Type of the Paper (Article)

Semi-automatic pineapple harvester for mechanization of pineapple harvesting in North East Hill (NEH) regions of India

Mayanglambam Aarbindro Singh [1]*, Satish Devram Lande [1] Indra Mani Mishra [1], Jai Prakash [2], Tapan Kumar Khura [1], and Susheel Kumar Sarkar [3],

[1] Division of Agricultural Engineering; Indian Agricultural Research Institute, New Delhi, India.
[2] Division of Fruits and Horticultural Technology; Indian Agricultural Research Institute, New Delhi, India
[3] Indian Agricultural Statistics Research Institute, New Delhi, India
* Correspondence: aarbindromayanglambam@gmail.com;

Abstract: The pineapple (*Ananas Comosus*) is one of the most valuable commercial fruits in the world. Harvesting of pineapple is a major operation in pineapple cultivation and is laborious, and energy-intensive involving 306 man-hours per acre approximately. Manual harvesting by sickle is always injury-prone, which reduces the harvesting efficiency because the pineapple consists of long-pointed leaves usually needle-tipped and generally bearing sharp, up-curved spines on the margins. The maximum displacement of the outer skin of the pineapple due to compression force (70N) was observed at 10.63 mm on the Kew cultivar and 9.19 mm on Queen Cultivar. The maximum cutting energy and force of pineapple stalk were obtained as 1243.313 mJ and 168.15375 N respectively for the Queen cultivar and 2037.511 mJ and 190.91 N respectively for the Kew cultivar. A prototype of a semi-automatic pineapple harvester consisting of a grabbing unit with a linear actuator, cutting unit (cutting blade & DC motor), handle and the battery was designed and developed. The harvester was powered by a 12V 7Ah lead acid battery and had the capacity to harvest 200 fruits per hour. The harvesting time of the semi-automatic pineapple harvester is 30% higher than that of manual harvesting.

Keywords: pineapple harvester; fruit harvesting; pineapple properties: harvester design; pineapple harvester prototype

---

1. Introduction

Pineapple (*Ananas comosus*) is a vital tropical fruit in the international market. It mainly contains vitamins A, C and carotene and refreshing sugar-acid balance and is a very rich source of vitamin C and organic acids [1]. Pineapple leaves are high in fiber and can be used as a textile material with excellent bacterial properties [2]. India produces around 6.69% (1,711,000 metric tonnes) of the total world production of pineapple [3] with productivity of 16.6 Metric Tons/ha [4]. As pineapple is a perennial fruit with a unique shape, it's far much less probably to be mechanized for huge-scale mechanization. Pineapples have long-pointed leaves of length 50-180 cm, usually, needle-tipped and generally bearing sharp, upcurved spines on the margins [5]. For pineapple cultivation in hilly parts of North-Eastern India where more than 40% of total production in India [6] , land preparation, plantation, weeding, irrigation, fertilizer application, earthing up, and harvesting are done manually. The post-harvest loss of pineapple at the farm level was found to be 6.82% of harvested fruits due to several reasons as pineapple fruits are very sensitive to pressure [7]. The harvesting is most often manual and the harvesters pass between the rows and pick the fruit either by breaking the stalk or cutting it with a cutting tool or sharp knife with a long wooden handle, severing the fruit's stalk with a clean-cut retaining 5-7 cm of the stalk with the fruit [8][9]. While cutting the stalk, they have to bend their body and there is a high chance of damaging the eye with the pointed leaves of pineapple as well as back pain and knee pain that occur most of the time to the farmers due to the bending posture while harvesting. Studies also tells that the harvesting operation is one of the most laborious farm operations consuming the most man hours per ha[10]. Moreover, pineapple grower faces challenges like heavy labour demand and a short harvest window at the time of harvesting. Proper mechanization of this difficult task will reduce the problems of labour shortage, safety problems during the harvesting process, problems of post-harvest losses and high cost of production. Many attempts were going on nowadays for harvesting fruits[11][12]. Very few attempts were made in the design and development of a pineapple harvesting system including a pineapple harvesting manipulator and its control system in-built with a vision system for pineapple harvesting as a part of pineapple harvesting robots [13]. A low-cost image acquisition platform for use in a pineapple harvester was also developed which includes two CMOS cameras, a tripod, a tripod head, a personal computer, and an illumination device[14]. Xia *et al*. [15] designed a pineapple harvesting manipulator which consists of a manipulator arm, an end-actuator, a positioning identification device, a travelling mechanism, a frame, a fruit box and a control system. Also, a semi-automatic pineapple picking machine, composed of a picking part, a lifting part, a pineapple conveying part, and a pineapple accumulate part was designed by Zhang *et al*. [16]. Du *et al*. [17]also developed an end effector based on physical characteristics of pineapple like mass, transverse diameter, vertical diameter, and stalk. A robotic system for harvesting pineapple containing a machine vision unit, two robotic manipulators mounted on a platform, custom end-effectors, and an image-based harvesting control unit was also developed and had 95.55% harvesting success rate with harvesting time of 12s per pineapple[18]. Guo *et al*. [19] designed an automatic straddle harvester for harvesting pineapples based on the planting mode and growing characteristics of the pineapple for maximizing financial returns and reducing damages to the fruit and plant. A multi-flexible fingered roller harvesting mechanism for pineapple was also designed and developed for batch packing of pineapple[20]. It was observed that the existing design of pineapple harvesters were either focusing on fully automatic with a vision system which is not economical for marginal and small farmers and those which are developed modified from brush cutter are feasible for long hour of working. As well as the design of a portable light weight pineapple harvester is needed. The design which can be used in hilly terrain was found to be operated using only petrol engine and found to be of heavy weight. Moreover, the efficiency of these harvester needs to be increased. For preventing mechanical harm and optimizing the energy use in harvester, the consideration of physical and engineering properties is need during design[21][22].It was also suggested that a better end effector in the shape of pineapple would to reduce fruit damage during pineapple harvesting[17]. So, this study aimed to design and develop portable semi-automatic harvester based on the physical and engineering properties of pineapple to overcome all practical problems associated with manual harvesting of pineapple for the small farmers of the NEH region of India.

