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Mechanised Threshing of Pod Grains used as food and Strategies to Optimise the Technique: A Review

Eric Amoah Asante[1]*, Joseph Oppong Akowuah[1], Samuel Appah[2] and George Obeng-Akrofi[3]

[1]Department of Agricultural and Biosystems Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[2]Department of Agricultural Mechanization and Irrigation Technology, University for Development Studies, Tamale, Ghana

[3]Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa, USA

*Corresponding author email: ericasante@knust.edu.gh

Abstract

Pod grains threshing using mechanical devices is essential in understanding the diversities involved in the application of machine–crop parameter combinations towards achieving best quality grain. The integration of pod grains' physical properties in optimizing product quality which is vital to meet the increasing global requirement is limited. However, with computing and technological advancements into thresher design and evaluation have been found to be capable of meeting these needs which are of interest to researchers. Over the past three–four decades, the applications of the technology in reducing impact force through modification of peg geometry have attracted researchers' widespread interest and the future looks promising. This review presents an overview of mechanical thresher development and the applications in the field of pod grain production chain. The role of grain physical properties in threshers design, operations and with force sensors to reveal the mysteries surrounding the causes of grain damage and how they can be minimised are stressed. The current trends and future advances of such studies are also presented.

Keywords: working principles; physical properties; impact force; seed damage; control strategy.

Introduction

Common beans (Phaseolus vulgaris L.) forms an important part of the global food demand specifically for those living in tropical and subtropical areas (*Mishra et al. 2016; Siddiq et al. 2010*). It is a unique source of nutrient to human and livestock in many unindustrialized countries (*Yi et al. 2016; Kinyanjui et al. 2014; Njoroge et al. 2015*). The grains are rich in protein and provide a good nutritional supplement (*Murdock and Baoua 2014*). The commonest beans include black, haricot, kidney, lima, mung, pinto and string (French or snap) beans. Many people living in Africa, specifically the northern part of Ghana; and Asia especially China, earn their living directly or indirectly through the cultivation of common beans. It has high economic value which makes it the most important pod grain in many parts of the world (*Kabas et al. 2007*). Some pod grains other than cowpea and soybeans have also been discovered and used as food over the years. The cultivation and consumption of these grains specifically, faba beans have been in existence for at least 5000 years which makes it a domestic crop (*Altuntas and Yıldız 2007*).

Enhancement in pod grain quality is vital to meet the increasing global requirement of high quality grain (*Zhang et al. 2014; Fitzgerald et al. 2009*) but the difficulty in separating the unwanted inedible glumes such as straw and husk from the seed existed at the early stages when man started using grains as food (*Irtwange 2009*). Though, the threshing operation is complex (*Yu et al. 2015*), it is an integral part in the beans production chain because it can affect the quantitative and qualitative loss after harvesting (*Chandrajith et al. 2016; Huang et al. 2013*). The process is found out to be a combination of the crop and machine variables for mechanized threshing or the combination of the crop and striking stick for traditional threshing (*Irtwange 2009*). The traditional modes of threshing in Africa, especially Ghana, and Asia, specifically India, are time consuming and labor intensive. The method exposes the product to losses and adulteration. The manual threshing is done by spreading the dried crop on the floor or putting it in sacks where it is struck with pestle (*Singh et al. 2008; Maunde 2011*). This is the basis for exploitation of women, and child labor leading to grain loss with the finished product containing impurities such as chaff and gravel (*Maunde 2011*). However, mechanized threshing combines both the threshing and cleaning (separation of the grain from the chaff) operations together at considerable efficiency.

In order to increase beans production, and improve upon the quality of the final product, thresher development has become essential (*Sudajana et al. 2002*). Consequently, the global demand for beans has resulted in the increase of machine size, with the related energy consumption, and operational cost (*Mesquita et al. 2000*). The impact force received by kernels during threshing operation, lead to various degrees of injuries and subsequent damage (*Xu et al. 2013; Allen and Watts 1997*). The performance of the threshing unit is vital in the effectiveness of a mechanical thresher (*Sudajana et al. 2002*). Despite the few setbacks, mechanical threshers have gained high reputation because they can be used for several seasons at a very high feed rate and improve upon the quality of the final product for human consumption.

