density of the material before transportation, potentially reducing transportation volume and handling costs. Furthermore, the produced pellets can provide an additional value stream from agricultural residues that would otherwise have limited economic value.

From the environmental perspective, on-site pelletization provides an opportunity to utilize agricultural residues as a renewable biomass resource rather than treating them as waste. The system can help reduce residue accumulation in agricultural fields and provide an alternative pathway for utilizing crop residues. The environmental performance of the system will depend on factors such as residue recovery, machine fuel or energy consumption, pellet utilization, and the distance that the pellets subsequently need to be transported.

Table 1. Comparative Analysis of On site management of agricultural residue by pelletization

Parameter	**Conventional residue management**	**Centralized pelletization**	**Proposed on-site integrated pelletization**
Residue collection	Separate/required	Separate/required	Integrated with harvesting
Pelletization location	Not applicable	Processing plant	Agricultural field
Loose-residue transportation	High	High	Reduced
Handling operations	Multiple	Multiple	Reduced
Pellet production	No	Yes	Yes
Machine mobility	High	Low	High
Control of processing conditions	Low	High	Moderate
Dependence on field conditions	High	Low–moderate	High
Potential residue utilization	Low	High	High
Potential value generation	Low	High	High
Main advantage	Simple residue handling	High production capacity	Harvesting + collection + pelletization in one system
Main challenge	Residue disposal/accumulation	Transportation and processing cost	Power, space, feedstock variation and integration

Table2.Agricultural Residue Pelletization Technology

Value Creation opportunity	Resource Conservation	Economic Value	Commercial potential	Sustainability
Agricultural residue Utilization	Very High	High	Excellect	Very High
On-site pelletization	Very High	Very High	Excellect	Very High
Reduction in transportation	Very High	Very High	Excellect	Very High
Low operating cost	High	Very High	Excellect	High

Integrated harvesting & pelletization	Very High	High	Excellect	Very High
Renewable energy production	Very High	High	Excellect	Very High

VI. CHALLENGES

One major challenge in agricultural-residue pelletization is the variation in feedstock properties. Agricultural residues differ in moisture content, particle size, density, composition, and physical structure, which can significantly affect pellet formation, density, strength, and durability. Therefore, maintaining suitable feedstock conditions before pelletization is essential for consistent pellet quality [2], [3], [6], [7].

A second challenge is the energy requirement of the pelletization process. Compression and densification require considerable mechanical energy, and inappropriate operating conditions can increase specific energy consumption while reducing pellet quality. The selection of suitable moisture content, die speed, compression conditions, and binder concentration is therefore important for achieving a balance between pellet quality and energy consumption [3], [4], [14].

Another important challenge is pellet strength and durability. Pellets must withstand handling, transportation, and storage without excessive breakage or degradation. Studies have shown that compaction conditions, biomass characteristics, binders, and moisture content influence pellet strength, durability, and water absorption. Achieving sufficient mechanical stability while maintaining economical production remains a key challenge [4], [7], [15].

Economic and logistical challenges are also significant in agricultural-residue pelletization. Collection, transportation, processing, equipment investment, energy consumption, and maintenance can influence the overall feasibility of pellet production. The low bulk density of loose residues makes transportation particularly difficult and costly. These issues have been highlighted in studies addressing economic feasibility, biomass pellet markets, and techno-economic aspects of densification [5], [12], [13], [18].

Finally, the integration of pelletization with a harvesting machine introduces additional engineering challenges. The pelletizer must operate within the available power, space, weight, and capacity limitations of the harvesting machine while maintaining continuous residue feeding and acceptable pellet production. Variations in field conditions and residue availability can further affect system performance. Existing research provides substantial knowledge on pelletization and individual pellet-machine design, but the integration of harvesting, residue collection, and on-site pelletization requires further investigation [10], [14], [16], [18].

VII. DISCUSSIONS

The review of 18 research papers demonstrates that agricultural residues such as rice straw, wheat straw, corn stover, and other crop residues have significant potential as renewable biomass resources. Pelletization converts these low-density materials into compact solid fuels, improving their handling, storage, transportation, and energy utilization. Thus, agricultural residues can be treated as valuable raw materials rather than waste [1], [6], [8], [10], [18].

