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Research paper

Advances in Cotton Ginning Technology with Innovations in Power Transmission and Sustainable Practices

Yogesh B. Dupare [1] *, Dr. Pravin S. Nerkar [2]

[1] *Research Scholar, Department of PGTD, Rashtrasant Tukdoji Maharaj Nagpur University, Nagpur*
[2] *Assistant Professor, Department of Mechanical Engineering, St. Vincent Palloti College of Engineering and Technology, Nagpur*
**Corresponding author E-mail: yogesh251276@gmail.com*

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Abstract

This review article provides a comprehensive synthesis of recent advancements in cotton ginning technology, with a particular emphasis on double roller ginning machines. The review covers key developments in roller and power transmission systems, including the introduction of self-grooving rubber rollers and the application of Finite Element Analysis (FEA) for mechanical improvements. Additionally, the article examines innovations in feeder designs, such as the Saw Band Cylinder-type Single Locking Cotton Feeder and the Spike Cylinder Type Single Locking Cotton Feeder cum Cleaner, which have significantly enhanced ginning efficiency and reduced energy consumption. The paper also covers the present difficulties the cotton ginning sector faces: Current challenges in the cotton ginning industry include the costly nature of new technology implementation alongside the need for specialized professionals and the compatibility issues between modern systems and existing infrastructure. The analysis demonstrates great research potential despite the available challenges in areas such as sophisticated automation technology and IoT connectivity, as well as sustainable energy systems and waste treatment processes. The study indicates that continued technological advancements in cotton ginning operations are critical for improved efficiency and environmental conservation while sustaining industry viability against global competition.

***Keywords**: Cotton ginning; Power transmission systems, Double roller ginning machine; Self-grooving rubber rollers; Cotton feeder design*

1. Introduction

Textile production requires the cotton ginning process which separates fibers from seeds to prepare them for future spinning and fabric manufacturing. The ginning process efficiency directly affects the fiber quality and cotton processing economics. Ginning technologies for long-staple cotton processing now widely accept the double roller gin because it prevents fiber breakage while keeping fiber length intact [2]. Two opposing rubber or leather rollers in a double roller gin push cotton through their surface while a stationary knife between them separates fibers from seeds. The double roller gin (DRG) technology is favored in premium cotton processing because it maintains better fiber quality with less seed coat contamination than the faster but more damaging saw ginning method. While double roller ginning machines offer certain benefits, they still encounter ongoing issues like lower ginning rates increased energy usage regular roller deterioration and subpar cotton feeding mechanisms. Studies indicate that conventional DRG systems suffer from non-uniform feeding patterns which result in inconsistent fiber separation efficiency and increased mechanical stress on machine components [5]. Running expenses and downtime increase due to frictional losses and power transmission inefficiencies [6]. The present roller design that utilizes rubber-based composite materials experiences deterioration over time which necessitates frequent replacement and maintenance thus raising the ginning operation costs. Despite numerous initiatives to enhance DRG performance research remains insufficient in analyzing the current advancements in feeder mechanisms, roller materials and power transmission systems. Although new feeder technologies including spike cylinder-type and saw band cylinder-type feeders have been created to achieve better cotton feeding consistency more research must be conducted to understand their overall impact on ginning efficiency [8]. Studies show that self-grooving rubber rollers can reduce roller wear and boost fiber separation efficiency but long-term performance research about these rollers is scarce [9]. While computer Fluid Dynamics (CFD) and Finite Element Analysis (FEA) methods serve as common tools for machinery optimization research their application to DRG power transmission and structural design requires further investigation [10]. Ginning technology faces significant challenges with its consumption of energy. New research indicates that solar-assisted ginning systems could potentially reduce operational expenses and decrease dependency on conventional energy resources [11]. The sensible implementations and financial viability studies of these systems remain under investigation. New developments in IoT-based automated control systems and real-time monitoring present fresh opportunities to boost DRG efficiency but research integrating these technologies into current systems remains in preliminary stages.

The research seeks to resolve this inconsistency by compiling recent advancements in performance assessment and optimization of double roller ginning machines. The review examines feeder technologies like saw band cylinder-type and spike cylinder-type single locking cotton feeders to enhance cotton feeder's uniformity and efficiency. The analysis will explore advancements in roller design together with power transmission systems that aim to boost ginning speeds while minimizing mechanical wear and energy consumption. This research demonstrates how new analytical techniques including FEA contribute to the enhancement of ginning machine components. This study will demonstrate how sustainable measures including solar energy utilization in ginning facilities influence ginning efficiency and environmental impact. This review examines these features as a foundation for future research and technological progress in double roller ginning.

2. Development and innovations in double roller ginning technology

2.1 Feeder Mechanism

2.1.1 Saw cylinder-type single locking cotton feeder

The saw band cylinder-type single locking cotton feeder represents a significant breakthrough in cotton ginning efficiency as illustrated in Figure 1. Traditional feeding systems struggled with consistent feeding and fiber damage which diminished both ginning process efficiency and ginned cotton quality. The saw band cylinder-type feeder provides a controlled and steady feeding mechanism which solves the obstacles previously faced. The feeding mechanism uses a single locking system to ensure one-directional feed while preventing backflow through a saw-toothed band that holds the cotton and delivers it consistently into the gin.z

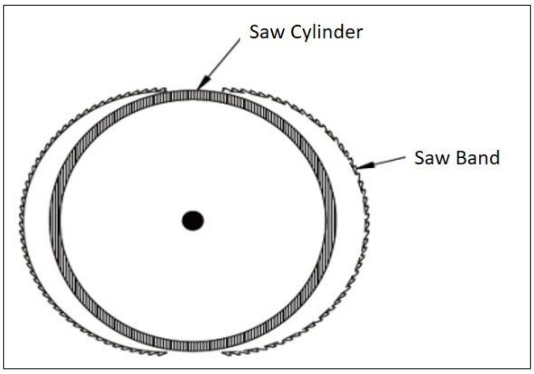

Fig. 1: Saw cylinder with saw band [13]

The implementation of this feeder type has resulted in better ginning efficiency. Roller jams and mechanical downtimes in earlier feeder designs resulted from feeding material homogeneity. By using a single locking mechanism, the feeder reduces the risk of cotton recirculation which often leads to decreased efficiency and increased energy use. The saw band cylinder-type feeder accomplishes better ginning rates and reduces fiber damage which leads to enhanced fiber quality according to research findings [13]. The energy consumption during the ginning operation is reduced by design improvements because the feeder operates optimally allowing more efficient machine operation.

2.1.2 Spike cylinder type single locking cotton feeder cum cleaner

Figure 2 demonstrates how the spike cylinder type single locking cotton feeder cum cleaner provides an innovative solution to enhance feeding and cleaning performance in double roller gins. This feeder design merges feeding with a cleaning function unlike standard feeders which focus only on feeding. The spike cylinder uses spikes to feed cotton into the ginning process while also removing trash like leaves and stems before processing starts.