Therefore, the objective of this paper is to present a comprehensive review on the topic of mechanized threshing of pod grain but mainly on soybean and cowpea. The publications are critically reviewed and classified into five major sections with the first section forming the introduction. The section 2 describes the working principles of the technology and the section 3 covers the control strategies of the technique. The effectiveness of the technique with reference to findings of previous researches has been discovered under the soybean threshers and cowpea threshers and presented in section 4. Finally, the gaps in the literature have been highlighted as well as making projections into the future and presented as the concluding remarks in Section 5.

2 Working principles of beans threshers.

Beans threshers are power driven machines developed for the threshing of the seeds after harvesting. The prime movers for these machines include electric motors; internal combustion engines and auxiliary power from tractor power take off (*Kumar et al. 2002*). The threshing can be achieved by three methods: Rubbing action, Impact and Stripping which take place in the threshing unit (*Mohan and Patel 1992*). The threshing units are classified according to functional components (Drummy, Regular or Through-put, and axial flow) and according to types of threshing cylinder (Syndicator, Hammer Mill or Beater type, Spike tooth type and Rasp bar type). The functional component type specifically the axial flow thresher achieves threshing when the crop is fed into the cylinder through a feeding chute located at one end of the threshing drum. The feeding can be in an axial, tangential or oblique direction and the movement of the crop between the threshing drum and concave is spiral (*Miu and Kutzbach 2007*). Due to the rushing of crop material during feeding, the grains are removed from the ears or the pod which marks the beginning of the threshing process (*Miu and Kutzbach 2008a*). Subsequently, several complete turning of the cylinder provides repeated impact on the grain (*Sessiz and Ulger 2003*). The threshed crop passing through the concave is cleaned by a set of sieves and a blower. The process results in high output and cleaning efficiency. Axial flow of the crop is facilitated by the use of louvers provided on the upper concave (*Sessiz and Ulger 2003; Manes et al. 2015*). The straw is then thrown out of the threshing unit by paddles. In the case of the threshing cylinder type, specifically the Spike tooth cylinder, the threshing drum is a hollow cylinder, made out of mild steel (MS) flat. The spikes or pegs which are made from square or round bars or flat iron pieces are welded or bolted over its entire periphery. However, round peg with adjustable length are used for the pegs in most threshers. The crop is fed along with the direction of motion of the rotating drum (*Neale et al. 2003*).

A typical thresher is fitted with a feeding chute at a slope of 10–15% at the input end of the threshing drum (*Kumar et al. 2002*). This slope facilitates easy flow of the crop into the threshing mechanism. The threshing process by which the grains are removed from the straw effectively begins at the feeding zone due to a sudden acceleration of material. Subsequently, a higher number of grains are threshed due to initial impact (*Petkevichius et al. 2008*). However, the degree of threshed seed depends on the straw placement with respect to the drum and rotor peg position (*Miu and Kutzbach 2008b; Asli-Ardeh and Abbaspour-Gilandeh 2008*).

During the past few decades, several researchers have attempted to develop and evaluate beans threshers (see Table 1). The technique ranges from manual to powered thresher development, assessment, and determination of the machine–crop parameter combinations for optimal performance. The future looks promising for such applications which are often carried out based on the rotor or cylinder speed, grain moisture content, cylinder–concave clearance and the impact force generated resulting from the geometry of the impacting body (*Utaku 2006*). In the following, a control strategy, advantages and limitation of mechanical threshers, the role of physical properties in thresher design and an overview of the designs and applications of threshers on soybean and cowpea using different parameters are presented.

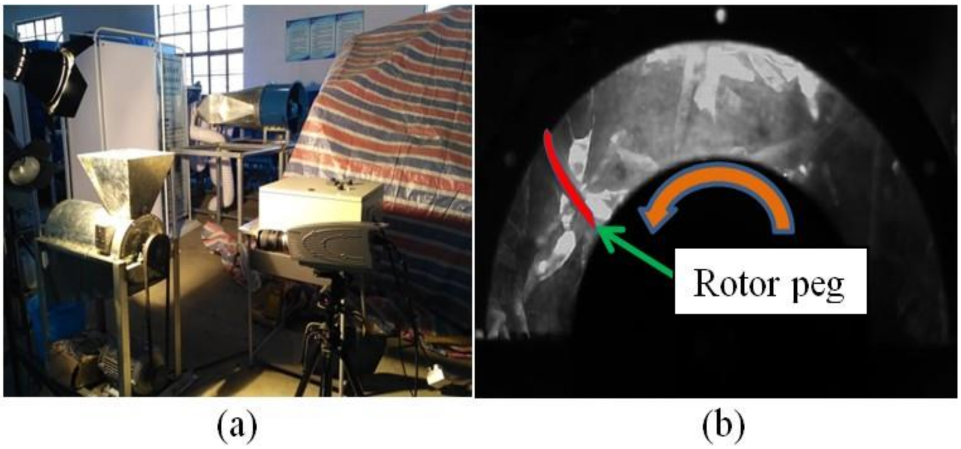


Figure 1: (a) A setup of high speed camera to capture the process of opening the pod to free the seed in the threshing chamber, and (b) the captured image showing how the rotor peg impacts the pod to free the seed.

