Progress on Research & Development in Pineapple Harvesting: Special Emphasis on Indian Scenario

Abstract: Pineapple harvesting in India still follows traditional manual practice, which is labour-intensive, inefficient, and time-consuming process. Apart from the adoption of awkward posture during repeated manual operation of harvesting, leading to body parts discomfort and in the long-run development of WMSDs, the traditional manual harvesting also induces easy injuries to farmers due to lack of safety measures. The present research aims to conduct an extensive literature review on the state-of-art of pineapple harvesting systems to highlight the existing scenario of research progress and to suggest possible future research directions. Research and development activities towards the identification of problems faced by farmers during pineapple harvesting in Indian scenario and understanding the real need of ergonomic design intervention to come up with a mechanized or semi-mechanized hand-tool type of harvester are the need of the hour to implement efficient, cost-effective and easy to use pineapple harvester.

Keywords: Fruit harvesting systems, Hand tools/equipment, Ergonomics, Pineapple, India

Pineapple (Ananas comosus) is the third most important tropical fruit in the world after banana and citrus. The leading pineapple producing countries are Costa Rica, Brazil, Thailand, Philippines, Indonesia, China, India, Mexico, Nigeria, and Colombia. In India, the area covered under pineapple cultivation is about 1.21 m.ha with the production of 2.00 m.t and productivity of 16.8 t/ha. The area under plantation and production of pineapple show a growing trend in India over the years (Figure 1). It is commercially cultivated across northeastern hilly (NEH) states, West Bengal, Kerala, Tamil Nadu, Andhra Pradesh, Karnataka, Bihar, and Maharashtra. In NEH region of India, pineapple is the second most important fruit crop due to climatic conditions prevailing in the region. The Govt. of India project “Horticulture Technology Mission” had also enhanced 140.7% in terms of both area and production of pineapple. It was also reported that NEH region contributed more than half of the entire country’s production. Further, the six out of eight states of NEH region consistently featured among the top ten pineapple producing belts in India, and almost all the farmers followed traditional cultivation practices.

Among the farm operations, harvesting task is one of the most important operations, and it is usually done manually. Manual harvesting is not only time consuming and labour intensive (20-30 man-days/ha) but also, exposes workers to health hazards and body strain due to awkward posture and repetitive task. However, there is very limited literature available on state-of-art of development on pineapple harvesting systems on the Indian context. Hence, the present study aimed to conduct an extensive literature review on the existing scenario of research & development in pineapple harvesting; and to suggest possible future research directions for improving mechanization level of pineapple harvesting in India.

Methodology

Literature for the present study was collected through a systematic search plan which included both online electronic search and offline search. The online electronic search was performed via Google Scholar, Scopus, and Web of Sciences using the keywords or phrases such as ‘fruit picking’, ‘mechanical fruit harvesting’, ‘pineapple harvesting’, and ‘pineapple cultivation in India’ for searching research articles, proceedings, newsletter, reports etc. The boolean functions like AND, OR and NOT were used during online search between keywords or phrases for further refinement of the output. The website of the Department of Agriculture Cooperation & Farmers Welfare (Govt. of India) and web portals of All India Coordinated Research Projects (AICRP) on Farm Implements & Machinery (FIM) were also visited to collect information on pineapple cultivation and research progress on pineapple harvesting in India. Besides, offline hand
searching from hard copies of AICRP projects reports for relevant documents was also performed.

The literature search was based on certain pre-defined inclusion/exclusion criteria (language, full text, year of publication, duplicity etc.). The present study included publications during 1990 to 2019 in English language only. A total of 55 articles (soft copies) and 3 relevant publications (hardcopy) were selected based on inclusion/exclusion criteria. Full texts of the screened articles/reports were read thoroughly and systematically segregated and presented under different heads in the following sections.

The process of literature survey for the present study is detailed by the flowchart given in Figure 2.