2. Materials and Methods

2.1.1 Measurement of physical dimensions of Pineapple

A major pineapple-producing area of Manipur namely, Saram Ching of Uyal, Thoubal was taken for study as it is a hilly terrain area. Two important pineapple cultivars of the NEH region[23] were selected for investigation. A total of 100 pineapples, 50 Queen and 50 Kew cultivars were randomly picked up for measurement of the physical and engineering properties. A stratified sampling method was used for the collection of samples in which the sample size is divided into two strata. The physical dimension of pineapple viz. transverse diameter, vertical diameter, and diameter of the stalk was measured using a digital vernier calliper of least count 0.01mm and weight was taken using a weighing balance of 1g least count.

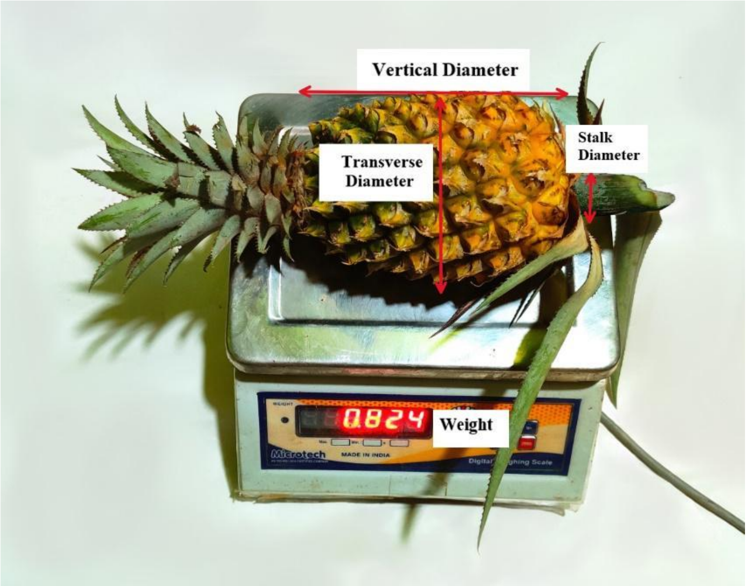


Figure 1. Measurement of physical dimensions of pineapple

2.1.2 Compression test on pineapple

The compression force describes the force applied to the pineapple when physical inward force applies on a surface of the pineapple which affects the self-life of the pineapple. To check the resisting capacity of pineapple surface during harvesting and in order to mimic the grabbing of pineapple during harvesting, an experimental setup shown in **Figure 2** was used. The experimental setup consisted of two grabbers made from PLA material designed using 3D printer, force sensor FSR placed on the surface of grabber, and a linear actuator to give the force of grabbing. The force sensor was connected to an Arduino UNO to collect force data on the computer.

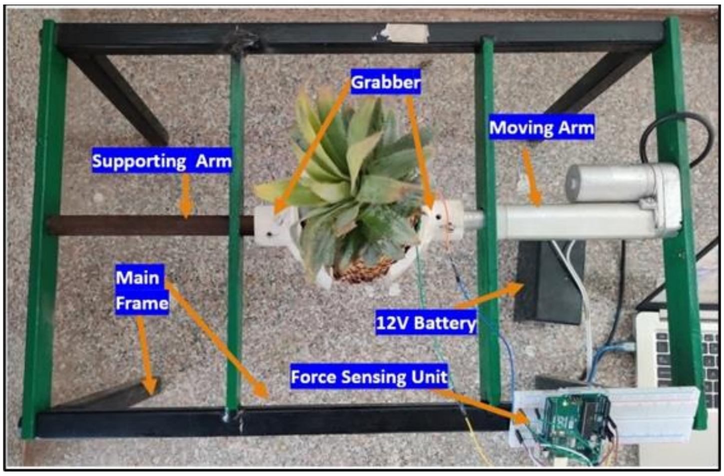


Figure 2. Experimental setup for compression force test

Using this experimental setup, two parameters affecting the shape of pineapple viz. force and displacement applying the optimum force required for grabbing the pineapple which was calculated using the following formula.

$$F \geq \frac{k.F}{2\mu} = k.\frac{mg}{2\mu}$$

where,
F= forward pressure given by the grabber's arm, N
k= factor of safety (2 was considered for the experiment)
m= mass of pineapple, kg

g = acceleration due to gravity, 9.8 m/s^2
μ = coefficient of static friction between pineapple and PLA material

Coefficient of friction was determined using the inclined plane method on PLA plastic surface [24]. Maximum mass of pineapple (1869 g) and minimum coefficient of static friction (0.4913) was considered. So, the optimum force required for grabbing was 37.32 N. The compression test was performed by giving a compression force up to 70N to the surface of the pineapple.

2.1.3. Determination of cutting force of pineapple stalk

The cutting force of the pineapple stalk during harvesting allows the pineapple to detach from the plant. It can be used to determine the application of cutting force during the cutter's movement while harvesting. The grabber used in the experimental setup for compression was replaced by a cutter and the cutting test was performed to find the cutting force and energy of the pineapple stalk.

2.2. Design of semi-automatic pineapple harvester

The design and development of the semi-automatic pineapple harvester was done at Engineering workshop of Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, India. The design of the harvester consists of critical parts like a grabbing unit, cutting unit, handle and linear actuator as shown in figure 3. All the parts were designed using Creo Parametric 7.0 Software and were assembled to get the prototype.

