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SMART SAFETY INTEGRATION IN TRADITIONAL CHAFF CUTTER MACHINES TO PREVENT UPPER LIMB AMPUTATIONS IN SOUTH ASIA

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Abstract
The use of chaff cutter machines is common in South Asia's rural communities when harvesting food for animals. While chaff cutter machines are vital in agriculture, they are the leading contributor of severe upper limb injuries, which include amputations in the fingers and hands. According to epidemiological studies done in various parts of Pakistan, India, and Nepal, chaff cutters are responsible for 45% of injuries sustained in agricultural machinery. Chaff cutter injuries account for about 40% of 500 recorded injuries due to agricultural machinery in Pakistan within six months. These injuries result in amputations, the rate of which varies between 35% and 60%. Most of the people injured using chaff cutter machines are less than 30 years old. The main reason behind such injuries arises from faulty engineering designs of the machinery. Typically, the conventional chaff cutter functions with exposed feed rollers along with a rotating blade without having any automatic detecting device. After entrapment, due to the pull of the feed rollers and the momentum of the flywheel, release becomes highly unlikely, often leading to irreversible harm. In order to deal with the issue, this study combines evidence collected from epidemiology with an engineering approach to improve on safety design. Such an improvement comprises of a hand detecting system, an automatic braking system for stopping the blade rotation, an enhanced blade cover along with an emergency switch. This new design intends to interfere in the process

1. INTRODUCTION
Farming is known to be among the riskiest occupations across the world, especially in developing and underdeveloped nations where workplace safety standards are poor [1]. Unlike other industries that use equipment of consistent specifications and whose safety practices are observed, farm equipment in rural areas tends to arise spontaneously [2]. In South Asia, where agriculture is the lifeline of village societies, mechanization has gained momentum during the last twenty years [3]. Pakistan utilizes more than 37% of its total workforce in agriculture, whereas India and Nepal rely greatly upon their subsistence farming practices for employment and sustenance. The process of mechanization has not only made agriculture more productive but has also generated new types of mechanical risks.

In many parts of South Asian agriculture, considerable use is made of small machines which are locally manufactured and do not have uniform safety measures [4]. One such machine commonly

used in agriculture is the chaff cutter machine which is alternatively referred to as the fodder cutter or the Toka machine. These machines are used for cutting straw, hay, and crop residues into smaller particles to be fed to livestock. The chaff cutters are installed on the farm and are used everyday by the farmer, the family member, and in some cases even by children. These chaff cutters are quite different from the larger industrial type agricultural machines in terms of their manufacturing and do not comply with any engineering safety standards.

Figure 1: Traditional Chaff Cutter Machine Design in Solid work

Several epidemiological studies in Pakistan, India, and Nepal during the past 10 years have found that chaff cutter is a major cause of serious upper limb injuries among agricultural workers in rural communities [6]. Several regional studies carried out in Pakistan and India revealed that about 45% of injuries caused by agricultural machines were due to chaff cutter incidents. A national survey involving orthopedic surgeons in Pakistan showed 507 agricultural machine injuries [7] in a six-month period, of which almost 40% was accounted for by injuries from fodder cutter machines. The hospital based case series in Punjab and Sindh provinces also reveal high prevalence of finger/hand amputations caused by these machines. In India, records at trauma centers show that chaff cutter injury contributes to a significant number of emergencies requiring treatment of upper limbs. In Nepal, studies based on observations have revealed that about 31% of injuries of hands admitted in trauma centers are due to injuries caused by fodder cutter machines, and a significant proportion of the victims are children below 15 years of age.

Figure 2: Amputation of hand by fodder cutting machine

The gravity of such injuries is especially alarming. While small cuts or skin scrapes may get better over time accidents with chaff cutters often cause people to lose limbs have complicated bone fractures, severe crushing injuries and lose the use of their body parts. Chaff cutter accidents can lead to amputation in 35% to 60% of cases according to hospital studies. This shows that many patients get hurt badly. When a person's hand is caught in the feed rollers of a chaff cutter, the force pulls their arm into the spinning blade. The blade spins fast and can cause a lot of damage. My research interests focus on nano mechanical energy harvesting systems [8], energy optimization through zero energy and green buildings [9,10], environmentally friendly emission control technologies [11], and advanced methodologies for vibration and noise control to promote sustainable [12] and efficient engineering solutions [13, 14].