Table 1: Summary of selected research papers on cowpea and soybeans threshing.

Author	Year	Crop	Objective
Cain and Holmes	1977	Soybeans	The effect of impact velocity on soybean seed quality
Paulsen et al.	1981	Soybeans	Effect of soybean seed moisture content on its resistance to impact damage.
Singh and Singh	1981	Soybeans	Assessment of crop and machine parameters combination on the threshing effectiveness and seed quality of soybean.
Bartsch et al.	1986	Soybeans	Effect of a single high-speed collision on soybean seed damage.
Mesquita and Hanna	1993	Soybeans	Evaluating the effectiveness of two belt system soybean thresher
Mesquita et al.	2000	Soybeans	To compare threshing efficiencies, damage and energy required to thresh soybeans at four different speeds.
Ukatu	2006	Soybeans	Combine safe impact velocities with appropriate clearances to maximise threshing efficiency.
Azadbakht et al.	2012	Soybeans	Effects of initial moisture content, impact and friction energy on threshing of soybean pods.
Sharma and Devnani	1980	Cowpea	The effect of operating parameters on cowpea threshing losses
Dauda	2001	Cowpea	Development of cowpea threshing equipment to improve on the quality, reduce damage and fast track the process.
Irtwange	2009	Cowpea	To alleviate the challenges that farmers face in relation to manual threshing
Maunde	2011	Cowpea	Performance evaluation of the threshing efficiency and seed damage of manual thresher

Maunde	2014	Cowpea	Alleviating the problem of separation and cleaning in the case of manual cowpea threshers
Asante et al.	2017	Cowpea	Assessment of the minimum duration of open air drying and best machine-crop parameters combination for optimum performance.
Fraser et al.	1978	faba beans	Some physical properties of faba beans
Singh and Goswami	1998	cumin seed	Assessment of compressive loading and grain moisture content effect on seed rupture force.
Allen and Watts	1997	Beans	To determine mechanical and aerodynamic properties of both beans and pods necessary to design thresher cleaning system.
Ogunjimi et al.	2002	locust bean	Assessing the mechanical properties of locust bean seed under loading.
Olajide and Ade-Omowaye	1999	Locust bean	To design equipment for handling, processing and storing locust bean
Baryeh and Mangope	2002	Pigeon peas	Evaluation of the physical properties of QP-38 variety of pigeon peas as a function of seed moisture content
Kabas et al.	2007	Cowpea	Some physical and nutritional properties of cowpea seed
Yalcın	2007	Cowpea	Investigating some moisture-dependent physical properties
Altuntas and Yıldız	2007	Faba bean	Assessment of moisture content influence on the coefficients of friction as well as rupture force, and specific deformation
Isik and Unal	2007	Red kidney beans	To investigate moisture-dependent physical properties, namely, axial dimensions, coefficient of friction and shelling resistance

3 Control strategy and guidelines of beans threshing operation

The threshing unit of an efficient thresher must be able to produce a flawless threshing with maximum crop throughput, and highest grain separation, preserving the grain quality in its natural form, and minimizes grain loss (*Myhan and Jachimczyk 2016*). However, this is an ideal case (*Miu and Kutzbach 2008b*). Therefore, to operate a thresher for the purpose of threshing pod grains at a very high efficiency, reduce damage and improve on the quality of the final product involve a control strategy. This is because improper threshing of beans mostly results in seed loss of up to about 5% of the crop (*Bruce et al. 2001*).