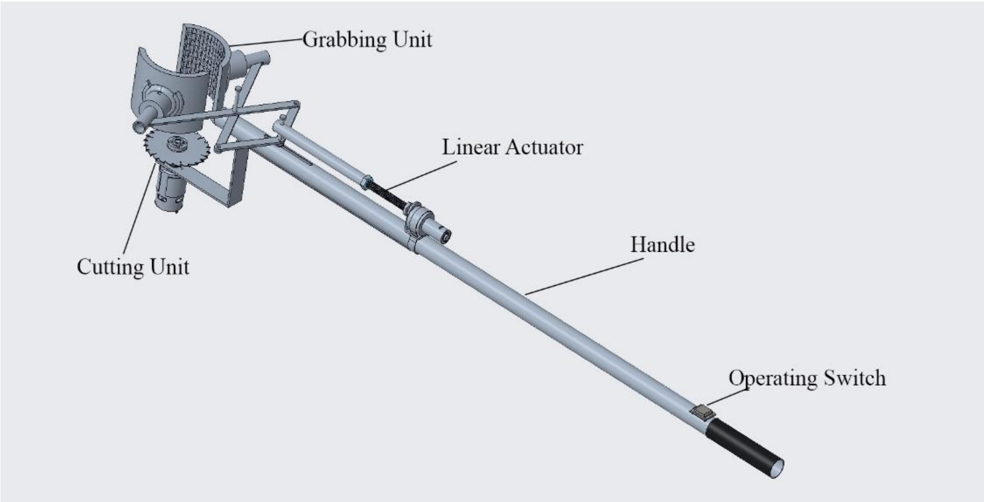


Figure 3. Components of the pineapple harvester

The design and development of the semi-automatic pineapple harvester was done at Engineering workshop of Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, India. The design of the harvester consists of critical parts like a grabbing unit, cutting unit, handle and linear actuator as shown in figure 3. All the parts were designed using Creo Parametric 7.0 Software and were assembled to get the prototype.

2.2.2 Material Selection

The selection of material for the harvester was a very important and crucial part as it can affect the quality and cost of the machine [25]. The best material is one which serves the desired objective at the minimum cost. Availability of the materials, suitability of the materials for the working conditions, cost, durability, strength, corrosion resistance, lightness, flexibility, and workability were considered when selecting the material [26]. Therefore, galvanized steel, mild steel, stainless

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

steel, flexible cables, and rubber grips were used in fabrication. The table 01 gives the selected material and selection criteria for each component

Table 1. Selection Criteria and Material for components of harvester.

Component	Criteria for selection	Selected Material
Handle	Handle Lightness, Strength, Corrosion resistance, Cost	Aluminum
Grabber	Readily obtainable, lightweight, 3D Printable, satisfying static friction test	PLA
Links used in Grabbing Unit	Stalk cutter frame Strength, cost, wear resistance and availability Mild steel Grips	Mild steel
Stalk cutter	Stalk cutting Strength, Lightness, Corrosion, and acidic reaction resistance	Stainless steel
Linear Actuator	Strength, corrosion	Stainless Steel
Grips	Flexibility, strength, wear resistance, availability	Rubber

2.3. Evaluation of developed semi-automatic pineapple harvester

The harvester was evaluated in the field of Saram Ching of Uyal, Thoubal, Manipur, India for its performance and for ergonomic analysis with parameters like Body part discomfort score, overall discomfort score and heart rate.

3. Results and Discussion

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Variation in physical properties of the pineapple

The observed mean values of the Queen cultivar for vertical diameter, transverse diameter, and stalk diameter were in the range of 78-156 mm, 78.00-123.40 and 12.33-24.63, respectively. Similarly, for the Kew cultivar of pineapple, the observed values of vertical diameter, transverse diameter, and stalk diameter were in the range of 105-197 mm, 94-125 mm and 15.67- 28.47 mm. As compared to the Queen cultivar, a higher vertical diameter of 197 mm was observed for the Kew cultivar and it was 20.8% higher than the Queen cultivar of pineapple. Also, the highest transverse diameter, and stalk diameter values were observed as 125 mm and 28.47 mm for the Kew cultivar. The weight of the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

pineapple was required for incorporation in the static analysis of the harvester. The observed mean value of the weight of pineapple Cultivars was in the range of 360-1869 g. The Kew cultivar was observed to be 27.5% higher than the Queen cultivar.

Table 2. Variation in physical properties of pineapple.

Cultivar of Pineapple		Vertical diameter of pineapple(mm)	Transverse diameter of pineapple (mm)	Pineapple Stalk diameter (mm)	Weight of Pineapple(g)
Queen	Mean	113.6600	94.6460	18.9713	821.9000
	Standard Deviation	21.28592	11.03302	4.09332	255.96351
	Minimum	78.00	78.00	12.33	360.00
	Maximum	156.00	123.40	24.63	1355.00
Kew	Mean	152.1200	109.5740	22.7773	1403.2800
	Standard Deviation	27.42533	6.52746	3.21575	215.64559
	Minimum	105.00	94.00	15.67	930.00
	Maximum	197.00	125.00	28.47	1869.00

3.1.1. Effect of compression force on the displacement of the outer skin of pineapple during grabbing

The maximum displacement of the outer skin of the pineapple at 70N was observed at 10.63 mm on the Kew cultivar and 9.19 mm for the Queen cultivar. The mean maximum displacement of Kew was 20.62 % more than the Queen cultivar. It was observed that the displacement influenced by the application of compressive force was in a linear manner with an R^2 value of 0.955.