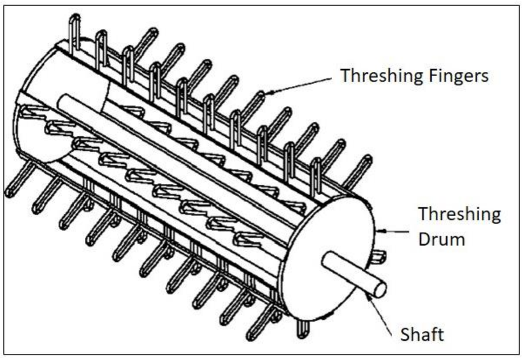

Fig. 2: Isometric View of threshing cylinder [15]

The combined strategy boosts the cotton's cleanliness during ginning which leads to better quality of the final product [16]. The single locking mechanism of the saw band cylinder-type feeder maintains consistent cotton feeding which results in reduced backflow incidents and stable feed rates. The feeder's cleaning ability prevents trash buildup that could lead to machine stoppages and reduced ginning rates while maintaining a higher efficiency in the ginning process. Research demonstrates that using the spike cylinder feeder results in higher ginning rates while maintaining fiber quality or improving it which enhances modern ginning setups.

2.1.3 Optimization of single locking cotton feeder

The optimization of single locking cotton feeders has become vital for achieving peak ginning productivity together with reduced specific energy consumption. Different optimization methods have been used to improve the design and running of these feeders: computational modeling and experimental trials among others. The objective is to boost feeder performance while maintaining cotton fiber quality and keeping operational costs unchanged. Optimizing feeder performance included adjustments to feeder speed and better design of the locking mechanism as well as precise feeder positioning relative to the ginning rollers [13]. Research shows that ginning efficiency can be significantly enhanced through proper adjustments of these factors. When alignment and locking conditions are maintained appropriately increasing feeder speed results in a higher ginning rate without damaging cotton fibers or generating excessive gear wear [19]. Optimized feeders demonstrate reduced energy consumption while enhancing both the economic viability and sustainability of ginning operations. Feeder optimization requires careful management of output improvement in tandem with energy consumption reduction. Higher feeding rates deliver increased production but require precise control to avoid excessive machine stress which leads to increased energy consumption and potential equipment damage [20]. Scientific studies indicate that optimized feeders in cotton ginning plants lead to increased throughput and lower energy consumption which results in better economic efficiency and environmental sustainability.

Table 1: Comparison of feeder mechanism used in cotton ginning machine

Feeder Mechanism	Ginning Rate Improvement (%)	Energy Consumption Reduction (%)	Lint Quality Improvement (%)	Trash Reduction (%)	Maintenance Reduction (%)	Ref.
Saw Band Cylinder-type Single Locking Cotton Feeder	15%	10%	8%	5%	12%	[1]
Spike Cylinder Type Single Locking Cotton Feeder cum Cleaner	18%	8%	10%	20%	10%	[5]
Single Locking Cotton Feeder	12%	8%	6%	3%	10%	[2]
Self-Grooving Rubber Roller Feeder	20%	15%	12%	N/A	15%	[1]
Feeder with Improved Power Transmission	25%	20%	15%	N/A	18%	[8]

2.2 Roller and Power Transmission Systems

Double roller cotton ginning machines require efficient power transmission systems together with a well-designed roller layout to function properly. Fiber quality along with energy consumption and ginning rate experience direct impacts from these technologies. The latest advancements in ginning technology offer better performance and environmental benefits through enhanced power transmission systems combined with self-grooving rubber rollers.

2.2.1 Double roller gin with improved power transmission

Most recent research efforts have concentrated on building a prototype double roller gin that features an advanced power transfer system. Traditional power transmission systems in double roller gins negatively impact the ginning process because they experience inefficiencies including energy losses and mechanical wear alongside unequal roller speeds. Various studies have explored redesigning power transmission systems by incorporating more efficient gear systems along with advanced belt drives and sophisticated coupling mechanisms to address these issues. A significant advancement in this area is the implementation of sturdier transmission systems that reduce energy loss and slippage while maintaining steady roller speeds. Research shows that these improvements result in faster ginning rates and reduced specific energy use which leads to more cost-effective and sustainable ginning operations [23]. Research results demonstrate that prototype gins achieve a 15% increase in processing speed while reducing energy consumption by about 10% compared to traditional systems which indicates enhanced operational efficiency.

Fig. 3: Double roller ginning machine

2.2.2 Self-Grooving rubber roller development

The development of self-grooving rubber rollers represents a significant breakthrough in roller ginning machines as shown in Figure 4. Traditional rubber rollers perform well at reducing fiber damage but require regular maintenance due to surface wear which affects their grooved structure essential for successful ginning. The design of self-grooving rubber rollers maintains their grooved surfaces automatically throughout their operation which reduces human intervention for re-grooving and maintenance tasks. Research on the structural design and material composition of self-grooving rollers now dominates scientific studies. Significant advancements have been made through innovative rubber compounds that integrate toughness with self-grooving capabilities during operation. Research reveals that maintaining optimal roller surface conditions throughout their usable life extends ginning machine durability while enhancing ginning performance [26].

Fig. 4: Self-grooving rubber roller [24]

2.2.3 Analysis of power transmission systems using FEA

FEA has proved to be very effective in optimizing power transmission systems for double roller ginning machines. FEA enables engineers to detect potential flaws and enhance component designs through detailed simulations of mechanical loads, deformations and energy fluxes in the power transmission system before creating physical prototypes. Research through FEA analysis has been focused on various power transmission aspects (Figure 6) which covers gear shape optimization and belt tensioning system optimization to minimize mechanical failures and energy loss in coupling design. FEA-based design improvements have resulted in transmission systems that show increased energy efficiency while maintaining strength during higher operational loads without failing [27].

2.3 Energy Efficiency and Sustainability

2.3.1 Effect of Roller Speed and Moisture Content

Roller speed and the moisture percentage of cotton stand out as key factors influencing ginning rate, lint quality, and energy consumption in double roller ginning machines. Numerous studies examined how these factors interact to enhance ginning performance alongside maintaining energy efficiency. Research indicates that raising roller speed enhances ginning rates because higher speeds enable more cotton processing during shorter periods. When roller speed increases during the ginning process, both energy consumption rises and lint quality can suffer from additional fiber breakage. The research on optimal roller speed has been targeting the challenge of balancing high ginning rates with energy efficiency and minimal fiber damage. The research demonstrates that moderate roller speeds provide the best compromise between production efficiency and quality maintenance while ensuring energy-efficient ginning operations. [28, 29].