Several approaches are available to grain thresher operators and must be employed to achieve the above objectives. One of which is the speed of the rotating or the moving components since it determines the impact frequency and the magnitude of the force (*Mesquita and Hanna 1995; Liu and Leonard 1993*). Therefore, it must be maintained at a level to produce an impact force that is just enough to break the pod whilst keeping the grain in its original shape and must be according to the response of the grain to impact (*Mesquita and Hanna 1995*). On the other hand, the clearance between the cylinder or the tip of the rotor peg and the concave must be adjusted according to the physical parameters of the crop so as to avoid extreme cracked seeds since it can lead to a very low value of the grain (*Ukatu 2006*). Furthermore, the effectiveness can be affected by the grain moisture content and feeding method (*Yalcın 2007*). One way to bring these challenges to acceptable level is to determine the required moisture content for a given rotor speed (*Ukatu 2006*). This is because the effectiveness of threshing does not only depend on the performance of the thresher itself, but also on the crop–machine parameters combination (*Miu and Kutzbach 2008b*). The speed of the crop during feeding must be very slow to avoid excessive breakage. This is because the grain velocity just before impact is one of the major causes of seed damage (*Vejasit and Salokhe 2004*).

Overall, it is required that the whole threshing process is carried out under optimal conditions (*Myhan and Jachimczyk 2016*). These should include quantitative assessment of the throughput and quality of the grain (*Abdi and Jalali 2013*). The quantitative assessment enables an operator to determine the duration of the operation whereas, the qualitative assessment help to ascertain whether or not the grain purity, seed damage and losses are within the acceptable levels (*Myhan and Jachimczyk 2016*). However, the extent of loss is influenced by the design characteristics, the prevailing operational conditions, and the physical properties of the crop (*Craessaerts et al. 2007*). Finally, automation of the threshing process is required because, when the losses are approaching unacceptable levels, the sensors will trigger the system to readjust. This can be made possible with availability of more sophisticated sensors and electronics which can monitor the separation and damage losses (*Coen et al. 2008; Zhao et al. 2011*). Continuous improvement in the control strategies of the technique are needed for effective research to serve as a leading threshing skill in the coming decades.

4 Advantages and limitation of mechanical threshers

Pod grains are basic products for human being worldwide. The challenges in threshing the pod has existed since the early stages when man started using grains as food (*Irtwange 2009*). In ancient days, people process beans by tearing the pod open and taking off the kernel by hand or simple tools. However, as society industrialized, with the increase in demand of high quality grains, mechanical threshers have been introduced. It started with hand operated threshers but has evolved over the years to the current engine powered threshers as well as the combine harvester. The current state of thresher development has several advantages which include:

The threshers reduced dependence on labor and increased efficiency. They help in meeting the growing demands of urban dwellers and the export market which requires the bringing of virgin lands under cultivation. Threshers allow large scale farmers to swiftly clear large tracts of crops, and prepare the ground for the next cultivation (*Paulsen et al. 2015*). Harvesting, threshing and winnowing are done at a time and no space is required for threshing and winnowing (*Hossain et al. 2015*). It saves the crop from natural calamities as well as shattering loss due to over maturity. In the case of combine harvesters, there is a reduction in grain loss compared to conventional harvesting, threshing and winnowing methods (*Veerangouda et al. 2010*). Harvesting cost is also lower than those of manual harvesting, threshing and winnowing of crops. However, there are some disadvantages which include; to the poor farmers, machines brought misery because it renders them jobless. Machines reduced dependency on labour leading to unemployment. The cost of using combine harvester is too high and not affordable to the small holder farmer (*Veerangouda et al. 2010*). Harvesting by combine harvester is difficult on small plots. Threshers are sometimes not readily available during the peak harvesting season. Spare parts and skill mechanic are scarce in the rural areas for repair and maintenance of complex threshers. Trained operators can be lacking for efficient field operation.

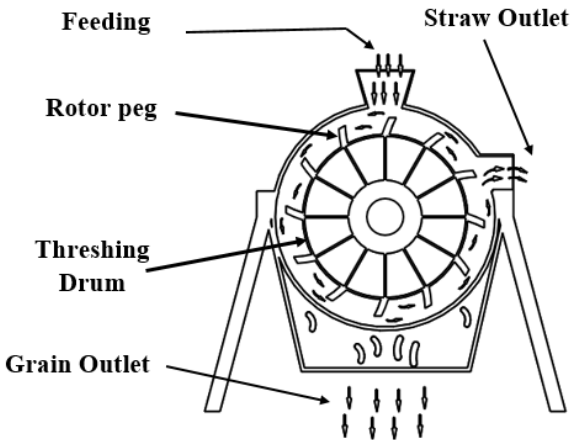


Figure 2: Schematic section of a pod grain thresher showing crop material flow and separation