**Review Findings**

**Pineapple Harvesting Process**: Conventionally, pineapple harvesting in India is done manually in such a way that the fruit is not damaged, and the crown is retained. The harvesting of pineapples at their maturity stage depends on the targeted market and purpose (Figure 3). The harvester also brings along a basket strapped over the shoulders to harvest ripe fruits by breaking the stalk or cutting it with a cutting tool or by using a sharp machete. The pineapple should be harvested with a 5-7 cm stalk and the crown attached with a sharp knife. It was also reported that pineapples for export were cut with a sizeable stalk for holding the fruit during transportation, whereas fruits for the local market were simply hand broken off.

**Pineapple Harvesting Problems**: Studies highlighted that most of the plantations in Meghalaya (India) do not maintain the recommended package of cultivation practices. De-suckering of excess suckers and slips hindered weeding operation and fruit harvesting tasks. Therefore, farmers had to place wooden planks over the plants and walked over the planks during harvesting. Moreover, manual harvesting is time-consuming, labour-intensive, inefficient, and also induces easy injuries to laborers due to spines and sharp tips of the leaves. However, safety practice is not often implemented. Further, the manual method causes back pain as harvesters have to stoop while harvesting, and it’s a repetitive task with a lot of body strain due to prolonged bending over to harvest pineapples.

**Fruits Harvesting Systems**: Before going to pineapple harvesting, it is important and critical to study the existing fruit harvesting systems that can be...
adopted for pineapple harvesting. Fruit harvesting systems can be broadly categorized in terms of fruit removal methods\textsuperscript{18}. They were manual (fruit removal by human hand) and mechanical (fruit removal by a mechanical machine or mechanism) harvesting systems. An overview of different harvesters for fruit harvesting is discussed in the following sub-sections.

**Manual Fruit Harvesters:** Manual harvesters are hand tools used to pick individual fruits. Manual harvesters having hold and twist type\textsuperscript{19}, push and cut type\textsuperscript{20}, scissor-type (pruning secateurs)\textsuperscript{21}, scissor inspired shearing type\textsuperscript{22}, and cutting/sniping blade type mechanisms\textsuperscript{23} were developed and evaluated for harvesting different fruits (Figure 4). A prototype of an ergonomic harvesting basket was developed and tested to reduce physiological workload and discomfort during simulated harvesting task\textsuperscript{24}. The improved basket reduced discomfort and overall workload. The study highlighted the potential for design improvement of manual tools and fabrication of the improved basket using lightweight materials into plantation sectors not only in Malaysia but also across Asia. Researches were focused on avoiding fruit damage, reduced drudgery, and on increasing efficiency & effectiveness of fruit harvesting\textsuperscript{19} for small and marginal farmers. Materials were selected by adopting weight point method\textsuperscript{22}, availability in local markets\textsuperscript{20}, expected prototype properties, design, and intended environment\textsuperscript{23}. Design considerations were ease of use, lightweight, low cost, and simple design\textsuperscript{20,23}. Other considerations like anthropometric data of farmworkers were reported apart from fruit crop characteristics\textsuperscript{21}. These harvesters are mostly developed for tall tree-fruits, not for fruit crops like pineapple that grows low on the ground.

**Semi-manual Fruit Harvesters:** Semi-manual harvesters comprise of hand tools where cutting mechanism

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**Figure 3.** Pineapple maturity stages for harvest (Adapted from references 4, 12, 17 & 53)

**Figure 4.** Some important fruit picking mechanisms of manual fruit harvesters (Adapted from references 19-23)
is not actuated by human power, but with some other power source. These harvesters having cutting mechanism actuated by battery-operated motor for different fruits was developed and evaluated globally (Table 1). Design considerations are more or less similar to manual harvesters. Attempts have been to make available simple in design, low cost, flexible, easy and safe, and effective harvester suitable for home gardens and small farms. It was reported that the problems and limitations of manual harvesting by handpicking and manual harvesters (fruit damage, time-consuming and effort in operation) were addressed by semi-manual harvesters and ergonomically safe harvester for long-duration operation as fruit picking mechanisms were actuated by electrical power source.