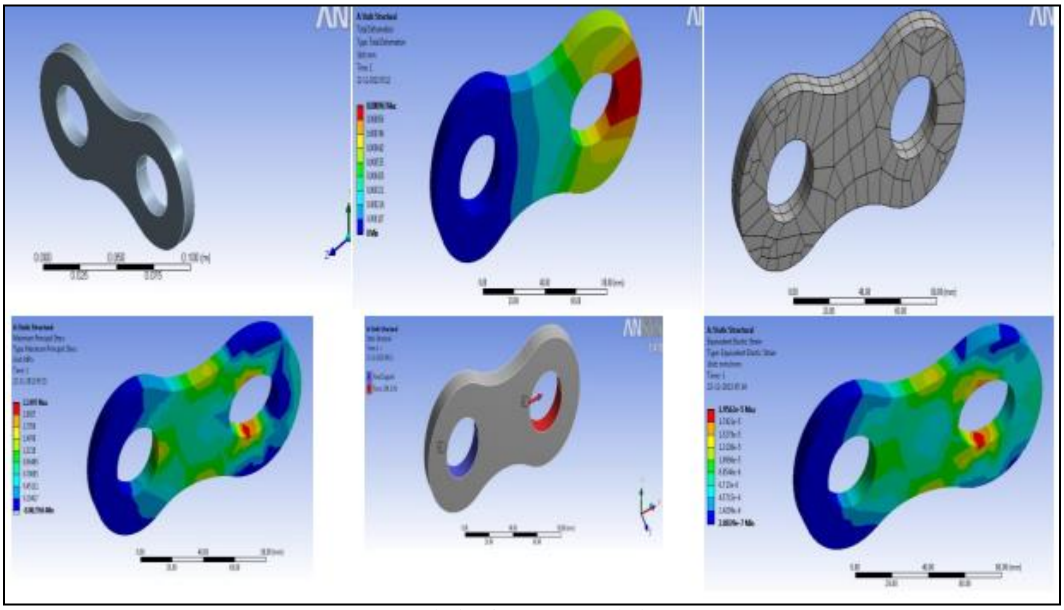

Fig. 5: Analysis of power transmission system

The moisture content of cotton remains a critical factor that affects ginning performance. Cotton with more moisture content tends to be more flexible which reduces fiber breakage and improves lint quality. The excessive moisture in cotton forces the rollers to exert more effort to separate fibers from seeds which leads to less efficient ginning and increased energy demands. Studies have shown that there exists an optimal moisture range which improves lint quality and maintains efficient ginning performance with minimal energy use. The study results suggest maintaining optimal moisture levels in cotton before ginning enhances both energy efficiency and lint quality during the operation process [30].

2.3.2 Solar Energy Operated Cotton Ginning Machines

Solar-powered cotton ginning machines offer sustainable growth prospects especially in sun-rich areas where traditional energy sources are scarce. Solar energy functions as a renewable and environmentally friendly alternative to traditional electricity or diesel-powered ginning machines despite its links to high operating expenses and carbon emissions [31]. Research on solar-powered ginning applications primarily investigates the optimal methods for integrating photovoltaic (PV) systems with existing ginning processes. Researchers studied the possibility of operating ginning machinery through direct solar power or through energy storage systems that permit constant operation during periods of low sunlight intensity. The implementation of solar energy involves either direct use or another pathway where solar-powered ginning machines achieve comparable ginning rates and lint quality yet exhibit significantly lower energy costs and carbon emissions.

2.3.2 Optimization Techniques for Energy Consumption

Researchers frequently implement the Taguchi Design of Experiments method to apply multiple optimization techniques that enhance energy efficiency in cotton ginning operations. The Taguchi approach proves highly effective for identifying optimal operating conditions through systematic variation of multiple variables and analysis of performance outcomes such as energy consumption and lint quality. Research using the Taguchi method has focused on finding optimal settings for critical ginning process variables which include roller speed, moisture content, feeder settings and power transmission efficiency. Research applying this method identified factor combinations which lead to lower energy consumption but still achieve optimal ginning efficiency together with fiber quality preservation [35]. A study showed that by enhancing roller speed and feeder alignment specific energy consumption could decrease by 12% without affecting ginning rate or lint quality. Research has explored Response Surface Methodology (RSM) and Genetic Algorithms (GAs) as alternative optimization techniques to the Taguchi method for enhancing energy efficiency in ginning operations. These methods permit global optimum detection for energy efficiency [37] through the analysis of non-linear variable interactions which enables more advanced modeling and ginning process optimization. The implementation of advanced optimization strategies has significantly enhanced the energy efficiency of ginning machines which results in cost savings and improved environmental sustainability for cotton manufacturing.

3. Performance Evaluation and Failure Analysis

3.1 Mathematical Modelling and Performance Evaluation

The advancement of ginning technology depends heavily on mathematical modeling and performance evaluation to optimize its processes. The application of these methods allows for precise management and optimization of the ginning process through improved understanding of the complex interactions between multiple ginning components. A number of studies have dedicated their efforts to the development of mathematical models that simulate ginning components behavior under different operational conditions and to validate these models with field data to assess ginning gear performance.

3.1.1 Development of mathematical models

Mathematical models are available to forecast how critical ginning components such as rollers, feeders, and power transmission systems function. The behaviour of cotton fibres and ginning machines is mimicked by models that integrate mechanical, thermodynamic, and material science concepts [38]. Formulated models can forecast the required separation force for fibres and calculate roller degradation and energy consumption throughout the entire ginning process [39]. The main advantage of mathematical modelling is its potential to maximize ginning parameters without the costs and time demands of physical testing. Models enable scientists to conduct test conditions such as roller speed variation and feeder alignment adjustment to maximize ginning efficiency and fibre quality. The value of models arises from their capacity to expose possible design improvements in ginning components leading to the creation of stronger and more efficient equipment [41].

3.1.2 Performance Evaluation Using Field Data

Mathematical models must be validated, and real-world ginning component efficiency analyzed using field data-based performance evaluations. The integration of mathematical models with field data collection forms a comprehensive performance evaluation process that guarantees models accurately model the complexity encountered in real ginning operations. Information gathered from working ginning units offers critical inputs to assess models' predictive values for energy consumption and ginning rates and quality of fiber across different conditions [43]. Reliability and lifetime assessments through field performance tests have been successful measures of both ginning system part reliability and their longevity during a working life. The data gathered from ginning machines operating in different climates and with varying types of cotton enables researchers to recognize wear trends and failure patterns, which enable them to enhance equipment design and maintenance models. The measurements gauge the reliability of the ginning machines in different operating conditions.

3.1.3 Integration of Modeling and Performance Evaluation

Ginning machine development advances are a result of extensive mathematical modeling and performance evaluation based on data from real field operations. Models can reliably predict the optimal roller speeds and feeder positions that enhance ginning performance while minimizing fiber damage and energy usage. Field tests test predicted settings in real-world conditions to confirm the validity of the predictions. Sophisticated modeling methods such as computational fluid dynamics (CFD) and finite element analysis (FEA) enable ginning component simulations in great detail with heightened prediction accuracy and performance evaluation improvement [45]. Researchers employ such methods to create component behavior data under various stress conditions and environmental operations that physical experiments cannot achieve. Using case studies, researchers reveal how mathematical modeling and performance evaluations advance ginning technology. Studies integrated modeling with field data to redesign the self-grooving rubber roller that yielded improved ginning efficiency and lower maintenance requirements. A research team employed mathematical models to enhance power transmission in double roller gins by forecasting the impact of different gear ratios and belt tensions on energy consumption and ginning speed [47].