The machine does not have detection or fast breaks so it keeps spinning even after you turn it off. This causes damage to tissues. Doctors have written about these injuries in journals. To prevent them people have tried to make others aware provide training and encourage behavior change. These efforts are important. They do not fix the main problems with how traditional chaff cutters work. Not much work has been done to make small agricultural equipment safer by using ideas from engineering, such as sensors to detect problems barriers to prevent accidents and fast braking systems. There is a need to change the current approach and focus on preventing injuries through engineering solutions. By studying how injuries happen and how machines work we can find design flaws. Add technical measures to prevent severe injuries. Chaff cutter accidents are a problem and we need to find ways to prevent them. The machines need to be designed with safety in mind to prevent injuries.

We need to make chaff cutters safer to prevent people from getting hurt. Amputations and severe injuries can be prevented with machine design. The current trend of relying on awareness and training is not enough. We need to adapt safety principles from engineering to make small-scale agricultural equipment safer. This can be done by integrating concepts such as detection by sensors interlocking barriers and breaking mechanisms. By doing we can disrupt the chain of events that lead to severe injuries. Preventing injuries is possible with the right design and technical measures. Chaff cutter safety is a matter of importance. It is essential to take an approach to prevent such injuries. The use of engineering solutions can play a role, in preventing chaff cutter accidents. Therefore, it is necessary to change the trend and focus on prevention through engineering means. Things can go wrong. This paper looks at injury statistics from here and thinks we should make a safer chaff cutter. The new chaff cutter would have an important feature. It would be able to detect hands it would have circuits that shut it down it would have built-in

brakes it would have covers, for the blades. It would have emergency stops [15].

2. Epidemiological Analysis of Chaff Cutter Injuries in South Asia

The problem of chaff cutter injuries is very serious, in South Asia. Many people get. Some injuries are very bad. They happen often The injuries can cause long-term problems Across studies done
In Pakistan in the provinces of Punjab, Sindh and Khyber Pakhtunkhwa there is a clear trend in demographics where youths make up most of the injured population. Youths are the ones who get hurt the most. Data from observations showed that in some regional studies more than 77 percent of the injured were under 30 years old. This is a deal because it shows how vulnerable adolescents and young adults are when they work with chaff cutters and take care of animals at home [16].

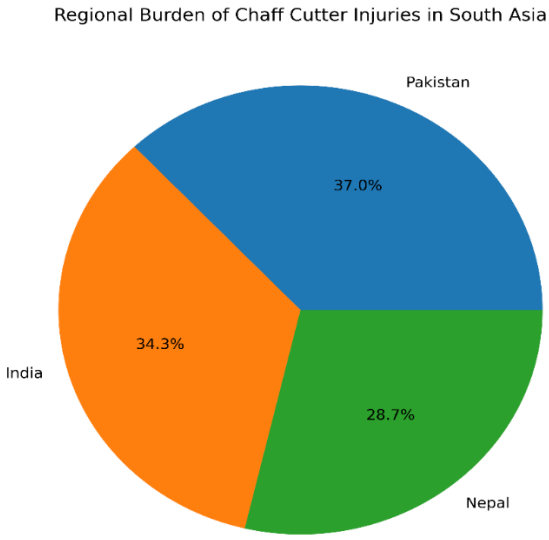

Figure 3: Regional Burden of Chaff Cutter Injuries in South Asia

A study was done in Gujranwala with 100 patients who got hurt by chaff cutters. The average age of these patients was 17 years. Most of the injuries happened to people between 1 and 20 years old. The worst injuries happened to teenagers. This means that children in areas start working with chaff cutters when they are very young. They help their parents with farm work like feeding animals and cleaning the chaff cutter. Sometimes they even sharpen the blades. There are reasons why so many young people get hurt by chaff cutters. One reason is that they do not know how to use the machines. They do not get training on how to work with chaff cutters. Chaff cutters are also small and easy to reach which makes it easy for people to get hurt [17]. Another reason is that chaff cutters do not have any protection. If someone puts their hand in the machine it gets pulled in. They cannot get it out. Chaff cutters are very dangerous, for young people who do not know how to use them. Chaff cutters need to be used to avoid injuries.
When you think about it a lot of people under 30 years old are getting hurt. This is a deal because young people are the ones who do most of the work in rural areas. If someone young loses a limb or gets hurt badly in their hand it affects their whole life [18]. They cannot. Do things that need hands. This also affects their family because they depend on them to help with farming and other things. So the fact that most of the people who get hurt are people under 30 years old means we need to do something to prevent these kinds of

accidents from happening in the first place. We need to find ways to make things safer for people, under 30 years old so they do not get hurt.