5. The role of physical properties in thresher design and operation

The availability of the physical properties of pod grains is critical for the threshing and handling equipment design (*Altuntas et al. 2005; Baryeh and Mangope 2002*). Such information is useful in sizing prime mover requirements, determining the hole size of separating sieves, and selecting the appropriate material for the equipment components that handle grain and crop material flow (*Al-Mahasneh and Rababah 2007; Ogunjimi 2002*). Other factors that are also essential for effective threshing operations are the mechanical properties of the grains which are profoundly influenced by the grain moisture content (*Razavi et al. 2007; Yalcın 2007; Baryeh and Mangope 2002*). Subsequently, the physical and the mechanical properties determine the behaviour of the crop when subjected to mechanical loading during threshing.

The sole objective of the studies on the physical and mechanical properties of grains was to provide a data base to aid thresher designers and operators to improve upon the work in such a wonderful industry. For instance, empirical information on the angle of repose is useful to consider the flowability of the grain during threshing (*Balasubramanian and Viswanathan 2010; Al-Mahasneh and Rababah 2007; Fraser et al. 1978*). The terminal velocity of grains is useful in the design of pneumatic conveyor and separation systems (*Baryeh 2002; Sacilik et al. 2003*). Furthermore, the friction coefficient between the grain and the structural surface in contact with the grain is useful in sizing motor requirements as well as the material for grain handling and transportation from one stage of the threshing process to the next (*Kabas et al. 2007; Al-Mahasneh and Rababah 2007*). The mechanical properties and aerodynamic properties of both beans and pods are also necessary to the design of threshing machine cleaning system (*Allen and Watts 1997*). Finally, the major axial sizes of seeds are valuable data than can enhance the selection of sieve sizes for separation during threshing (*Amin et al. 2004*).

Despite the fact that there are several factors that contribute to the above mentioned physical and mechanical properties of pod grains, many studies have discovered grain moisture content as the major factor. This is because it extremely influences the behavior of the crop when subjected to mechanical loading during threshing which are the most important physical parameters required for the design of grain handling equipment (*Razavi et al. 2007; Akaaimo and Raji 2006*). As a result, there has been increasing interest among scientists to perform empirical research in order to quantify the relationship between grain moisture content and such properties (Al-*Mahasneh and Rababah 2007*). The current trend in the demand for high quality grains makes studying into such properties the largest areas of interest and the future looks promising in terms of the utilization of such data for innovative grain handling equipment design and threshing. A key work by *Fraser et al. (1978)* made significant contributions to the research into the physical properties of pod grains. The authors developed a protocol to quantify faba beans physical properties and reported an increase in the static coefficients of friction of the faba beans with the increase in grain moisture content. In another study, *Olajide and Ade-Omowaye (1999)* assessed the static coefficient of friction of locust beans on the surfaces of three structural materials and published an interesting report of an average decreasing trend with the highest in the case of plywood, followed by galvanized steel while it is lowest for glass perpendicular to the grain. Similarly, *Kabas et al. (2007)* quantified the coefficient of static friction of cowpea seeds and obtained a decreasing trend against the surfaces tested with the highest in the case of rubber, followed by plywood while it is lowest for galvanized sheet.

Information on the influence of crop moisture content variation on coefficient of friction against structural material surfaces, rupture energy and shelling resistance enables the understanding of the behavior of the crop during threshing at different drum speeds and cylinder-concave clearance (*ElMasry et al. 2009; Aydin 2007*). *Baryeh and Mangope (2002)* showed how the variation of crop moisture affects the above mentioned properties. In their study, the authors assessed the physical properties of pigeon pea as a function of the grain moisture content and reported that the terminal velocity had a linear correlation with the moisture content. However, the coefficient of static friction increased nonlinearly from 0.28–0.51 for plywood, 0.23–0.38 for galvanised steel and 0.18–0.31 for aluminium. The authors then recommended that low moisture content is a necessary condition for the design of pneumatic equipment to handle the grain so as to reduce energy input. In a similar approach, *Unal et al (2006)* quantified the effect of seed moisture content on the physical properties of black-eyed pea and reported that the terminal velocity increased linearly with the increase in moisture content. The authors further reported an increase of 0.380–0.434 for rubber, 0.355-0.399 for galvanised iron, 0.346-0.383 aluminium, 0.333-0.375 for stainless steel, 0.323-0.374 for glass and 0.278-0.342 medium density fibreboard in the static coefficient of friction as the moisture content increase. The shelling resistance of black-eyed pea decreased as the moisture content increased with the highest force obtained while loading along the Z-axis (thickness). In a similar technique, *Isik and Unal (2007)* quantified the shelling resistance of red kidney bean and reported a decrease from 98.26 to 53.67 N as the moisture content increased. Other studies by *Yalcın (2007)* on cowpea, *Altuntas and Yıldız (2007)* on faba beans and *Isik and Unal (2007)* on red kidney beans proved similar linear relationship between the seed moisture content and the coefficient of static friction for the various structural materials surfaces investigated. Work by *Altuntas and Yıldız (2007)* provided an astute procedure as to how the effect of seed moisture on specific deformation and rupture energy can be investigated. Subsequently, they reported a general increase in magnitude of the specific deformation and rupture energy with increasing moisture content after applying the procedure on faba beans.