3.2 Failure Analysis of Beater Shaft

The beater shaft shown in Figure 7 has a crucial role in the process of cotton ginning through the supply of necessary force for the separation of fibers from seeds during double roller ginning processes. High working loads and recurring pressures lead to frequent beater shaft failures that produce high operational downtime and increased maintenance costs. Research groups have been focusing on what the core reasons for such failures are while they develop preventive solutions. Using Finite Element Method (FEM) in combination with other analysis techniques enables failure analysis to reveal important information regarding beater shaft failures that enable engineers to design stronger and more resistant components.

Fig. 6: Beater Shaft Assembly

3.2.1 FEM-based failure analysis

FEM is an effective tool in analysing mechanical component failure such as beater shaft on ginning machines. FEM can simulate in detail stress patterns and deformation together with possible points of failure for various operating conditions. FEM has been used in several studies to study beater shaft performance under various loads to determine the points of stress concentration and fatigue failure sites. The research team simulated conditions of operational stress on the beater shaft during the process of ginning using FEM analysis. The research discovered that stress concentrations typically develop at the shaft's keyway and near its bearings which are locations where materials are most likely to experience fatigue initiation. The research team recommended design modifications to incorporate fillets and reshape the keyway to reduce stress concentrations and thereby increase the operational lifespan of the shaft by identifying high-stress regions. A separate FEM study examined how failure susceptibility changed with various material properties and shaft dimensions. According to the findings even when cyclic loads reached high levels choosing stronger materials alongside modifying shaft diameter significantly reduced failure risks. Frequent maintenance checks and inspections are essential for early detection of wear patterns to prevent major equipment failures according to this study.

3.2.2 Analytical and experimental approaches

Numerous analytical and experimental methods besides FEM have been employed to understand beater shaft failures. The failure mechanisms identified through FEM studies gain additional understanding through techniques such as metallurgical analysis, fatigue testing, and fracture mechanics. Fracture mechanics investigations have been used to study crack expansion in beater shafts at locations identified by FEM as having high stress levels. Research indicates that a crack initiates rapid propagation under cyclic loading which leads to sudden and catastrophic failure. Through research into fracture behavior of shaft materials scientists have developed appropriate heat treatment and surface hardening techniques to prevent crack propagation. Experimental tiredness testing serves to validate results obtained from FEM simulations. Experimental tests put beater shafts through repeated loading cycles that match real operating pressures. Both experimental fatigue testing results and FEM simulations have revealed critical shaft failure sites which will enhance material selection and shaft design strategies. Metallurgical analysis which includes microstructural inspection and hardness tests has been utilized to examine the material characteristics of broken beater shafts. The research identified early failure causes stemming from inappropriate heat treatment procedures along with material defects and surface irregularities. With improved manufacturing techniques researchers decreased failure rates while extending the life span of beater shafts [23].

3.3 Noise Parameters and Operator Safety

The functioning of twin roller gins within cotton ginning machines leads to elevated noise levels which pose a significant threat to the safety and health of operators. Long-term exposure to high noise levels results in various health issues such as increased stress, hearing loss and accident rates. The scientific study of noise parameters in ginning machinery together with operator safety effects and risk reduction methods has been a longstanding research focus.

3.3.1 Noise levels in ginning machines

The acoustic properties of ginning processes primarily depend on mechanical interactions within components such as rollers, beaters and power transmission systems. Several elements affect the frequency and degree of the noise produced: The sound from ginning operations stems from factors including machine design together with operational speed plus equipment quality [54]. Studies demonstrate that noise emissions from different ginning machines frequently surpass occupational safety regulations for exposure limits.

Researchers documented that ginning plant noise averages between 85 to 105 dB(A) but reaches much higher values during operations like feed and seed separation. The majority of occupational safety standards [55] specify that these noise levels exceed the established hearing damage threshold which is set at 85 dB(A) for an 8-hour work period. The significant noise intensities demonstrate the necessity for effective noise control measures to protect workers against potential health dangers.

3.3.2 Impact on operator health and safety

Noise exposure presents significant health and safety challenges for operators in the cotton ginning industry. Prolonged exposure to high noise levels leads to Noise-Induced Hearing Loss (NIHL) which is irreversible and significantly affects an individual's quality of life. Ginning machine operators experience a higher risk of developing Noise-Induced Hearing Loss (NIHL) because they work near loud equipment for extended periods as research demonstrates [56]. Noise exposure during ginning operations leads to health issues beyond hearing impairment and includes stress alongside tiredness and heart problems. Prolonged loud noise exposure increases stress which leads to fatigue and a greater accident risk due to decreased concentration and awareness. Scientific studies show that constant noise exposure leads to hypertension through stress reactions which elevate blood pressure levels over time [57,58]. Noise disrupts communication channels and reduces the ability to detect warning signals which are essential for preventing industrial accidents thereby affecting operator safety. The presence of alarms or instructions becomes hard for operators to hear when they work in noisy areas which results in a higher possibility of them making errors or having accidents. The absence of quick and clear communication poses a serious danger in ginning operations which require efficient and safe workflow procedures.

3.3.3 Mitigation Strategies

A number of methods have been proposed and put into use to mitigate noise risks during ginning activities. The use of administrative controls and engineering modifications coupled with personal protective equipment (PPE) provides efficient noise reduction in ginning operations by targeting their intervention directly at the noise source. Noise production can be reduced by engineers through the redesign of equipment parts through noise-absorbing material applications to rollers and beaters and building enclosures or barriers around loud machinery to confine workers away from them. The noise output from machines can be reduced through optimizing functional design aspects which reduce the speed of parts without decreasing the efficacy of the ginning process. Changes to work processes are administrative controls that serve to reduce employees' exposure to noise. Administrative controls to restrict noise exposure are scheduling noisy activities during periods of low worker presence, rotating operators between jobs to minimize their exposure time in loud areas, and performing routine equipment maintenance to avoid the buildup of noise from wear. Employee training on the hazards of noise exposure and proper use of PPE will improve working conditions through awareness. Earplugs and earmuffs are the basic hearing protective devices, which are the backbone of successful noise reduction. Research indicates that correct use of PPE reduces risk of hearing loss by reducing exposure to noise by 20–30 dB based on protection type. PPE becomes effective by proper fitting and frequent use thus requiring extensive training and education programs. Operators' health and safety are severely threatened by high noise levels during cotton ginning operations which requires detailed noise management plan development. A combination of engineering enhancements and administrative practices with proper PPE use creates a safer work environment by controlling noise exposure. The main research focus for future work must be the design of low noise ginning methods and automated systems to minimize noise exposure while maintaining efficiency at work.

4. Design Modifications and Future Trends

4.1 Component Design Verification and Modification

Effective and stable performance of ginning machines under different conditions necessitates constant component design verification and adjustment which facilitates their improvement. Ginning machine components such as feeders, rollers, and leather groove cutters experience high operating stress which necessitates their design to ensure machine performance. This section discusses research that is concerned with the design verification and adjustment of major components with special emphasis on leather groove cutters which facilitate double roller gins to operate effectively.