Table 1: Regional Burden of Chaff Cutter Injuries in South Asia

Country	Study Type	Total Agricultural Machine Injuries	% Attributed to Chaff Cutter	Reported Amputation Rate	Most Affected Age Group
Pakistan	National orthopedic survey	507 (6 months)	~40%	~38% overall; up to 60% in hospital series	<30 years
India	Regional trauma centers	Varies by state	30–45%	35–50%	15–30 years
Nepal	Trauma center observational study	175 hand injuries	31% of hand injuries	~40% fracture; severe open injuries common	<15 years

Gender wise distribution also differs across geographical locations. However, most epidemiological studies have shown a preponderance of male patients who comprise up to 60-80% of the total number. The reason for this trend lies in their greater participation in agriculture and the use of equipment on farms in rural South Asia [19]. In rural areas of Pakistan, however, up to 50% of injured individuals have been females. This high involvement in injuries is due to chaff cutter utilization at home when women feed their livestock and operate such machines. Consequently, the statistics show that the occurrence of such injuries goes beyond farmers, who use machines at their work places, and involves even family members who prepare fodder for animals.

An anatomical distribution of chaff cutter injuries also has some common features in all the regions under consideration. Right upper extremity injuries have occurred most often, representing more than 70% of cases in different clinical studies. It seems logical to assume that the reason for this distribution is related to right-handedness. Operations, where the leading hand is responsible for pushing the fodder into the feeding chute, with the other hand holding it down. Consequently, the leading hand is placed in closer proximity to the feed rolls and the moving blades, thus posing greater chances of entrapment [20].

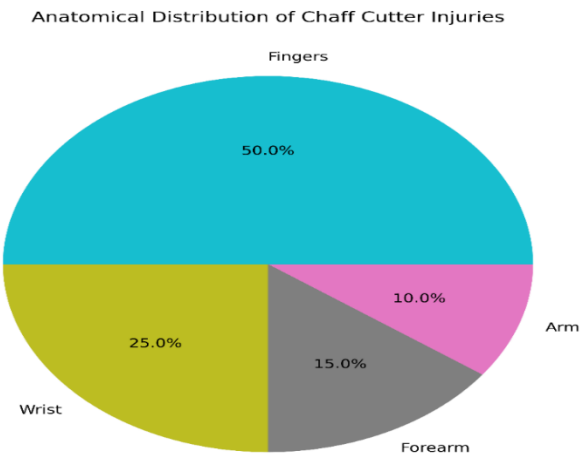

Figure 4: Anatomical Distribution and Severity

The injury location pattern clearly reveals certain regularity. The fingers and distal parts of the hands comprise about 55% of all injuries, thus becoming the most Vulnerable parts. Injuries occurring at the wrist level and the distal part of the forearm constitute another 30% percent of cases and mainly involve tendon injuries and bone fractures. Injuries of proximal forearm and arm are rarer but generally have serious consequences because of the more intensive blood loss and deep injury. These types of injuries tend to happen because of the delayed machine stopping or its inability to be stopped quickly [21]. From the mechanical point of view, the chain of events starts with accidental trapping of fingers between feed rollers, after which the pulling force produced by the rollers draws the arm closer to the rotary blade assembly in a matter of seconds. The reason why there is no possibility to stop such kind of machinery promptly and easily lies in the great inertia of flywheels of conventional chaff cutters that rotate at quite high speeds; therefore, even the immediate turning off the device will not stop blades immediately. It leads to the extensive injury of tissues [22].