The literature shows that pellet quality depends strongly on feedstock and processing conditions. Moisture content, particle size, biomass composition, compression pressure, die configuration, operating speed, and binder addition influence pellet density, strength, durability, and water resistance. Proper control of these parameters is therefore essential for producing consistent and high-quality pellets [2], [3], [4], [7].

Energy consumption is another important factor in pellet-machine operation. High compression requirements and unsuitable moisture or operating conditions can increase specific energy consumption. Optimization of moisture, die characteristics, feed rate, binder use, and machine parameters can improve pellet quality while reducing energy requirements [3], [4], [14]. This is particularly important for the proposed system because the pelletizer will operate using the available power of the harvesting machine.

The studies also demonstrate the economic potential of agricultural-residue pelletization. Converting residues into pellets can create additional value, although feedstock availability, collection and transportation costs, energy consumption, equipment investment, maintenance, and pellet market value influence overall feasibility [5], [12], [13], [18]. The low bulk density of loose residues also creates transportation and handling difficulties, making on-site densification an attractive approach [5], [10], [12].

Recent research has progressed from fundamental pelletization to machine development, process optimization, co-pelletization, and techno-economic assessment [1], [9], [14], [16], [17]. However, most existing studies treat pelletization as a separate operation after residue collection and transportation. Limited attention has been given to mobile systems that collect and pelletize residues directly during harvesting [10], [14], [16], [18].

Therefore, the proposed “On-Site Management of Agricultural Residue by Pelletization” extends existing research by integrating the pelletization unit with the harvesting machine. The system can potentially combine harvesting, residue collection, conditioning, and pelletization into a continuous field operation while reducing loose-residue handling and transportation. Further development should focus on machine integration, power requirements, feedstock variability, pellet quality, production capacity, energy consumption, residue recovery efficiency, and economic feasibility.

VIII. CONCLUSIONS

In conclusion, the reviewed research demonstrates that agricultural residues such as rice straw, wheat straw, corn stover, and other crop residues can be effectively converted into valuable renewable biomass fuel through pelletization. The studies establish that pellet quality and energy consumption depend strongly on parameters such as moisture content, particle size, compression conditions, die configuration, feed rate, and machine operating speed [2]–[4], [7], [14]. Pelletization also offers economic and environmental benefits by increasing biomass density and improving its handling, storage, transportation, and utilization [5], [8], [10], [18]. However, most existing systems perform residue collection, transportation, and pelletization as separate operations. This indicates a clear opportunity for an integrated approach. The proposed on-site agricultural-residue management system, in which the pelletizer is integrated with the harvesting machine, aims to collect and densify residues directly during harvesting, thereby reducing loose-residue handling and transportation while producing useful biomass pellets. The proposed system therefore provides a promising approach for efficient, economical, and sustainable agricultural-residue management and renewable biomass-fuel production.

Future Scope

The future scope of the proposed on-site agricultural-residue management system by pelletization includes further improvement of the integrated harvesting and pelletizing mechanism to achieve higher residue collection efficiency and continuous pellet production. The system can be optimized for different agricultural residues such as rice straw, wheat straw, corn stover, and other crop residues by adjusting the feeding, chopping, conditioning, and compression mechanisms. Further development can focus on optimizing pelletizer speed, die size, feed rate, moisture content, and compression conditions to improve pellet density, durability, production capacity, and specific energy consumption.

The system can also be developed into a fully automated and intelligent field-based pelletization machine. Sensors can be incorporated to monitor residue moisture, feed rate, machine load, pellet quality, and power consumption during operation. Automatic control of the feeding and pelletizing parameters could help maintain consistent pellet quality under changing field conditions. Future versions may also incorporate improved power transmission, energy-efficient drives, variable-speed control, and suitable mechanisms for handling variations in residue quantity and composition.

In the long term, the proposed system can be expanded into a commercial mobile biomass-processing unit capable of operating with different harvesting machines and crops. Economic and environmental assessments can be carried out to determine the reduction in transportation, labor, and residue-handling costs and to evaluate the overall sustainability of the system. The produced pellets can be further investigated for applications in boilers, biomass heating systems, and other renewable-energy applications. Integration with decentralized biomass supply chains and rural energy systems could further increase the value of agricultural residues and support sustainable agricultural waste management.

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