The diligently complete information covered by the authors gives a good indication of the role physical properties of pod grains play in thresher design and elucidating their response to impact during threshing. It is now clear that the rupture strength, coefficient of friction, terminal velocity, and the shelling resistance of pod grains were highly dependent on moisture content. The seeds became brittle at high-moisture content and required less force to rupture (*Karababa and Coskuner 2013; Paksoy and Aydin 2004*). Furthermore, an increase in the moisture contents of all pod grains leads to an increase in friction coefficient on all structural surfaces (*Yalcin 2007; Altuntas and Yıldız 2007*). Several methods were formulated and the authors recommended low moisture content of the crop as a necessary condition to have reliable physical property required for effective pod grain handling. Considering the literature and harmonizing methods to investigate the effect of moisture content on physical and mechanical properties, quite a number of them only focus on the behavior of the crop during mechanical handling. However, the authors failed to critically make use of the full potential of such studies to unravel the amazing influence of crop water content dynamics on mechanical impact damage during threshing. This calls for in-depth studies to help in filling these research gaps.

6 Development and evaluations of pod grains threshers

6.1 Soybeans

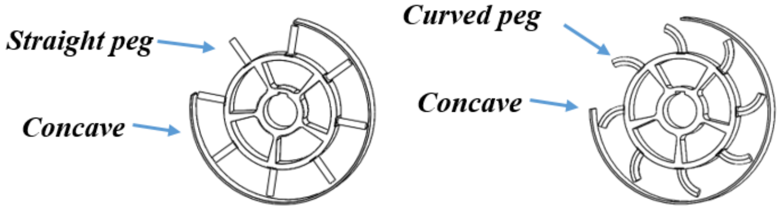
The major concern of beans traders and farmers is the damage caused to the seed due to impacts of the moving parts of crop threshing units and incorrect clearances between the stationary and moving component. Therefore, developing beans threshers with a part that can impact the grain with less force and reduce seed damage to an acceptable level is the focus of current researchers (*Ukatu 2006*). Based on literature, in the field of beans threshing technology, some good research outcome as well as inconsistencies in the analysis about the effectiveness, have been found. For instance, one of the ground-breaking works to unravel the main cause of grain damage which results in low quality of the final product was done by *Cain and Holmes (1977)*. The authors tested an impact force device on soybean and reported that the damage depends on impact velocity as well as the seed moisture content. Consequently, a further research to assess the quality of soybean seed as a result of single high speed collision was carried out by *Paulsen et al. (1981)*. The outcome convinced the authors to conclude that the impact velocity and seed moisture content are the primary sources that contribute to seed quality. The relationship between soybean moisture and impact velocity was also investigated by *Bartsch et al. (1986)* and reported that an impact velocity of 15 m/s, was enough to crack a seed at 8% moisture content. The authors further concluded that the seed damage due to impact increases with decreasing moisture.

High efficiency of grain threshing is another interesting research area in the development and evaluation of threshers. Although it is mostly challenging to quantify machine-crop parameters for a reliable threshing, perseverance of some researchers has led to many remarkable findings. An important aspect of the excellent assessment of a two belt system soybean thresher by *Mesquita and Hanna (1993)* revealed that the effectiveness reduces with increasing moisture. The authors further recommended that the energy needed to thresh the pod is 0.12 J. Further reduction in crop material processing other than grain is also a key source of high quality beans and can lead to a more efficient use of energy (*Miu 1999*). In view of the above, *Mesquita et al. (2000)* developed an experimental device that uses nylon cords for the impact force to thresh uncut soybean crops and achieved 99 % efficiency. However, the authors stated that the performance largely depends on the ground speed.

