DESIGN, DEVELOPMENT AND EVALUATION OF LEAFY CROP HARVESTER

Ph. D. (Agril. Engg.) Thesis

by

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Pushpraj Diwan

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CERTIFICATE-I

This is to certify that the thesis entitled **"Design, development and evaluation of leafy crop harvester"** submitted in partial fulfillment of the requirements for the requirements for the degree of **Doctor of Philosophy** in Agricultural Engineering of Indira Gandhi Krishi Viswavidyalaya, Raipur, is a record of bonafide research work carried out by **Pushpraj Diwan** under my guidance and supervision. The subject of the thesis has been approved by the students Advisory Committee and Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged.

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This is to certify that the thesis entitled "**Design, development and evaluation of leafy crop harvester**" submitted by **Pushpraj Diwan** to the Indira Gandhi Krishi Vishvidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in Agricultural Engineering in the Department of **Farm Machinery and Power Engineering** has been approved by the external examiner and student's advisory Committee after oral examination.

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Pushpraj Diwan

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%	Per cent
&	and
mm	mili meter
cm	centimeter
m	meter
km	kilometer
ha	hectare
hp	horsepower
i.e.	That is
kg	kilogram
g	gram
mg	milligram
Mha	million hectare
kJ	kilo Jule
MJ	Mega Jule
MPa	Mega Pascal
N	Newton
y	year
l	liter
h	hour
s	second
kW	kilo Watt
rpm	revaluations per minute
et al.	et alibi

LIST OF ABBREVIATIONS

Agril. Engg	Agricultural Engineering
C.G.	Chhattishgarh
FAE	Faculty of Agricultural Engineering
IGKV	Indira Gandhi KrishiVishwavidyalaya
PhD	Doctor of Philosophy
Avg.	Average
CV	Coefficient of Variation
SD	Standard Deviation
m. c.	moisture content
SE(m)	Standard error mean
SS	Sum of square
MSS	Mean sum of square
SV	Source of variance

THESIS ABSTRACT

a)	Title of the thesis :	Design, development and evaluation of leafy crop harvester
b)	Full Name of the Student:	Pushpraj Diwan
c)	Major Subject:	Farm Machinery and Power Engineering
d)	Name and Address of the: Major Advisor	Dr. R.K. Naik Department of Farm Machinery and Power Engineering, Swami Vivekanand C.A.E.T.& R.S., FAE, I.G.K.V., Raipur
e)	Degree be Awarded:	Doctoral of philosophy in Agricultural Engineering

Signature of the Student

Signature of Major Advisor

Date: 11/11/2021

Signature of Head of the Department

ABSTRACT

Leafy vegetables have a very high protective food value and are very easy to grow. Due to its high nutritive value, it is very popular in India. The harvesting operation of green leafy vegetable crops is normally done manually. Manual harvesting method is very tedious and time taking operation. A study was planned to design and develop a leafy vegetable harvesting machine at Department of Farm Machinery and Power Engineering, SVCAET&RS in year 2018-19. A purposive survey was conducted to know the status of adopted method for harvesting of leafy crops. Biometric characteristics and engineering properties of leafy crop were observed to know the behavior of the leafy crop in the field as well as after harvesting. In survey, various problems during harvesting of leafy crops by

different adopted method were evaluated by considering growth parameters of leafy crop like plant height, number of branches and yield. A harvester was developed successfully with four units viz. cutting units, conveying unit, storage unit and transport cum drive unit. The cutting unit consists of a reciprocating blade (stainless steel), a blowing unit powered by 1 hp small petrol engine. The conveying unit was made up off canvas material which was powered by ground wheel by several gear drive mechanism. The whole unit was supported by a sturdy frame made up of mild steel.

The performance evaluation of the developed leafy crop harvester was conducted by taking various independent parameters like forward speed, cutting height and air velocity and analyzed by using Factorial Randomized Block Design. All output parameters like header loss, conveying loss and harvesting efficiency as well as field capacity, field efficiency, fuel consumption were evaluated to test the performance of the machine. A comparative study between existing harvesting methods and developed leafy crop harvester was also conducted. During study it was found that the machine works satisfactorily in field condition. The harvesting efficiency was observed maximum at forward speed 1.0 km h^{-1}, 150 mm cutting height and at air velocity at 4 m s^{-1} for different leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach. The leaf harvesting capacity of the machine was observed to be 127, 520, 512, 398 and 145 kg h^{-1} for chickpea, green amaranthus, red amaranthus, fenugreek and spinach, respectively. The developed machine reduces the drudgery involved in leafy crop harvesting significantly over manual methods. It was also reduced the cost of operation of about 58.61% over manual harvesting of leafy crop. The cost of the prototype is ₹ 43,245.00/-, whereas cost of operation per hour was assessed ₹ 162.97/-. The BEP of the machine was calculated as 77.84 h y^{-1}, and payback period was observed to be 1.89 years.