**Mechanical Fruit Harvester**: The mechanical harvesting techniques are trunk shaking, limb shaking, canopy shaking, air shaking, and the use of a chemical agent to assist harvesting by loosening the fruits. Researchers have also reported pneumatic cut-clamp litchi picking, self-propel shaker, mechanical beater with catching frame (reversed umbrella) for olive, lateral canopy shaker for olive harvesting, tractor operated trunk shaker for almond harvesting, a mobile platform for orange harvesting and motorized variable-length plucking/cutting machine for coconut.

For pineapple, the harvesting process is reported to be mechanized in major pineapple growing countries like Malaysia, Philippines, Thailand, Costa Rica, and Indonesia using heavy machinery such as boom harvester. However, a group of farmworkers manually chopped the fruits and collected the chopped fruits mechanically into a collecting trailer located on the farm road by using boom harvester. The viable acreage for the implementation of mechanized field operation was a minimum of 40 ha. Moreover, the orchard environment must also be configured to suit the requirements of the harvesting system for efficient use of machinery systems. Some researchers also highlighted the major aspects of cultural practices (field conditions, row-spacing, plant spacing, plant population, and plant shape & size) that affected the mechanical harvesting of fruits.

For individual pineapple fruit picking, pineapple picking mechanisms were designed based on the principle of a shutter mechanism to achieve pineapples picking of different sizes. Besides, a structure was also designed for semi-automatic pineapple picking machine. The harvester consists of a picking (a multi-bar mechanism), lifting, conveying, and collecting parts. However, researches on pineapple fruit picking are mostly in the design and experimental stages. Some important fruit picking mechanisms of mechanical harvesting discussed above are shown in Figure 5.

**Robotic Fruit Harvester**: In robotic fruit harvesting, the main tasks are the detection of fruit & location, gripping, and picking. Researchers have reported robotic harvesting of apple, citrus fruits, sweet pepper under protected cropping systems, tomatoes, strawberry, spherical fruits, and coconut. Fruit detachment mechanisms used were arm with a circular saw (common for coconut), oscillating blade, electric cutter, screwing operation, grasping, and laser cutting device. It was also highlighted that the reason for the lack of success of robotic harvesting included technical, economic, horticultural (crop-specific biological systems), and producer acceptance issues.

Some researchers (mostly from China) have initiated works on robotics in pineapple harvesting. Pineapple harvesting manipulator (comprising of grabbing mechanism, hand driving mechanism, and rotating mechanism) and pineapple picking end-actuator (sliding-lever double-fulcrum structure) for pineapple fruit clamping were designed and studied.

### Table 1. Reported fruit picking mechanisms of semi-manual harvesters (Adapted from references 25-26 & 55-57)

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Target Fruit</th>
<th>Country</th>
<th>Picking Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Widyan et al.</td>
<td>Picking tree-top and high-to-reach fruits</td>
<td>Jordan</td>
<td>Pruner (cutter) and dc motor-driven extension mechanism</td>
</tr>
<tr>
<td>(2006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jhala et al.</td>
<td>Mango</td>
<td>India</td>
<td>Motor operated circular blade for cutting</td>
</tr>
<tr>
<td>(2018)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamam et al.</td>
<td>Peach</td>
<td>Egypt</td>
<td>Electrical picking hook &amp; electrical picking holder type</td>
</tr>
<tr>
<td>(2011)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamam et al.</td>
<td>Washington, valencia, mandarin &amp; lemon</td>
<td>Egypt</td>
<td>Rotary cone &amp; electrical scissors harvesting heads</td>
</tr>
<tr>
<td>(2011)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+Dress &amp; Ibrahim</td>
<td>Prickly Pear</td>
<td>Libya</td>
<td>Motorized scissor type cutter producing reciprocating motion</td>
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<tr>
<td>(2017)</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Pineapple fruit parameters such as physical (size, shape & weight) and mechanical (compressive-deformation characteristics) properties dependent on factors like fruit maturity stage and variety are critical for the design of zero damage picking end-actuator with high clamping accuracy. However, these researches are under experiment stages.