The qualitative and quantitative loss of seed during threshing is another area of interest to many researchers and grain merchants. Besides considering the impact force as the main determinant of the grain loss, other factors such as moisture content and threshing speed are crucial for optimal performance of the threshing mechanism (*Azadbakht et al. 2012*). Singh and Singh (1981) investigated the effect of machine-crop parameters on threshing effectiveness on the quality of two varieties of soybean and reported a linear relationship between pod moisture content and unthreshed grain. Consequently, the authors stated that the threshing speed had only little effect on the germination percentage of both varieties. Another area of interest is the relationship between the geometrical shape of the rotor peg and the related impact force which also determines the damage of the seed. In view of the high need of reducing perpetual damage to grains, *Utaku (2006)* modified the threshing fingers of a rotor, compared the performance with that of the conventional pegs on soybeans seed, and reported a significance decrease in seed damage. This research has significantly contributed to the search for geometrical shapes of impacting bodies that would produce less force and consequently reduce seed damage. However, the author failed to practically quantify the impact force which is necessary for developing curved working surfaces. In another study *Azadbakht et al. (2012)* verified whether or not seed moisture content and energy play important roll on the threshing percentage, and reported that both parameters had significant effects with the maximum threshing percentage occurring at the minimum moisture content. This was after the authors investigated the effect of three initial seed moisture content levels, impact and friction energy on threshing of soybean pods. They then concluded that impact threshing requires lower energy levels, while higher energy levels are required for the threshing of pods done by friction. All the above studies have contributed significantly in the fight to improve soybean threshing at an affordable cost. To have detail information about the above reviewed studies, the authors entreat the readers to refer to the full articles online.

6.2 Cowpea

The challenges related to effective cowpea threshing have existed for many years. However, many attempts have been made in the development of cowpea threshing equipment to improve on the quality of the final product, reduce damage and fast track the process. To elevate the efficiency of manual cowpea threshing, Maunde (2011) developed and evaluated the performance of a manually operated cowpea thresher and reported 90 % threshing efficiency. However, the thresher could not carry out separation and cleaning operations which are the major limitations to the performance of manual threshers *(Omid et al. 2010)*. Consequently, the author recommended a possibility of motorizing it, and making provision to address the limitations. In view of these, motorized threshers were also introduced to alleviate the above-mentioned challenges that farmers face. One of the typical studies to address these problems was carried out by *Irtwange (2009)* and obtained overwhelming average threshing efficiency of 96.29%. This was after the researcher fabricated a motorized cowpea thresher and tested it using recommended beater and fan speeds of 500 rpm and 1,400 rpm respectively. Subsequently, *Maunde (2014)* developed a motorized thresher to solve the problem of separation and cleaning in the case of manual cowpea threshers, and achieved 97% threshing efficiency. All the above studies have provided significant information towards effective threshing of cowpea and soybeans. However, gaps exist for new research direction. These include quantifying the impact force that are developed by rotor pegs or any other machine parts that come in contact with the grain during threshing. Determination of the best curved peg geometry that will significantly reduce impact force and to large extent decrease grain damage must be the focus of current researchers. Data on the actual speeds of the moving components relating to specific moisture contents of the crop for optimal performance have not been fully determined. Details on these projections into the future are highlighted in the section 7.



(a) **(b)**

Figure 3: Schematic section of pod grain thresher mechanisms showing (a) Traditional peg and (b) Curved peg

7 Additional issues and concluding remarks

It is now obvious that mechanized threshing technique is a valuable tool in cowpea and soybeans production chain due to the massive usage in fast tracking the qualitative and quantitative demand of farmers and consumers. Although presently, there are several on-going studies in the area of more efficient thresher design, and machine-crop parameters combination for optimal performance, there is still a lot of work that needs to be done with this technology. Continuous improvement in the techniques and methodologies are needed for effective mechanized threshing research to serve as a leading technology in the coming decades. Theoretical model development, simulation and validation of such works with experimental results are expanding areas of research interest.