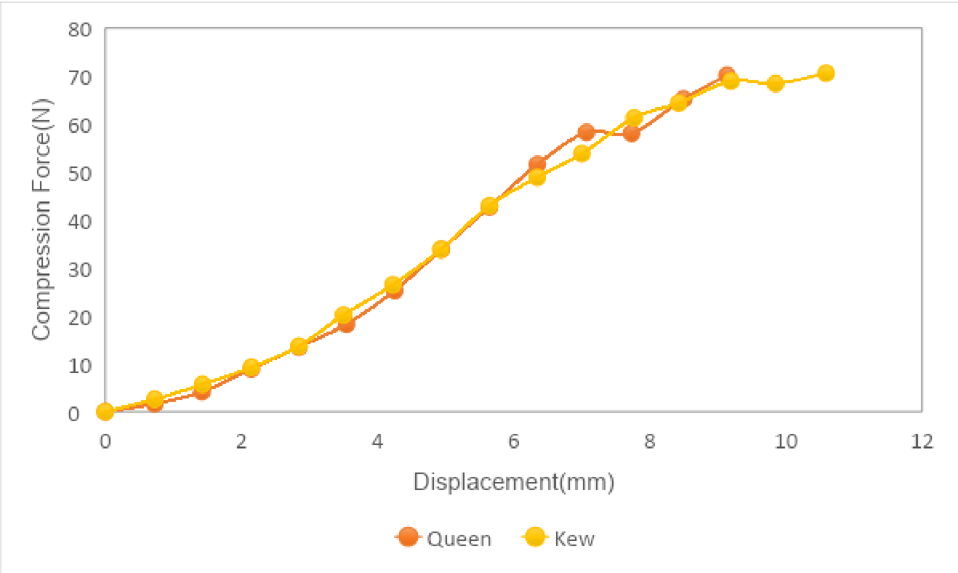


Figure 4. Variation in maximum inward displacement(mm) of pineapple skin due to compression force(N).

A similar observation was found in the compression test performed by Du et al. (2), where the pineapple was deformed slowly from 0-1.7 mm and increased more rapidly when the deformation was greater than 2.5 mm. But no yield point was observed up to a force of 50N.

3.1.2. Variation in cutting force of two cultivars of pineapple stalk

The maximum value of cutting force was observed for Kew Cultivar along with maximum displacement as compared to Queen Cultivar of pineapple. The trend reveals that the stalk cutting energy requirement for Kew Cultivar was higher than Queen. The peak cutting

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

force was in the range of 155.36 – 183.49 N with a mean value of 168.15 N for the Queen cultivar of pineapple. Whereas, the peak cutting force for Kew Cultivar of pineapple was in the range of 167.89 – 210.35 N. The mean peak cutting force for the Kew cultivar was 11.97 % higher than the Queen cultivar.

The stalk cutting energy helped in determining of power required for detaching pineapple from the pineapple plant. The cutting energy for Queen Cultivar of pineapple was in the range of 997.74 - 1449.23 mJ. Whereas for Kew Cultivar, it was in the range of 1818.10 – 2313.69 mJ. The mean cutting energy for Kew was 39 % higher than the Queen Cultivar.

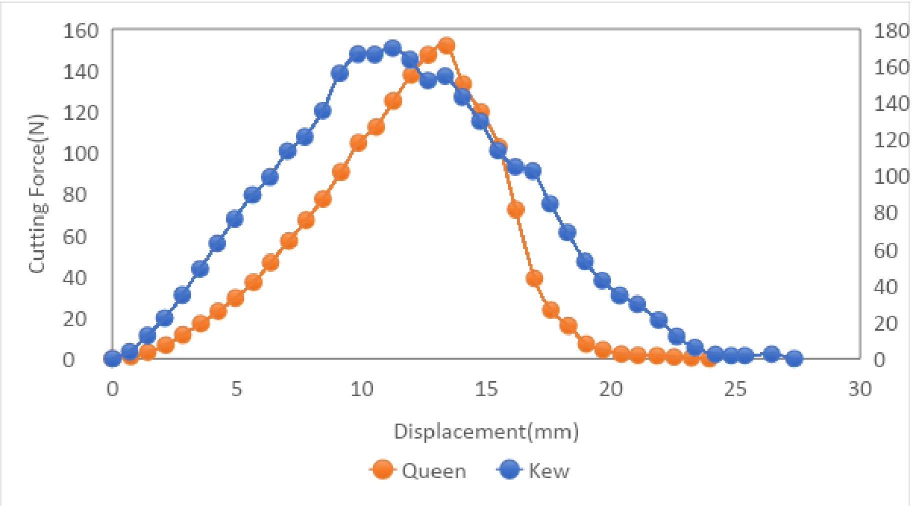


Figure 5. Variation in stalk cutting force between two cultivars of pineapple.

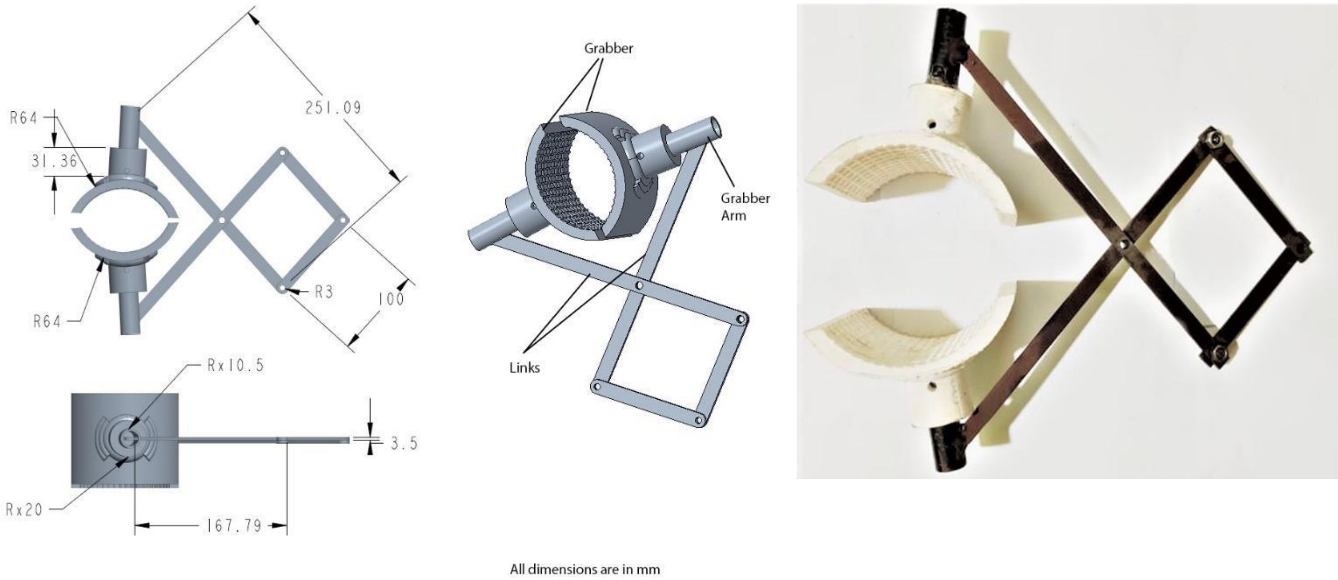
3.2. Prototype of Semi-Automatic Pineapple Harvester