Table 2: Anatomical Distribution and Severity

Injury Site	Frequency	Severity
Fingers	40–55%	Amputation common
Wrist	20–30%	High
Forearm	10–15%	Moderate–Severe
Arm	<10%	Severe

The one aspect, which emerges most prominently from various studies, is the incidence of amputation, and the rates are as high as 35% to 60%. One of the largest orthopedic surveys in Pakistan found that 38% of all machine accidents led to amputations [23]. The clinical literature reports that creation of a stump is the commonest procedure performed in such cases. The condition becomes even more serious in electrically operated chaff cutters as the speed and torque leads to increased force of cutting with reduced reaction time. From the available literature from Nepal, we find that the majority of injuries take place on weekends and holidays due to the increased exposure period for the child. 49 percent of all cases have bones that break and a lot of cases have open wounds that are very serious like Gustilo type II and III. This shows that getting hurt by a chaff cutter is not a cut it is a big deal that affects the muscles and bones.

3. Mechanical Failure Analysis

Chaff cutter injuries are not just accidents that happen by chance. They are actually a result of how chaff cuttersre designed and the physics that are at play when we use chaff cutters. When a chaff cutter hurts someone it is because of what happens when the machines parts move and interact with each other. This is something that can be understood by looking at the physics of chaff cutters including things, like friction, torque and angular momentum that affect how chaff cutters work. Chaff cutter injuries are a result of these things coming together in a way.

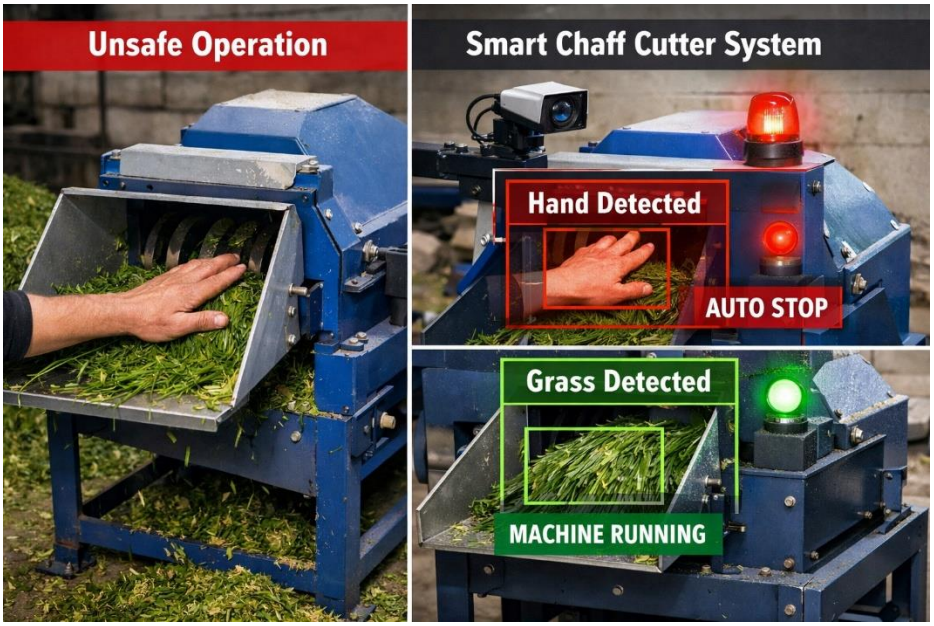

Figure 5: Smart safety system flowchart for a fodder-cutting machine using AI, sensors, and automatic braking to protect the operator.

This injury pattern commences with manual loading of fodder into a narrow feed chute. Chaff cutters use pairs of feed rollers spinning in opposite directions to hold and pull fodder into the chopping unit [24]. These feed rollers produce enough frictional force to counteract any resistance created by dense fodder. However, the rollers do not distinguish between fodder and skin. In case a hand or finger inadvertently gets inside the feeding area, the rollers exert compressional and tangential forces creating a torque that pulls the limb inside. The leverage effect of feed rollers [25] means that a human operator can generate lower than the pulling force produced by the rotating rollers, making escape nearly impossible once entrapment occurs.