Pineapple Harvesting in India

Pineapple is propagated mostly through suckers, slips, and crowns. Pineapple propagation from suckers produces fruits in 15-18 months, whereas it takes 20–24 months after planting from slips and crowns. It is a perennial fruit crop having an economic life of 5–7 years, though the crop is maintained beyond 12–15 years through crop manipulation by many of the farmers in the NEH region. Plantations ranged from 20–25 years old are even common in some states in the region. Pineapple is cultivated mostly in the humid tropical region. The temperature between 22°-32°C, rainfall ranging from 100-150 cm, and sandy loam soils are ideal for proper growth of the plant. Pineapple plantation without a recommended package of cultivation practices or the most common practice, which is a single-row system with a wide spacing plantation method, can accommodate only about 8,000-10,000 plants/ha. This method may have resulted in low productivity. The yield could be enhanced from an optimum national yield of 15 t/ha to about 50-60 t/ha under high-density plantation. The major pineapple producing states with recommended varieties for different states in India are given in Table 2.

A study was reported on mechanization of pineapple cultivation in NEH region of India during 2016-17. The study revealed that farmers were using locally made hand tools (sickle) for harvesting pineapple in Meghalaya and other neighboring pineapple growing states of NEH region (Figure 6). Among various cultivation operations, weeding and harvesting were two major operations, which require a higher amount of manual energy. The man-days/ha requirement under various operations of pineapple cultivation in NEH region is given in Figure 7.

To address the issues of manual pineapple harvesting, a semi-manual pineapple harvester was developed and evaluated at CAU Imphal. The harvester consisted of a sharp serrated rotating blade powered by a 1.5 hp petrol engine and a lever-operated finger to hold the fruit after cutting from the stalk. The harvester could harvest about 250 to 280 per hour without much drudgery and fatigue as compared to 150 fruits that can be harvested by the conventional method.

Discussion and Future Research Directions

Fruit harvesting systems can be categorized as either a manual, semi-manual, mechanical, or robotic one. Various fruit picking mechanisms have been developed globally for manual, semi-manual, mechanical, and robotic harvesting systems to increase efficiency and effectiveness of fruit harvesting and to reduce fruit damage and associated human drudgery. However, mechanical harvesting systems developed so far for fruit and vegetable harvesting were mostly suitable for large scale production.
Table 2. Major pineapple producing states of India
(Adapted from reference 58)

<table>
<thead>
<tr>
<th>Major pineapple producing states</th>
<th>Recommended Varieties</th>
<th>Peak Harvesting Season</th>
</tr>
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<tbody>
<tr>
<td>Arunachal Pradesh</td>
<td>Kew and Queen</td>
<td>August</td>
</tr>
<tr>
<td>Assam</td>
<td>Kew and Queen</td>
<td>July-August</td>
</tr>
<tr>
<td>Bihar</td>
<td>Kew and Queen</td>
<td>-</td>
</tr>
<tr>
<td>Kerala</td>
<td>Mauritius</td>
<td>May-June</td>
</tr>
<tr>
<td>Karnataka</td>
<td>Kew and Queen</td>
<td>June-July-August</td>
</tr>
<tr>
<td>Manipur</td>
<td>Kew, Queen, and Mauritius</td>
<td>July-August</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>Kew, Queen, and Giant Kew</td>
<td>July</td>
</tr>
<tr>
<td>Mizoram</td>
<td>Kew and Mauritius</td>
<td>August</td>
</tr>
<tr>
<td>Nagaland</td>
<td>Kew and Queen</td>
<td>June</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>Kew, Queen and Mauritius</td>
<td>Round the year</td>
</tr>
<tr>
<td>Tripura</td>
<td>Kew and Queen</td>
<td>June</td>
</tr>
<tr>
<td>West Bengal</td>
<td>Giant Kew and Mauritius</td>
<td>July-August</td>
</tr>
</tbody>
</table>

with hectares of land. Moreover, robotic fruit harvesting would be viable through the multidisciplinary approach to understand both crop factors as well as machine factors as each target crop has a unique nature of biological systems.