The use of modelling as a research tool in combination with practical assessment for critical analysis of the role grain moisture content play on the physical features, feeding rate as well as mechanical properties, presents an excellent opportunity for studying the effect on the impact damage during the threshing process. This is because the above-mentioned parameters are directly linked to the performance of the threshing unit. In that circumstance, a strong database for linking the role of the above-mentioned parameters with the drum speed, geometry of the impacting body and the feeding rate could be obtained. It could also be exciting in the future to incorporate more studies on material kinematics in axial threshing units since only few published research results are available (*Miu and Kutzbach, 2007*). This area is fairly unexplored and so could pave the way for providing the information needed to understand the effect of rotor speed, spirals angle, feeding rate and material moisture on the performance of such threshers. With much improvement in system design and configuration, the provision of further insights into the threshing processes could be discovered. Thus, pave the way for the optimization of the axial flow thresher performance as a measure towards ensuring availability of high quality soybean, cowpea and other pod grains in the coming decades. An understanding into grain structural stresses responses to compressed and impact mechanical loading is the key to developing threshing models for different varieties of pod grains. Further research into the above-mentioned properties is also essential for the design of the threshing equipment.

Another area of interest which is essential for a rational design of efficient thresher and optimization of the threshing process is the knowledge of fracture characteristics of the seed (Saiedirad et al. 2008). Although, some few research results on grain rupture have been published, only few are current. In one of such studies, Allen and Watts (1997) determine the mechanical and aerodynamic properties of both beans and pods. The aim was to obtain the necessary information for effective design of the threshing and cleaning system. The results showed that the average energy required to cause fracture of a single bean under quasi-static load was higher than that for impact loading and an average terminal velocity of 9 m/s from the aerodynamic tests. However, the authors recommended 6 m/s as the required average terminal velocity for effective separation of the threshed pods. Another step towards quantification of mechanical properties instigated Singh and *Goswami (1998)*, to subject cumin seed to compressive loading under variable seed moisture. The authors then confirmed that the rupture force increased with increasing deformation and decreasing moisture content in the horizontal and vertical orientations. Similarly, *Ogunjimi et al. (2002)*, assessed the mechanical properties of locust bean seed under loading and established that the seed orientation that provided the highest resistance to cracking is in the vertical axis with the thickness having the least resistance to cracking. The above published results have proven that the influence of seed moisture on the seed coat rupture and subsequent deformation in response to mechanical loading varies with the variety of the crop and orientation of the seed. There is, however, little information on the exact grain moisture content, drum speed, and the geometrical shape of the impacting body which is critical to the crop–machine parameters combination for optimizing the threshing process. Furthermore, there is scanty data on the feeding mechanism that leads to better orientation of the pods before impact. Hence, much needs to be done in making data on the above-mentioned parameters available to enhance effective thresher design and manufacturing. Though, several attempts have been made to measure the impact force developed from the working surface of impacting bodies, it appears that there is a major challenge in obtaining the exact impact force. This is because to date there is no agreement among researchers as to the standard approach for such measurements for different working surfaces originating from different geometrical shapes. The way forward to bridge this gap and harmonise the system is to identify and shared among researchers, suitable computer simulation software and codes through an open source libraries and educational forums to enhance pioneering research into the evaluation of impact force.

Further research attention must be focused on measuring the impact force practically for the various geometrical shapes of the impacting thresher parts. Over the years, most researches into grain resistance to cracking and subsequent deformation in response to mechanical loading, focused on single impact. However, this technique does not provide the impact force received by all possible contact points along the working surface of the rotor peg. Furthermore, several points on the working surface of the rotor peg serve as grain contact point during drum rotation. Consequently, the impact force close to the rotor-peg joint is less than that at the tip of the peg regardless of the peg geometry. Therefore, there is variation in the impact force along the working surface. The entire impact force can be obtained if multiple impact force sensors are fixed on the working surfaces of the peg or on the concave and connected to the data logger to take readings of the impacts received by the grain. In this regard, all impact forces generated by all contact points along the working surface can be assessed for the various peg geometries.

To achieve all of these, it requires that researchers dedicate more time, and effort to overcome the challenges ahead which also goes with cost. However, gigantic progress in this direction could be made through effective collaboration among industry players, government institutions and research institutions. In conclusion, this review has brought to light the prospects of the techniques and an attempt to set up a standard for the improvement of soybean, cowpea and other pod grains quality. It is therefore crucial for future research to focus more on exploring how the technology could be used to provide relevant data for the benefit of the scientific community.

Conflicts of Interest

The authors for this review paper have no conflict of interest to declare.

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