The prototype of a semi-automatic pineapple harvester was fabricated using the design consideration at the divisional workshop of Agricultural Engineering, IARI, New Delhi, India.

3.2.1. Design and development of Grabbing unit

The grabbing unit is responsible for holding the pineapple while harvesting. Grabber, grabber arm and links are the major components. A Scissor mechanism was used for opening and closing the grabbing unit. The grabber was based on the shape of a pineapple which is cylindrical in shape [27]. The grabber was engraved with various horizontal and vertical grooves for increasing friction between the pineapple skin and the grabber's inner surface. The inside curved concave surface of the grabber unit was designed by using the maximum transverse diameter of 110mm ±15 mm for proper holding and positioning of the body of the pineapple fruit without disturbing the crown of the pineapple. Readily obtainable, lightweight and moreover, material which can be 3D printed was the consideration for the material of the grabber. With the above consideration and based on the static friction characteristics test of the pineapple surface [28], PLA was selected as the material for grabber. The links were developed from medium carbon steel material due to their lightweight compared to other materials like iron. The links were able to hold the weight of the pineapple and grabber arm. The maximum stress was found in the grabber's arm during static analysis. So, the material for the grabber's arm was chosen to be stainless steel for nullifying the effect of stress on the grabber's arm.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

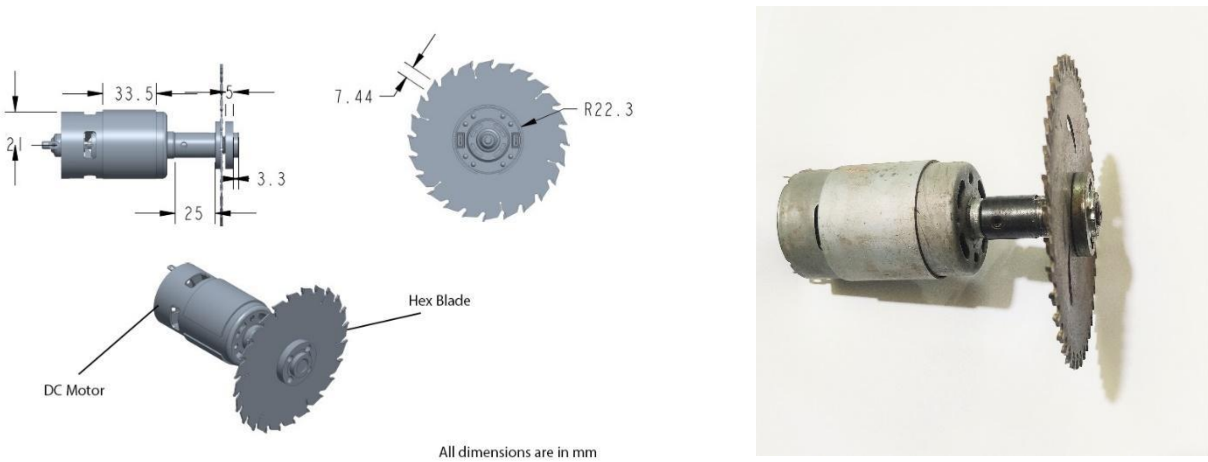


(**a**) (**b**)

Figure 6. (**a**) Design of Grabbing Unit; (**b**) Developed grabbing unit

3.2.2. Cutting unit

The cutting unit is used for cutting the pineapple stalk while the pineapple is being held by the grabbing unit. The design consideration consists of simplicity in mechanism, availability in market and hardness of pineapple stalk, hardness of blade material, blade holding setup, and operating conditions, such as cutting energy of pineapple stalk. The design criteria for the motor were based on the cutting energy of the stalk of pineapple and the RPM of the motor. The cutting unit was designed based on the vertical diameter of the pineapple and stalk diameter. The distance between the plane passing through the cutting blade and a plane passing through the bottom of grabbing unit was based on the vertical diameter of the pineapple. The maximum diameter of the stalk of pineapple was used in the selection of the diameter of the cutting disk. A hex saw disk made from HSS material of 110 mm was selected for avoiding maximum breakage. The rotating speed of the motor for the cutter was based on the cutting energy for the stalk to optimise the energy consumed by the cutting unit. A DC motor with 3000RPM, 12V was found to be the best commercially available motor for the condition.