4.1.1 Leather groove cutters: design and verification

Leather groove cutters maintain grooves of double roller ginning machines in a clean condition so that cotton fibers can be separated from seeds. Cutters' accuracy and strength directly influence the performance quality and efficiency of ginning machines. Several years of research were focused on the enhancement of the design of leather groove cutters to increase performance and extend their lifespan. With material selection and geometric design analysis, the research hoped to improve wear resistance and cutting accuracy of leather groove cutters. With Finite Element Analysis (FEA) simulations of cutting, researchers identified regions of stress concentration within the cutter during operation. Through geometric modifications which concentrate on the cutting angle and edge radius adjustments researchers demonstrated that a uniform stress distribution can extend cutter life while reducing wear. A separate research study explored different heat treatment methods to determine their effects on leather groove cutters' durability and hardness. Carburizing treatment resulted in enhanced surface hardness for cutting materials which led to improved wear resistance. An evaluation of treated cutters under actual ginning conditions showed they experienced less wear and required fewer maintenance sessions compared to untreated cutters [55]. The performance of new leather groove cutters has undergone design verification studies to ensure their effectiveness. When performance measures like groove precision and cutter wear rate are closely monitored in controlled settings the investigations include prototype testing. The investigative results provided valuable feedback which will enhance cutter designs to meet industrial application standards [56].

4.1.2 Design modifications of other key components

Design changes for several components of ginning machines including parts other than leather groove cutters have improved their durability and effectiveness. Rollers experience significant wear during ginning operations, which prompts regular design modifications to boost their performance and longevity. The study focused on the utilization of self-grooving rubber rollers while experimenting with different roller surface patterns. The research highlighted how these rollers maintain perfect groove depth throughout their operational life leading to benefits such as decreased maintenance needs and superior fiber quality. A simulation with FEA showed how the self-grooving roller design minimizes stress concentrations and prevents premature wear when interacting with cotton fibers. The design of feeder systems along with single locking cotton feeders has been adjusted to improve ginning productivity while simultaneously decreasing energy consumption. Field research has identified optimal feeder structures through experimental validation and mathematical modeling techniques. The investigations resulted in feeder designs that deliver consistent cotton feeding while reducing the energy consumption of the ginning machine [58].

4.1.3 Verification and testing protocols

The validation of design changes occurs through rigorous testing methods which include physical experiments and simulations. FEA remains the central foundation of verification because it enables scientists to recreate mechanical component behavior across multiple operational scenarios. The models assist in identifying potential failure sites and confirming the effectiveness of design modifications before prototype development stages. Case studies demonstrate successful design changes which improve ginning machine component performance. A study which redesigned leather groove cutters led to a new model that improved ginning efficiency by 15% and reduced maintenance needs by 30%. A modified feeder system design study reported a reduction in energy usage by 10% alongside an increase in ginning production by 20% [60].

4.2 Future Trends in Ginning Technology

Through continuous transformation the cotton ginning sector aims to increase efficiency while cutting operational costs and improving the quality of cotton processing. Current advancements in ginning technology emphasize sustainable practices while integrating automated systems with machine enhancements. Modern technological developments in cotton processing technology address current industrial challenges and establish foundations for future transformative changes. This section analyzes upcoming trends in cotton ginning and pressing technologies along with recent advancements that seek to lower expenses and boost efficiency.

4.2.1 Recent advances in ginning technology

The high level of automation in ginning processes reduces human involvement which results in both decreased labor expenses and improved throughput. Energy consumption stands as the primary factor which determines the operational costs during cotton ginning. Current advancements focus on improving energy efficiency through machine process optimization and component enhancement. Modern ginning operations now produce a much smaller energy footprint through the implementation of energy-efficient components combined with improved insulation and variable frequency drives for motors. Research into solar power and other alternative energy sources presents a sustainable solution for ginning especially in rural locations with limited electricity access. The performance and durability of ginning machine components have advanced through the use of modern materials. The use of wear-resistant alloys and self-grooving rubber rollers in key components has extended ginning machine life while reducing maintenance expenses and operational shutdowns. These compounds improve ginning output consistency and fiber quality [63]. Research has concentrated on optimizing operating parameters such as roller speed, cotton moisture content, and feeder settings. The application of Taguchi Design of Experiments (DOE) together with alternative methods has led to the discovery of optimal settings that boost ginning efficiency and reduce both energy consumption and fiber damage. Research outcomes translate into guidelines and best practices which enable ginning plants to achieve better operational effectiveness [63]. Environmental concerns have sparked the development of more sustainable methods in ginning. The adoption of renewable energy sources coincides with increasing efforts to reduce water and chemical consumption during the ginning process. Research is being conducted into the circular economy within the cotton industry through waste fiber and byproduct recycling which incorporates cottonseed [64].

4.3 Potential Future Trends in Cotton Ginning and Pressing Technologies

4.3.1 Smart Ginning Technologies

Future ginning technology will be driven by advancements in smart technologies such as IoT, AI, and ML. IoT-enabled sensors can perform ongoing machine performance tracking and detect wear and tear early which allows automated corrections and predictive maintenance to transform cotton ginning operations while reducing downtime and maintenance costs. Artificial intelligence-driven analytics enables real-time fiber quality assessment which allows machines to dynamically adjust ginning settings for optimal fiber quality. The advanced automation levels can drastically reduce waste amounts while minimizing fiber damage and enhancing production efficiency. Machine learning algorithms analyze historical operation databases to optimize operating parameters and power consumption across different cotton types. Smart ginning technologies enable better production efficiency while reducing operational costs and maintaining stable cotton quality levels.

4.3.2 Sustainable and Eco-Friendly Ginning Technologies

The search for sustainable practices to lower environmental impact has led to innovative ginning methods becoming essential for development. The application of solar power on ginning machines is going to be the most popular trend in regions with an abundance of sunlight. Ginning companies converting to renewable energy sources will reduce their fossil fuel dependency and costs while minimizing carbon emissions. Scientists investigate waterless ginning technologies to remove water usage on specific ginning processes. Current fiber processing methods utilize water for fiber conditioning and dust control but future technology will employ dry processing to save water while ensuring fiber quality. Ginning facilities may adopt environmentally friendly practices since sustainability labels and green certifications fuel sustainable industry incorporation.

4.3.3 Modular and Flexible Ginning Systems

The demand for flexible solutions in the market will compel the ginning industry to embrace modular systems that enable easy changes for different processing requirements. Modular ginning systems enable facilities to adjust their processing to suit different types of cotton and grow operations to address seasonal requirements while introducing new technology without significant infrastructure changes. Operators employing modular systems can change between different ginning configurations based on cotton type and quality. Medium and small-scale ginning units are highly benefited by modular ginning systems which provide economic solutions for processing various cotton supplies. Applying simple upgrades on specialized modules such as lint-conditioning or sophisticated cleaning systems technology advancements can be seamlessly integrated over time [9].