The study also highlights the state-of-art and potential research gaps in the pineapple harvesting process in particular (Figure 8). It was observed from the study that in major pineapple growing countries, pineapple is harvested with heavy machinery such as boom conveyer harvesters. The size of the field and topography of those countries permit the use of such heavy machinery. But, these machines served only the purpose of collecting harvested fruits from the field into a temporary collection point after individual fruits were chopped off manually by a group of farmworkers. Further, the farm plot must have the correct plot dimension along with the good provision of headlands and farm roads for efficient use of machinery systems. A minimum of 40 ha was reported to be the viable acreage for the implementation of mechanization with some relevant assumptions. Some researchers attempted to address the problem of individual pineapple picking using a semi-manual harvester and robotic pineapple harvesters. Researches on individual pineapple fruit picking are mostly in design and experimental stages. These attempts have not been successful for field implementation so far. Thus, the benefits have not been realized at the grass-root level. Though there is scope for large machinery or robotic harvesters in other major pineapple growing countries, it is not applicable in Indian scenario and NEH region of India in particular due to several constraints which include relatively small land-
holdings of pineapple growers, generally hilly terrain of the lands, economic backwardness of the farmers, non-familiarity of the local farmers with highly mechanized large harvester and robotic harvester, and relying more on predominant traditional harvesting practices. Therefore, pineapple harvesting in India still follows the traditional method of manual harvesting by using a sharp knife/sickle/dao for plucking individual pineapple fruit.

Various bottle-necks associated with traditional pineapple harvesting practices in India have been discussed in the earlier section. Manual harvesting is labour intensive, inefficient, and time-consuming process. Apart from the adoption of awkward posture during repeated manual operation of harvesting leading to body parts discomfort and in the long-run development of WMSDs\textsuperscript{10,17}, traditional manual harvesting also induces easy injuries to laborers due to lack of safety practices.

Further, studies related to various ergonomics aspects of pineapple harvesting process have not received much attention in Indian scenario, except few studies dealing with injuries (due to spines and tips of the leaves) and backpain and body strain to farmworkers (due to awkward postures and repetitive task). Following the literature review, it is envisaged that due consideration should be given on land-holding of the farmers, the topography of the land, climatic conditions, socio-demographic characteristics and economic status of the pineapple growers for successful mechanization of pineapple harvesting in the Indian context to reduce the human drudgery, time requirements, and labour intensiveness.

Research and development activities towards the identification of problems faced by farmers during pineapple harvesting in Indian scenario and understanding the real need of ergonomic design intervention to come up with a mechanized or semi-mechanized hand-tool type of harvester are the need of the hour to implement efficient, cost-effective and easy to use pineapple harvester. It is important to remember that the successful mechanization could only be achieved if it is affordable, its operation is similar to the traditional practice of harvesting and if it is easily manufactured and maintained by local artisans and with locally available resources. The design and development of improved farm tools/equipment based on users’ needs and context of use could be achieved through five stages of the design process, as given in Figure 9.

Ergonomic studies on pineapple harvesting processes are needed to be undertaken to assess the risk factors involved in pineapple harvesting to incorporate the findings and recommendations in design interventions for mechanized pineapple harvesting.

**Conclusions**

From the study, it was observed that the design of the harvesting system (tool/equipment) alone could not achieve efficient harvest mechanization. The orchard environment should also be studied to make a harvesting
system suitable for efficient fruit harvesting to achieve maximum benefit from mechanical harvesting. Moreover, there is a need for ergonomic studies on pineapple harvesting operation to assess the risk factors involved in pineapple harvesting in Indian conditions. Though there is scope for large machinery or robotic harvester in other major pineapple growing countries, it is not applicable in the Indian scenario and NEH region of India in particular. Therefore, the design of either manual or semi-manual pineapple harvester or design modification of existing locally evolved hand tools as per the mechanization gaps would benefit the Indian pineapple farmers in a better way. This study can provide as a reference for future research endeavors on pineapple harvesting with special emphasis on the Indian scenario.

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