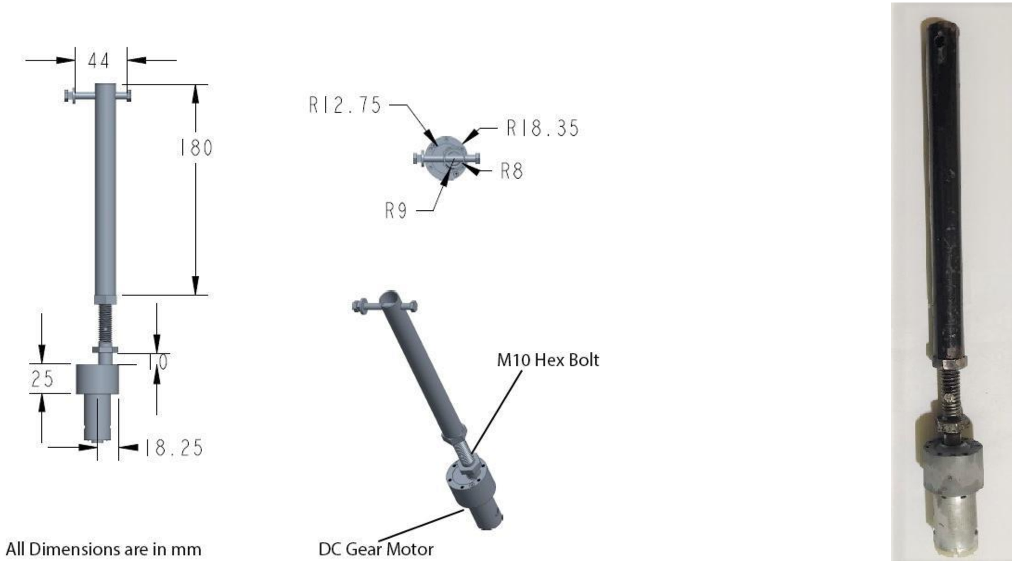
(**a**) (**b**)

Figure 7. (**a**) Design of Cutting Unit; (**b**) Developed Cutting Unit

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

3.2.3. Linear Actuator

The linear actuator makes the movement of the grabbing unit. The working principle is to convert a rotating movement into a linear movement. The design consideration of the linear actuator was the force required for moving the grabbing unit, the weight and the hardness of the material. Based on availability in the market, cost of operation and maintenance, ability and suitability to perform the harvesting operation, were the design criteria. A novel method of lead screw linear actuation of 100 mm stroke was implemented. An M10 hex bolt was taken and a 5mm diameter hole was made exactly at the centre of the bolt head. The hole was made 2cm deep and a hole of 2mm diameter was made perpendicularly. The hex bolt was attached to a 12V 600 RPM High torque Gear motor to give the rotation. The M10 nut was taken and it was welded with a 16 mm diameter cylinder of 20 cm length.



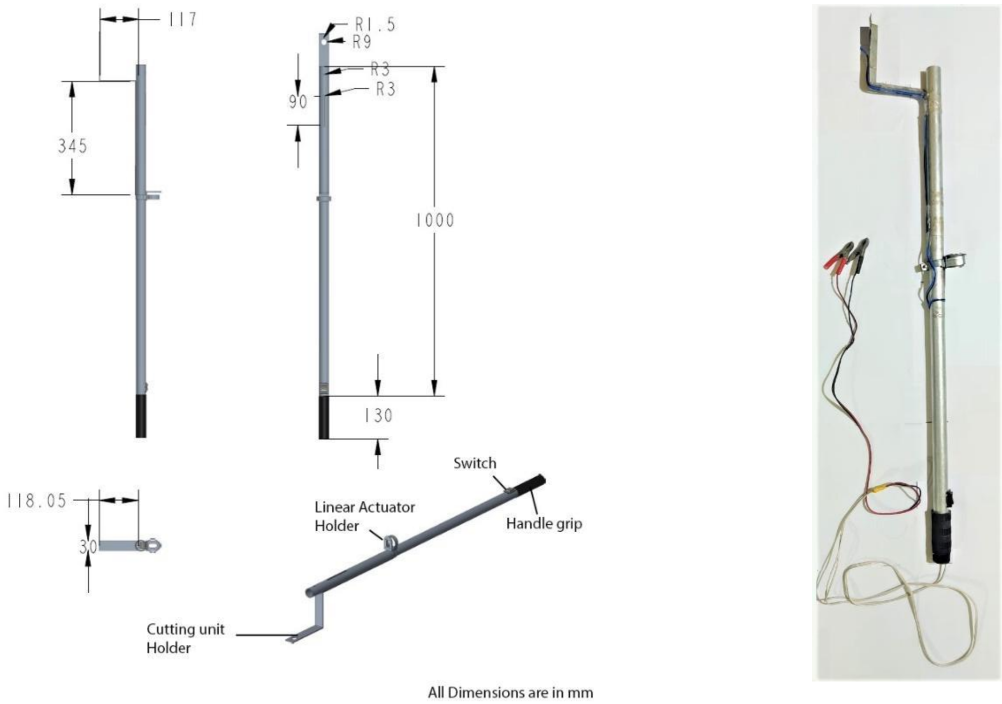
(**a**) (**b**)

Figure 8. (**a**) Design of Linear Actuator; (**b**) Developed Linear Actuator

3.2.4. Handle

The handle is used for holding the harvester by the operator and for attaching other parts to it. The design considerations were lightweight and the strength of the material. The harvester was aimed at minimizing weight. Aluminium was found to be the best suitable element for the handle as the specific weight of the element is very less compared to other commonly available materials such as steel and iron. In addition to the above point, aluminium is a self-lubricating element, and a lesser frictionless element was needed for the smooth sliding mechanism of the grabber.

 doi:10.20944/preprints202210.0120.v1



(**a**) (**b**)

Figure 9. (**a**) Design of Handle; (**b**) Developed Handle.