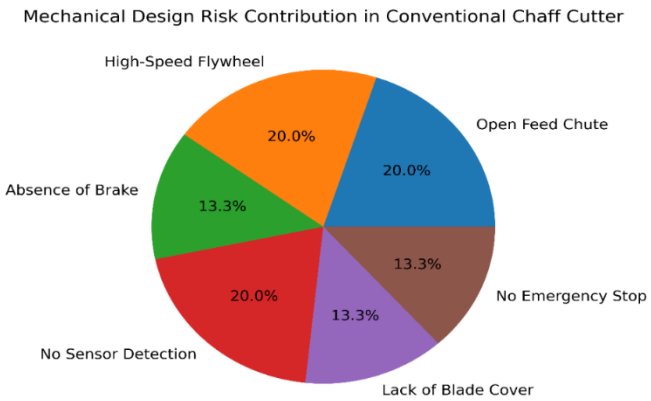

Figure 6: Mechanical Risk Factors in Conventional Chaff Cutter

After entrapment [26], the hand is quickly moved towards the revolving flywheel fitted with sharp blades. The flywheel normally rotates at a very fast speed, with speeds varying from hundreds to the number of revolutions is thousands per minute according to the power rating of the motor. Under such operating conditions, the blades are characterized by high tangential speed and significant cutting momentum [27]. Kinetic energy accumulated in a rotating body is instantly transmitted to biological tissue upon impact, causing deep cuts, bruises, or complete loss of body parts. The inability of the blades to absorb any energy due to its inflexibility makes impact forces more concentrated and causes greater destruction of tissues.

The inertia of the flywheel plays an important role in increasing the degree of tissue damage. Even if electricity is disconnected, the rotation of the flywheel is not immediately stopped. Inertia forces ensure continued rotation of the mechanism for a few seconds according to natural deceleration [28]. For this reason, residual kinetic energy is sufficient for damaging tissues. The thing about not having a braking system is that it can only stop when it feels friction and air gets in the way which's not enough to make it stop quickly.

Furthermore, many designs do not have any kind of safety guard to keep the feeding area separate from the cutting mechanism [29]. The feed rolls are really close, to the blades so you do not have time to react only a fraction of a second to fix anything that goes wrong. When you think about the mechanics of the cutting mechanism the constant pulling force, the fast rotation speed and the rotating parts all work together to make it really unsafe. The cutting mechanism has a lot of energy. It is not controlled well.

Table 3: Mechanical Risk Factors in Conventional Chaff Cutter

Design Component	Risk Mechanism	Injury Contribution Level
Open Feed Chute	Direct hand access to rollers	Very High
High-Speed Flywheel	High kinetic energy transfer	Very High
Absence of Brake	Continued blade rotation after power off	High
No Sensor Detection	No pre-contact prevention	Very High
Lack of Blade Cover	Direct exposure	High
No Emergency Stop	Delayed shutdown	High

Most locally manufactured machines lack:

- Interlocked guards,
- Reverse roller systems,
- Emergency braking,
- Torque-limiting clutches,
- Automatic detection mechanisms.

This design deficiency makes injury nearly inevitable once entrapment begins.

4. Proposed Engineering Safety System

We need to think about the dangers that come with using chaff cutters. These machines can hurt people. To make them safer someone came up with a design. This design has layers of protection. The system will have sensors that can detect things. It will also stop by itself. Slow down really fast. This will help prevent injuries from the blades of the chaff cutters. The chaff cutters will be safer, with this system.

4.1 Hand Detection Sensor System

The new design uses sensors or proximity sensors at the feeding chute inlet point. If a person's hand is in the area where it should not be the sensor sends a message to the control panel. This message is sent to the control panel immediately. The control panel then stops the motor away. This makes the machine safer for people to use. It also reduces the chance of a person's hand getting hurt by the blades of the machine [30]. The new design, with sensors or proximity sensors really helps to keep people safe when they are using the machine with infrared sensors or proximity sensors.

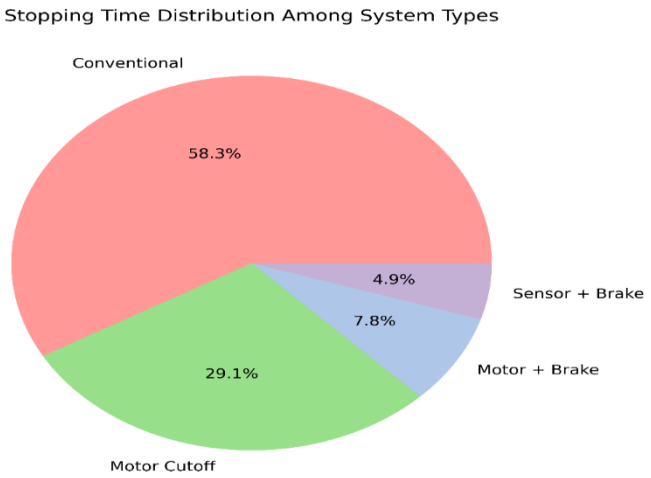

Figure 7: Stopping Time Comparison

4.2 Automatic Instant Shutdown Mechanism

The sensor feeds into a relay controlled motor shutoff system. Once detected, the relay cuts off the electric power source feeding the motor, thereby interrupting the torque transfer process [31]. This guarantees that the shutdown happens automatically without the need for operator activation of any switches.