4.3.4 Advancements in Cotton Pressing and Bale Formation

Producers ought to be able to create heavier cotton bales that preserve cotton quality through advances in cotton pressing technology. The industry will soon witness the introduction of sophisticated hydraulic pressing techniques that apply pressure evenly through cotton bales. The current improvements aim at enhancing bale density that leads to lesser storage space and transportation costs for logistics. Computer-controlled robotic presses may utilize real-time assessments of fiber quality to control levels of compression and ensure consistent bale creation. These technological improvements keep cotton structure intact during pressing and stop flaws that occur when fibers get compacted or break. Bales that are denser and smaller but retain high fiber quality become easier to handle and save on transportation costs while being viable for long-term storage [10].

5. Challenges and Opportunities

5.1 Current Challenges

5.1.1 High initial investment costs

Advanced ginning technology implementation that combines IoT integration with renewable energy systems and automation demands significant financial resources. Equipment replacement or upgrades present major financial obstacles for small and medium-sized ginning businesses because of the large costs involved. The costs associated with new machinery purchase expand to encompass staff training expenses and infrastructure modifications while meeting new operational standards [67].

5.1.2 Technical expertise and workforce training

Modern cotton ginning technology requires staff who are trained to operate and maintain advanced equipment. Rural ginning facilities often face technical knowledge shortages because this information remains difficult to obtain in these locations. The absence of properly trained employees creates barriers to the effective implementation and enhancement of new technological systems. Staff members require continuous education to remain updated on new technological advancements that entail both time and financial commitments [68].

5.1.3 Integration with existing systems

Integrating modern technology into existing ginning methods presents a significant challenge. Numerous ginning operations depend on outdated equipment which may not support IoT systems or contemporary automation methods. Achieving flawless integration while ensuring that existing operations remain uninterrupted requires strategic planning and possibly extensive retrofitting. The integration process becomes more complicated because operational continuity must be preserved when transitioning to new technology [69].

5.1.4 Sustainability and environmental regulations

Despite the increasing importance of sustainability businesses still struggle to adhere to environmental regulations. The traditional ginning process requires high water and energy consumption which makes it hard to reduce these inputs without affecting production levels. The ongoing problem remains how to dispose of ginning byproducts in an environmentally friendly way. Facilities face a challenging regulatory environment when they invest resources to implement sustainable methods.

5.1.5 Market and economic pressures

Ginning plants may experience decreased profitability due to unstable market conditions within the cotton sector. The unpredictable nature of cotton prices, market demand shifts, and global trade regulations creates difficulties for ginning operations to plan long-term investments in new technologies. The need to reduce costs creates economic pressure that restricts facilities from investing in research and development activities.

5.2 Opportunities for Future Research

5.2.1 Advanced automation and robotics

There is significant potential when we investigate the development of advanced robotics and automation technologies for cotton ginning. Upcoming research should focus on creating advanced automated systems that can adapt to various cotton grades and processing conditions to optimize the ginning process in real-time. Robotics technology offers solutions for handling labor-intensive tasks which reduces human workload and enhances overall operational efficiency [61].

5.2.2 Integration of IoT and data analytics

When data analytics merges with Internet of Things (IoT) technology it creates significant opportunities for improving ginning operations. Research into IoT-enabled sensors and systems that provide real-time monitoring of machine operation, cotton quality, and energy use stands to enhance operational efficiency by using data analysis to optimize facility performance while predicting repair needs and decreasing downtime. IoT systems provide the capability to facilitate seamless integration between new technologies and existing infrastructure.

5.2.3 Sustainable energy solutions

The push for sustainability requires essential research into alternative energy sources for ginning operations. Solar energy presents significant potential for powering ginning operations in regions that receive abundant sunlight. Research moving forward should focus on creating hybrid systems that combine solar power with additional renewable resources to ensure stable energy availability while improving solar systems for ginning purposes. Energy storage technologies designed to meet ginning operations needs represent a primary innovation opportunity.

5.2.4 Water conservation and waste management

Research efforts in future cotton ginning studies need to focus primarily on waste management techniques and water conservation measures. The creation of techniques which significantly reduce water consumption or eliminate water necessity in the ginning process will greatly enhance sustainability. Researchers should focus on creating practical strategies to recycle and repurpose ginning byproducts like waste fibers for different industries and transform cottonseed into biofuel.

5.2.5 Resilience to market fluctuations

Future research should investigate ways to adapt ginning operations to better respond to market demands. Modular and adaptable ginning systems that can be efficiently scaled to match market demand along with financial models designed to reduce price volatility effects represent key strategic elements. Research should explore the development of value-added products like premium organic cotton processing and specialist ginning services to manufacture high-quality textiles as a way to diversify income sources away from commodity markets [67].

6. Conclusion

This review paper has analyzed new advancements in cotton ginning technology while focusing particularly on twin roller ginning machines. The drive to make ginning more efficient while reducing energy consumption and improving fiber quality alongside sustainable practices has driven technological advancements in ginning systems. The development of self-grooving rubber rollers together with the optimization of roller and power transmission systems and the application of finite element analysis (FEA) to improve mechanical components represent important innovations. The design and operation of multiple feeder types such as the Spike Cylinder Type Single Locking Cotton Feeder cum Cleaner and the Saw Band Cylinder-type Single Locking Cotton Feeder have made significant advancements. These advancements solved traditional industry problems by enhancing cleaning procedures while boosting ginning efficiency and reducing energy consumption. Despite progress within the sector, cotton ginning operations face multiple challenges such as expensive startup costs, necessary technical expertise, difficulties with method integration and maintaining sustainability under strict regulations. These difficulties present new opportunities for scientific investigation and technological progress. The sector will experience transformation through the combined adoption of sustainable energy solutions and advancements in automation, IoT, and data analytics. Subsequent research must maintain its focus on these domains and advance resilience to market fluctuations along with waste management and water conservation techniques. By solving these problems and embracing innovative opportunities the cotton ginning sector will ensure its ongoing relevance and sustainability within the dynamic global marketplace.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