3.2.5. Power Source

A convenient, easily available and clean power source was the basis of the power supply. The power supply was based on the energy drawn by the grabbing unit, linear actuator and cutting unit. The power source was chosen to be battery operated considering it is a clean fuel and does not give vibration during the power generation. A 12V-7Ah lead Acid rechargeable battery was used to power the pineapple harvester and it was carried inside a bag hanged by the operator.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0120.v1

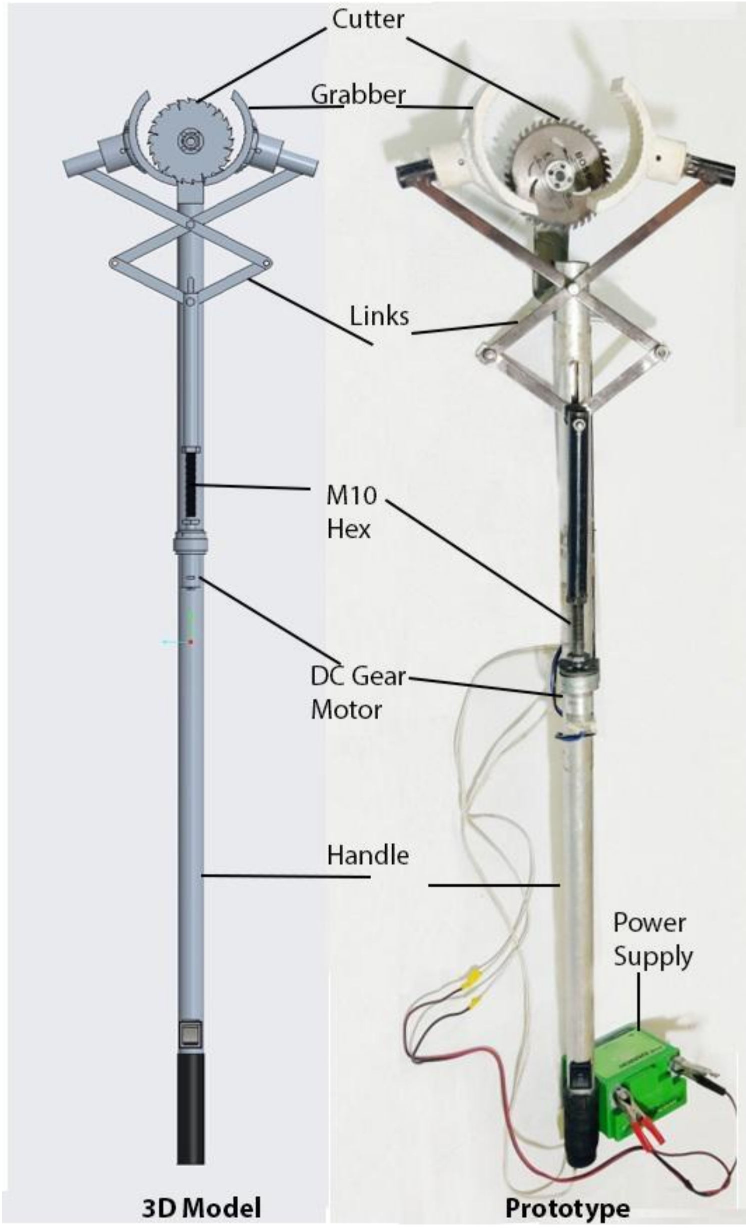


Figure 10. 3D Model and Prototype of the Semi-Automatic Pineapple Harvester.

3.3. Evaluation of the developed Semi-Automatic Pineapple Harvester

The harvester was evaluated in the field and found that it was capable of harvesting 200 pineapples at maximum. The harvesting efficiency of the harvester was 25.35 higher than the manual harvesting method. The overall weight of the harvester was found to be 3.5 kg. As compared to manual harvesting, harvesting using the developed harvester reduces body part discomfort score, overall discomfort score and heart rate by 53.55 %, 30% and 24.3 % respectively. The power required for the running of the semi-automatic pineapple harvester was calculated theoretically. The energy required for grabbing the unit per pineapple was 150.0264 mJ. Whereas the energy required for cutting one pineapple stalk was 2313.69 mJ. The total theoretical energy required for harvesting one pineapple by the semi-automatic pineapple harvester was 2.463 J and 0.421 W respectively.

4. Conclusions

From this research, it was found that physical properties viz. transverse diameter, vertical diameter, stalk diameter and weight of Kew cultivar were greater than queen cultivar significantly. So, for designing the handheld semi-automatic pineapple harvester, these parameters were critically important. For safe harvesting of the pineapple, compression test and cutting test were helpful and it also helps in extending the self-life of the pineapple after harvesting. The developed harvester will greatly reduce the drudgery of the workers by reducing the ergonomic parameters and enhancing the efficiency of the harvesting.

Author Contributions: Conceptualization, M.A.S., S.D.L. I.M.M and T.K.K.; methodology, M.A.S., S.D.L.; software, M.A.S.; validation, S.D.L., I.M.M., J.P., T.K.K. and S.K.S.; formal analysis, M.A.S.; investigation, M.A.S.; resources, M.A.S.; data curation, M.A.S.; writing—original draft preparation, M.A.S.; writing—review and editing, S.D.L. and J.P.; visualization, M.A.S..; supervision, S.D.L., I.M.M.; project administration, I.M.M.; funding acquisition, S.D.L. All authors have read and agreed to the published version of the manuscript."