4.3 Mechanical Braking System

The method that has been used to overcome flywheel inertia is the fitting of mechanical brakes to the shaft of the flywheel. This involves the use of friction or disk brakes that operate through the application of torque when applied, bringing about a quick decrease in speed [32].

Table 4: Stopping Time Comparison

System Type	Stopping Time	Injury Severity Risk
Conventional Chaff Cutter	3–8 seconds (natural inertia)	Very High
Motor Cutoff Only	2–4 seconds	High
Motor Cutoff + Mechanical Brake	<1 second	Low
Sensor + Brake Integrated System	Milliseconds detection + <1 sec stop	Very Low

4.4 Blade Protective Cover

The new design has an enclosure around the blades made of high-strength steel. The enclosure stops any hands from reaching the blade assembly [33], which also has an interlock feature that deactivates the blades in case the cover opens during the process.

4.5 Emergency Stop Buttons

Various emergency stop devices are placed at accessible locations on the machine. These mushroom-type buttons are capable of breaking off power as well as triggering the brake system almost instantly. In case anyone fails, there is always another backup.

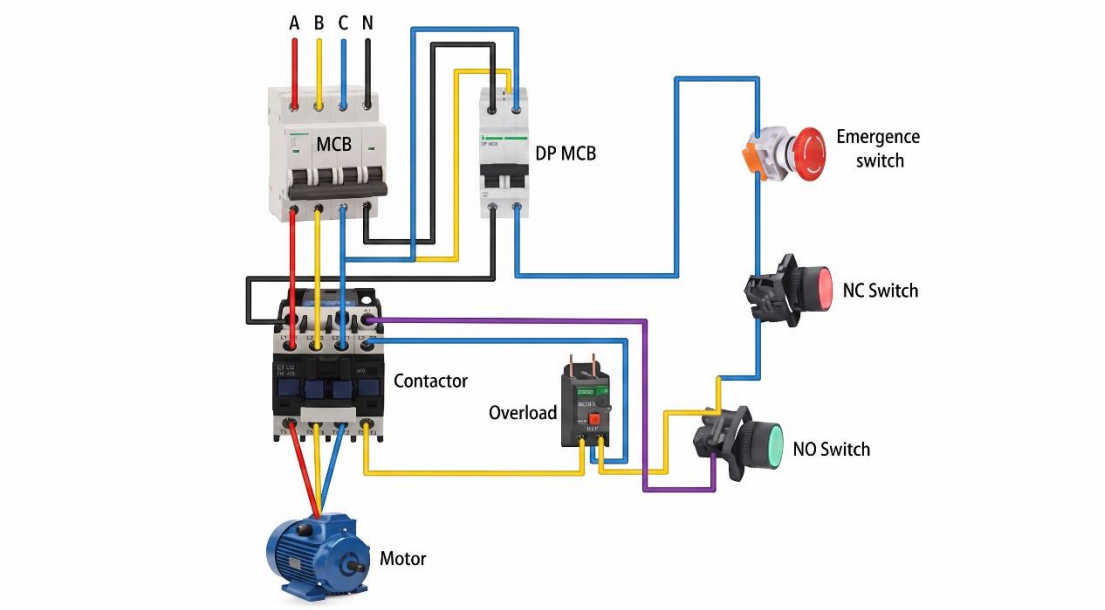

Figure 8: Emergency Stop Buttons Circuit

Table 5: Proposed Safety System Components and Functional Role

Safety Feature	Engineering Principle	Expected Risk Reduction Mechanism
Hand Detection Sensor	Infrared/Proximity detection	Stops machine before blade contact
Automatic Motor Cutoff	Relay-based electrical interruption	Eliminates continued torque supply
Mechanical Brake System	Friction disc braking	Reduces flywheel stopping time
Blade Protective Cover	Physical barrier	Prevents accidental hand insertion
Emergency Stop Buttons	Manual override control	Immediate shutdown capability
Interlock Mechanism	Safety compliance design	Prevents operation without cover