References

[1] Sluijs M (2015), Impact of the ginning method on fiber quality and textile processing performance of Long Staple Upland cotton. *Textile Research Journal* 85. https://doi.org/10.1177/0040517515569524.
[2] Flachs A (2019), *Cultivating knowledge: Biotechnology, sustainability, and the human cost of cotton capitalism in India*. University of Arizona Press.
[3] Tesema GB & Fetene GN (2024), Cotton Harvesting, Post-harvest Handling and Storage. In: Babu KM, Kabish AK, Tesema GB & Semahagn BK (eds), *Cotton Sector Development in Ethiopia: Challenges and Opportunities*, Springer Nature Singapore, Singapore, pp. 115–136. https://doi.org/10.1007/978-981-99-9149-5_6.
[4] Watson SA (1988), Corn marketing, processing, and utilization. In: *Corn and Corn Improvement* 18, 881–940.
[5] Peng N, Widjojo N, Sukitpaneenit P, Teoh MM, Lipscomb GG, Chung T-S & Lai J-Y (2012), Evolution of polymeric hollow fibers as sustainable technologies: Past, present, and future. *Progress in Polymer Science* 37, 1401–1424.
[6] Peng H, Zhang H, Shangguan L & Fan Y (2022), Review of tribological failure analysis and lubrication technology research of wind power bearings. *Polymers (Basel)* 14, 3041.
[7] Amernick BA (2012), *Patent Law for the Nonlawyer: A Guide for the Engineer, Technologist, and Manager*. Springer Science & Business Media.
[8] Arude VG, Deshmukh SP, Patil PG & Sukla SK (2020), Influence of single locking of cotton bolls on ginning performance of double roller gin for short staple cotton.
[9] Patil PG & Arunde YG (2014), Recent advances in cotton ginning technology in India. In: *6th Meeting of the Asian Cotton Research and Development Network*, International Cotton Advisory Committee, Dhaka, Bangladesh, p. 12.
[10] Tausif M, Jabbar A, Naeem MS, Basit A, Ahmad F & Cassidy T (2018), Cotton in the new millennium: advances, economics, perceptions and problems. *Textile Progress* 50, 1–66.
[11] Kaya M (2020). Evaluation of the Existing Solar Energy and Rainwater Potential in the Total Roof Area of Buildings: Izmit District Example. *Research Article*.
[12] Elmogahzy Y (2019). *Engineering Textiles: Integrating the Design and Manufacture of Textile Products*. Woodhead Publishing.
[13] Arude VG, Deshmukh SP, Shukla SK, Patil PG (2018). Development of Saw Band Cylinder-Type Single Locking Cotton Feeder for Double Roller Gin. *Journal of Agricultural Engineering* 55: 21–32. https://doi.org/10.52151/jae2018552.1651.
[14] Arude VG, Deshmukh SP, Patil PG, Shukla SK (2020). Power. *AMA, Agricultural Mechanization in Asia, Africa and Latin America* 51: 24–28.
[15] Abubakar A, Ukasha S (2021). Development of a Pedal Operated Paddy Thresher. 2: 1–6.
[16] Patil PG, Patil V (2010). Development of Prototype Double Roller Gin with Improved Power Transmission and Its Performance Evaluation. *Journal of Engineered Fibers and Fabrics* 5: 20–25. https://doi.org/10.1177/155892501000500403.
[17] Arude VG, Deshmukh SP, Patil PG, Shukla SK (2019). Optimization of Single Locking Cotton Feeder for Maximizing Ginning Output and Minimizing Specific Energy of Double Roller Gin. *Textile Research Journal* 89: 2364–2375.
[18] Patil PG, Padole PM (2004). Double Roller Cotton Ginning Machine: Its Drawbacks and Possible Modifications. 440023.

[19] Othman F, Sadeghian MS, Ebrahimi F, Heydari M (2013). A Study on Sedimentation in Sefidroud Dam by Using Depth Evaluation and Comparing the Results with USBR and FAO Methods. *International Proceedings of Chemical, Biological and Environmental Engineering* 51: 6. https://doi.org/10.7763/IPCBEE.
[20] Nerkar PPS, Agrawal JF, Deshpande PD (2014). Analysis of Power Transmission System for Ginning Machine with Feeding Mechanism Using FEA. 2014: 29–32.
[21] Nerkar PPS (2018). An analysis of solar energy operated cotton ginning machine for sustainable development of rural India. *International Journal of Research in Applied Science and Engineering Technology* 6: 2972–2977. https://doi.org/10.22214/ijraset.2018.3650.
[22] Kapse AN, Nerkar PPS (2015). Mathematical modeling and performance evaluation of feeder for ginning machine using field data based model 3: 294–296.
[23] Nagardhane MW, Handa CC (2015). Failure analysis of beater shaft of double roller ginning machine using FEM. *IJSRD – International Journal for Scientific Research & Development* 3: 2321–0613.
[24] Monica E, Nagardhane W, Handa CC (2015). Validation of failure of beater shaft of double roller ginning machine using mathematical failure analysis approach. *IJIRST – International Journal for Innovative Research in Science and Technology* 2: 177–181.
[25] Taiwade RV (2021). Wire arc additive manufacturing: a comprehensive review and research directions. *Journal of Materials Engineering and Performance* 30: 4768–4791.
[26] Bajaj L, Sharma MK (2012). Future trends in cotton ginning and pressing technologies. *Bajaj Steel Industries Ltd.*: 1–9.
[27] Gajghate VB, Sachin (2016). Double roller auto feeder ginning machine noise parameters and its effects on operator and its related hazards. *IJSTE – International Journal of Science Technology & Engineering* 3: 51–56.
[28] Atel LK, Sheikh MJ (2018). Design modification and analysis of double roller mini ginning machine 4: 994–999.
[29] Taiwade RV (2022). Microstructure and mechanical properties of wire arc additively manufactured bimetallic structure of austenitic stainless steel and low carbon steel. *Journal of Materials Engineering and Performance* 31: 8531–8541.
[30] Ingale S, Deshmukh TR (2017). Study and design optimization of autofeeder side cover of ginning machine: A review. *International Journal of Innovative and Emerging Research in Engineering* 4: 25–32. https://doi.org/10.26769/ijiere.2017.4.11.191514.
[31] Agzamov MM, Yunusov SZ, Gafurov JK (2017). On the technological development of cotton primary processing, using a new drying-purifying unit. *IOP Conference Series: Materials Science and Engineering* 254. https://doi.org/10.1088/1757-899X/254/8/082017.
[32] Dhongade GK (2016). Performance improvement of cotton processing industry by using Taguchi DOE 2: 78–84.
[33] Rambhad KS (2016). Component design verification and modification of double roller ginning machine 1: 21–26. https://doi.org/10.13140/RG.2.1.5088.6163.
[34] Handa KJBC (2015). Methodology for design and fabrication of leather groove cutter machine for double roller ginning machine – A review. *IJSRD* 3: 304–306.
[35] Rajabov O, Salimov S, Temirov A, Yokubov M (2021). Influence of the circumferential speed of the spiked cylinders on the efficiency of cleaning raw cotton. *Journal of Physics: Conference Series* 2094. https://doi.org/10.1088/1742-6596/2094/4/042074.
[36] Ambatkar RD, Sambhare RB, Dahake VB, Wakode RA (2020). Automatic raw cotton feeding system. *IOSR Journal of Electronics and Communication Engineering (IOSR JECE)* 15: 40–46.
[37] Estur G, Gergely N (2010). The economics of roller ginning technology and implications for African cotton sector. *Economic Roller Ginning Technology and Implications for African Cotton Sector* 129. https://doi.org/10.1596/27585.
[38] Iyer VG, Mastorakis NE (2009). Properties of covering materials of roller used in cotton roller gin. *Proceedings of the 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology (EMESEG '09)*: 66–78.
[39] Iyer VG (2020). Environmental health impact assessment of chrome composite leather-clad rollers used by Indian cotton roller ginning industries and design and development of eco-friendly alternatives. *International Journal of Emerging Trends in Health Sciences* 4: 36–67. https://doi.org/10.18844/ijeths.v4i1.4496.
[40] Iyer VG, Mastorakis NE (2009). Design and production of an eco-friendly ginning technology for the processing of eco lint colour cotton fibres. *Proceedings of the 2nd International Conference on Environmental and Geological Science and Engineering (EG '09)*: 57–67.
[41] Iyer VG (2019). Sustainable cotton roller ginning process for Indian cotton double roller gins. *World Journal of Textile Engineering and Technology* 5: 123–132. https://doi.org/10.31437/2415-5489.2019.05.1.
[42] Iyer VG, Mastorakis NE (2009). Design and production of an eco-friendly ginning technology for the processing of eco lint colour cotton fibres. *Proceedings of the 2nd International Conference on Environmental and Geological Science and Engineering (EG '09)* 127: 57–67.
[43] Singh G, Iyer GV (2004). Environmental impact studies of chrome rollers used by cotton roller ginning industries and design and development of pollution-free chromeless RCF rollers. *Environmental Monitoring and Assessment* 96: 163–181. https://doi.org/10.1023/B:EMAS.0000031725.88628.a3.
[44] Student MT (2015). Design and development of non-continuous type pneumatic conveying systems for ginning industries 2: 157–163.
[45] PAC (2015). Design and analysis of needle roller bearing at gudgeon pin of ginning machine. *International Journal of Research in Engineering and Technology* 4: 35–39. https://doi.org/10.15623/ijret.2015.0411007.
[46] Bodhe A, Vishawakarma AK, Tatekar A, Deshmukh DS (2023). Study on the analysis of cotton ginning machine transmission system. *IOP Conference Series: Earth and Environmental Science* 1142. https://doi.org/10.1088/1755-1315/1142/1/012111.
[47] Bodhe AB, Agrawal JF, Deshpande VS (2016). Mathematical model for optimal performance of cotton pre-cleaning machine 3: 2001–2004.
[48] Pandey A, Agrawal A, Thombre M, Chowdhury VR (2014). An improvement of productivity in manufacturing system. *IOSR Journal of Mechanical and Civil Engineering* 2014: 76–82.
[49] Obidov A, Vokhidov M, Abdurahmonov J (2021). Exploring the efficiency of experimental construction of sorting ginned cotton seed machine. *Engineering* 13: 18–29. https://doi.org/10.4236/eng.2021.131002.
[50] Hosseinali F, Thomasson JA (2018). Multiscale frictional properties of cotton fibers: A review. *Fibers* 6. https://doi.org/10.3390/fib6030049.
[51] Tumuluru J.S., Armijo C.B., Whitelock D.P., Funk P.A. 2023. Modeling and optimization of high-capacity experimental reclaimers to minimize the seed and lint loss during roller ginning of Upland and Pima cotton. *Processes* 11. https://doi.org/10.3390/pr11102868.
[52] Hu W., Chen X., Wang J., Li Y. 2020. Construction and finite element simulation of the saw type gin stand using fractal theory. *Textile Research Journal* 90: 2755–2768.
[53] Shen X., Lu X., Guo J., Liu Y., Qi J., Lv Z. 2023. Nondestructive testing of metal cracks: Contemporary methods and emerging challenges. *Crystals* 14: 54.
[54] Lara R., Jimenez-Romero R., Perez-Hidalgo F., Redel-Macias M.D. 2015. Influence of constructive parameters and power signals on sound quality and airborne noise radiated by inverter-fed induction motors. *Measurement* 73: 503–514.
[55] Haney P.B., Lewis W.J., Lambert W.R. 2009. *Cotton production and the boll weevil in Georgia: History, cost of control, and benefits of eradication*.
[56] Mishra P.K. 2017. *Development and evaluation of tractor operated header for cotton harvesting*.
[57] Bechere E., Boykin J.C., Meredith W.R. 2011. Evaluation of cotton genotypes for ginning energy and ginning rate. *Journal of Cotton Science* 15: 11–21.
[58] Nodirbek M., Shukhratjon K., Khamit A. 2021. Influence of the ginning process on the quality of raw cotton. *Engineering* 13: 739–748. https://doi.org/10.4236/eng.2021.1312052.
[59] Womac A.R., Byers E.E., Thomas K.G., Hillenbrand B., Smith A., Bitra V.S.P. 2021. Modeling cotton module builder and loader to enhance biomass testing. *Applied Engineering in Agriculture* 37: 911–928.
[60] Donkoh M.B. 2021. *Assessment of occupational health and safety of wood machining operation at a wood processing and marketing centre in Ghana*.