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bartolomé, A.P.; Rupérez, P.; Fúster, C. Pineapple Fruit: Morphological Characteristics, Chemical Composition and Sensory Analysis of Red Spanish and Smooth Cayenne Cultivars. *Food Chem.* **1995**, *53*, 75–79, doi:10.1016/0308-8146(95)95790-D.
2. Enping, L.; Anping, G.; Yunling, G. Development and Application Status and Prospects of Pineapple Leaf Fiber [J]. *Text. Her.* **2006**, *2*, 32–35.
3. Food and Argriculture Organization of the United Nations [FAO] Fao Publications Catalogue 2019. **2019**.
4. Government of India, M. of A.& F.W.D. of E.& S. Pocket Book of Agricultural Statistics 2020. **2020**, 1–137.
5. Morton, J.F. *Fruits of Warm Climates.*; JF Morton, 1987; ISBN 0961018410.
6. Sema A. A4 - Maiti, C.S. A4 - Dietholhou, A.A.-S. Pineapple Cultivation in North East India - a Prospective Venture. *Acta Hortic.* **2011**, *v.*, 69-78-2011 v. no.902.
7. Ningombam S; Noel AS; Singh J Post-Harvest Losses of Pineapple at Various Stages of Handling from The Farm Level Up to The Consumer in Manipur. *Int. J. Agric. Sci. Cit.* **2019**, *11*, 9235–9237.
8. United Nations Pineapple: United Nation Conference On Trade and Development. *An INFOCOMM Commod. Profile* **2016**, *New York* &, 1–22.
9. Joy, P..; Roshida Rajuva, T.. Harvesting and Postharvest Handling of Pineapple. *Icarda* **2009**, *15*, 1–15.
10. Rukunudin, I.H.; Mohammud, C.H.; Abd. Rahim, H.; Rohazrin, A.R. Field Evaluation of Mechanization System for Large Scale Pineapple Production on Mineral Soils in Malaysia. *Acta Hortic.* **2011**, *902*, 299–306, doi:10.17660/actahortic.2011.902.33.
11. Davidson, J.R. Imece2015-50482 Mechanical Design and Initial Performance Testing of an Apple-. **2017**, 1–9.
12. You, K.; Burks, T. Development of a Robotic Fruit Picking End Effector and an Adaptable Controller. *2016 Am. Soc. Agric. Biol. Eng. Annu. Int. Meet. ASABE 2016* **2016**, 1–14, doi:10.13031/aim.20162455128.
13. Wang, H.; Li, B.; Liu, G.; Xu, L. Design and Test of Pineapple Harvesting Manipulator. *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.* **2012**, *28*, 42–46, doi:10.3969/j.issn.1002-6819.2012.z2.008.
14. Li, B.; Wang, M.; Wang, N. Development of a Real-Time Fruit Recognition System for Pineapple Harvesting Robots. *Am. Soc. Agric. Biol. Eng. Annu. Int. Meet. 2010, ASABE 2010* **2010**, *6*, 4958–4968, doi:10.13031/2013.29922.
15. Xia, H.M.; Zou, X.J.; Wang, H.J. Virtual Simulation Design of the Pineapple Harvesting Manipulator. *Adv. Mater. Res.* **2011**, *268–270*, 1194–1199, doi:10.4028/www.scientific.net/AMR.268-270.1194.
16. Zhang, L.; Tang, S.; Li, P.; Cui, S.; Guo, H.; Wang, F. Structure Design of A Semi-Automatic Pineapple Picking Machine. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *452*, doi:10.1088/1757-899X/452/4/042155.
17. Du, X.; Yang, X.; Ji, J.; Jin, X.; Chen, L. Design and Test of a Pineapple Picking End-Effector. *Appl. Eng. Agric.* **2019**, *35*, 1045–1055, doi:10.13031/aea.134051045.
18. Anh, N.P.T.; Hoang, S.; Tai, D. Van; Quoc, B.L.C. Developing Robotic System for Harvesting Pineapples. In

Proceedings of the 2020 International Conference on Advanced Mechatronic Systems (ICAMechS); 2020; pp. 39–44.
19. Guo, A.F.; Li, J.; Guo, L.Q.; Jiang, T.; Zhao, Y.P. Structural Design and Analysis of an Automatic Pineapple Picking and Collecting Straddle Machine. *J. Phys. Conf. Ser.* **2021**, *1777*, doi:10.1088/1742-6596/1777/1/012029.
20. Liu, T.; Liu, W.; Zeng, T.; Cheng, Y.; Zheng, Y.; Qiu, J. A Multi-Flexible-Fingered Roller Pineapple Harvesting Mechanism. **2022**.
21. Akbarnejad, A.; Azadbakht, M.; Asghari, A. Studies of the Selected Mechanical Properties of Banana (Cavendish Var.). *Int. J. Fruit Sci.* **2017**, *17*, 93–101, doi:10.1080/15538362.2016.1259083.
22. Vishwakarma, R.K.; Shivhare, U.S.; Nanda, S.K. Physical Properties of Guar Seeds. *Food Bioprocess Technol.* **2012**, *5*, 1364–1371.
23. Saloni, S.; Chauhan Assistant Professor, K.; Tiwari Assistant Professor, S.; Chauhan, K.; Tiwari, S. Pineapple Production and Processing in North Eastern India. *J. Pharmacogn. Phytochem.* **2017**, *6*, 665–672.
24. Varnamkhasti, M.G.; Mobli, H.; Jafari, A.; Keyhani, A.R.; Soltanabadi, M.H.; Rafiee, S.; Kheiralipour, K. Some Physical Properties of Rough Rice (Oryza Sativa L.) Grain. *J. Cereal Sci.* **2008**, *47*, 496–501, doi:10.1016/j.jcs.2007.05.014.
25. Kahandage, P.D.; Hettiarachchi, S.W.; Weerasooriya, G.V.T. V Design , Development , and Performance Evaluation of a Mechanical Device for Harvesting Pineapple. **2021**, *5*, 1109–1116.
26. Khurmi, R.S.; Gupta, J.K. A Text Book of Machine Design, New Delhi: S. *Chand Co. Ltd.* **2006**, 657–680.
27. De La Cruz, J.; García, H.S. All-about Pineapple PINEAPPLE Post-Harvest Operations-Post-Harvest Compendium. *Food Agric. Organ. United Nations* **2005**, 2–37.
28. Hohimer, C.J.; Wang, H.; Bhusal, S.; Miller, J.; Mo, C.; Karkee, M. Design and Field Evaluation of a Robotic Apple Harvesting System with a 3d-Printed Soft-Robotic End-Effector. *Trans. ASABE* **2019**, *62*, 405–414, doi:10.13031/trans.12986.