5. Expected Impact of the Safety Design

If we look at the information about illnesses and injuries we can see that chaff cutters are the cause of 40% of the injuries from farm machines in different parts of South Asia [34]. Some surveys done in hospitals show that 60% of people who get hurt by chaff cutters lose a limb, which means that most of the time accidents with chaff cutters cause big problems for people instead of just small injuries. Therefore, if we can just reduce the number of times people get their limbs caught in these machines a bit it will make a big difference for the health of the public. The safety system with layers is designed to stop the machine from hurting people so it will find hands near the machine and then stop the machine quickly [35]. It seems reasonable to think that if this system can reduce the number of times people lose a limb in an accident by 50% it will really help reduce the big problems that traumatic amputations cause in communities and that is a big deal, for chaff cutters and the people who use them because chaff cutters are a major cause of these problems.

Apart from health-related gains, the socio-economic ramifications are likely to be significant as well. Considering that most of the victims belong to age groups younger than 30, injury prevention helps to ensure that rural households avoid being deprived of their potential economic contribution [36]. In case of a hand injury among farming population, the consequences usually include a lifelong disability and loss of income

generation ability. Hence, not only does the application of safety principles improve safety, but it also contributes to socio-economic development of the rural regions. Moreover, a multi-tier strategy ensures a greater reliability due to redundancy. Even if one of the protective measures turns out ineffective, there is always another one available. As such, in case of wide spread implementation of a safety-oriented design, the nature of injuries may shift from those resulting in limb amputation to near misses [37].

Table 6: Engineering Performance Parameters for Proposed Design

Parameter	Conventional System	Proposed Safety System
Flywheel RPM	800–1200 RPM	Controlled RPM
Emergency Stop Response	Manual only	Automatic + Manual
Blade Exposure	Open	Fully Enclosed
Human Detection	None	Active Sensor System
Brake Mechanism	None	Integrated Mechanical Brake
Redundancy	Low	Multi-layer safety

The inclusion of sensor detection with mechanical braking ensures that both phases of harm starting and sustaining are accounted for. By minimizing time to stop and protecting the blade, this invention converts a dangerous tool into a safe agricultural machine in keeping with contemporary safety engineering.

6. Conclusion

Injuries from the chaff cutter machine are a problem for people who work in rural areas of South Asia. This is especially true, for children, teenagers and young people who get hurt by the chaff cutter machine. The chaff cutter machine injuries are an issue that affects the health of people who live and work in these areas. The epidemiological trend that is consistently seen in Pakistan, India, and Nepal reveals the extent of injuries sustained through this mode of workplace accident. Incidences of finger/hand amputations, open fractures, and crushing illustrate how such workplace injuries are not minor occupational accidents, but trauma events. In fact, the occurrence of injuries in economically active age groups only adds to its seriousness [38]. An examination of mechanisms of injuries reveals that the primary problem is the mechanical flaw of the machinery itself, rather than an issue of employee ignorance or carelessness. Traditional chaff cutters use bare feed rollers [39], a high speed rotating blade, and flywheels, which do not have any mechanism that allows for quick stopping. Once the machine catches the individual's limb, there is no escape from it, making the occurrence of an accident almost certain. Hence, mere training cannot solve the problem.

The safety enhanced chaff cutter concept is a multi-faceted approach in engineering design since both active and passive safety concepts are combined [40]. The addition of hand detection sensors facilitates early detection of hazards, while the automatic switch-off mechanism ensures there is no transfer of torque. Mechanical braking reduces the amount of time required to stop the machine and dissipation of any remaining kinetic energy. Blade guard ensures limited physical exposure to the dangerous components, while emergency stop facilities offer another safety measure [41]. The combination of these aspects forms a multilevel protection paradigm aimed at mitigating the risks from mechanical factors. Through the integration of epidemiology and mechanical innovation, this study highlights that effective prevention of injuries in agriculture involves the application of engineering measures [42]. The adoption of safety integrated chaff cutters could help mitigate the risk of preventable upper limb amputation injuries.

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