[61] Ghaffar A., Habib ur Rahman M., Ali H.R., Haider G., Ahmad S., Fahad S., Ahmad S. 2020. Modern concepts and techniques for better cotton production. In *Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technology*, 589–628.

[62] Barnes E., Morgan G., Hake K., Devine J., Kurtz R., Ibendahl G., Sharda A., Rains G., Snider J., Maja J.M. 2021. Opportunities for robotic systems and automation in cotton production. *AgriEngineering* 3: 339–362.

[63] Wanjura J.D., Armijo C.B., Delhom C.D., Boman R.K., Faulkner W.B., Holt G.A., Pelletier M.G. 2019. Effects of harvesting and ginning practices on Southern High Plains cotton: Fiber quality. *Textile Research Journal* 89: 4938–4958.

[64] Zhang Z., Huang J., Yao Y., Peters G., Macdonald B., La Rosa A.D., Wang Z., Scherer L. 2023. Environmental impacts of cotton and opportunities for improvement. *Nature Reviews Earth & Environment* 4: 703–715.

[65] Hardin R.G. IV, Barnes E.M., Delhom C.D., Wanjura J.D., Ward J.K. 2022. Internet of things: Cotton harvesting and processing. *Computers and Electronics in Agriculture* 202: 107294.

[66] Rahaman M.T., Pranta A.D., Repon M.R., Ahmed M.S., Islam T. 2024. Green production and consumption of textiles and apparel: Importance, fabrication, challenges and future prospects. *Journal of Open Innovation: Technology, Market, and Complexity* 100280.

[67] Ikiara M., Ndirangu L. 2003. *Developing a revival strategy for Kenya's cotton-textile industry: A value chain approach*. Kenya Institute for Public Policy Research and Analysis.

[68] Adeleke A.A. 2024. Technological advancements in cotton agronomy: A review and prospects. *Technology and Agronomy* 4.

[69] Van Niekerk H.C. 2018. *An integrated supply chain programme for the South African cotton garment industry – Pilot study*.

[70] Kühlert M., Klingen J., Gröne K., Hennes L., Terrapon-Pfaff J.C., Jamea E.M. 2024. *Pathways towards a green economy in Egypt: Analyzing decarbonization and resource efficiency pathways along value chains to support green private sector development in Egypt*.

[71] Lima A.C., da Silveira J.A.G., Matos F.R.N., Xavier A.M. 2017. A qualitative analysis of capital budgeting in cotton ginning plants. *Qualitative Research in Accounting & Management* 14: 210–229.

[72] Pelletier M.G., Wanjura J.D., Wakefield J.R., Holt G.A., Kothari N. 2023. Cotton gin stand machine-vision inspection and removal system for plastic contamination: Hand intrusion sensor design. *AgriEngineering* 6: 1–19.