शोध सारांश

अ)	शोध का शीर्षक	:	पत्तेदार फसल कटाई यंत्र का डिजाइन, विकास और मूल्यांकन
ब)	छात्रा का पूरा नाम	:	पुष्पराज दीवान
स)	प्रमुख विषय	:	प्रक्षेत्र यांत्रिकी एवं शक्ति अभियांत्रिकी
द)	प्रमुख सलाहकार का नाम	:	डॉ. आर.के.नायक
	और पता		प्रक्षेत्र यांत्रिकी एवं शक्ति अभियांत्रिकी विभाग, कृषि अभियांत्रिकी संकाय, आई.जी.के. वी., रायपुर (छ.ग.)
ई)	सम्मानित उपाधि	:	कृषि अभियांत्रिकी मे पी.एच.डी.

पुष्पराज

छात्र के हस्ताक्षर

प्रमुख सलाहकार के हस्ताक्षर

दिनांक 11/11/2021

विभागाध्यक्ष के हस्ताक्षर

सारांश

पत्तेदार सब्जी में पोषक तत्व बहुत अधिक मात्रा में पाया जाता है, और इसको उगाना भी बहुत आसान होता है। इसमें पोषक तत्वों की बहुत अधिक मात्रा के कारण यह भारत में बहुत अधिक लोकप्रिय है। पत्तेदार सब्जियों की फसल की कटाई का कार्य सामान्य रूप से हाथ से किया जाता है। हाथ से कटाई का कार्य बहुत ही धीमा और कठिन होता है। वर्ष 2018–19 में स्वामी विवेकानंद कृषि अभियांत्रिकी महाविद्यालय के प्रक्षेत्र यांत्रिकी एवं कृषि शक्ति विभाग में पत्तेदार सब्जी कटाई यंत्र की डिजाइन और विकसित करने की योजना बनाई गई थी। पत्तेदार सब्जी के लिए अपनाई जाने वाली पद्धति के स्थिति को जानने के लिए एक उद्देश्य पूर्व सर्वेक्षण किया गया था। पत्तेदार फसल के विभिन्न गुणों का अध्ययन खेत में किया गया, जिससे कटे हुए पत्तेदार फसल का व्यवहार कटाई के उपरांत जाना जा

सके। सर्वेक्षण में पत्तेदार फसल में में अपनाई जाने वाली कटाई पद्धति में होने वाली समस्याओं का अध्ययन किया गया, जिसमें फसलो के मानक जैसे पौधे की ऊंचाई, शाखाओं की संख्या और उपज की मात्रा को मापा गया। पत्तेदार फसल काटने वाले यंत्र यंत्र कटाई यूनिट, कन्वेइंग यूनिट, स्टोरेज यूनिट और ट्रांसपोर्ट यूनिट के साथ सफलतापूर्वक विकसित कर लिया गया था। जिसमें एक रिसिप्रोकेटिंग कटर बार और एक ब्लोवर लगा हुआ था, जो 1 अश्व शक्ति की पावर वाले इंजन से चलता था। इसमें कन्वेइंग यूनिट, गेयर और चक्के की मदद से चलता था। इस पूरी इकाई को स्टील से बने फ्रेम में रखा गया था। विकसित पत्तेदार फसल कटाई यंत्र का मूल्यांकन विभिन्न मापदंडों जैसे आगे बढ़ने की गति काटने की ऊंचाई और हवा का वेग को लेकर किया गया था, जिसका विश्लेषण आर.बी.डी. डिजाइन के माध्यम से किया गया। यंत्र के प्रदर्शन का मूल्यांकन हेडर लॉस, कन्वेइंग लॉस और कटाई दक्षता के साथ–साथ कार्य क्षमता, कार्य दक्षता, ईंधन खपत जैसे मापदंडों के आधार पर किया गया। विकसित किए गए पत्तेदार फसल कटाई यंत्र का तुलनात्मक मूल्यांकन अन्य कटाई पद्धति के साथ भी किया गया। परीक्षण में पाया गया कि यंत्र खेत में सही तरीके से कार्य करता था। कटाई की दक्षता सबसे अधिक अलग अलग फसल के लिए जैसे चना भाजी चौलाई भाजी लाल भाजी और मेथी के लिए 1.0 किलोमीटर प्रति घंटा, 150 मि.मि. कटाई की ऊंचाई और हवा की गति 4 मी. प्रति सेकंड में पाया गया। यंत्र की कटाई क्षमता 127, 520, 512, 398 और 145 किलोग्राम प्रति घंटा क्रमशः चना भाजी, चौलाई भाजी, लाल भाजी, मेथी और पालक के लिए पाया गया। विकसित किया गया यंत्र होने वाली थकान को हाथ से कटाई की तुलना में बहुत कम कर देता था। इसने कार्य की लागत को भी हाथ से कटाई की तुलना में 58.61% तक कम कर दिया था। विकसित किए गए यंत्र की एक इकाई का मूल्य ₹ 43245 है, जिसकी कार्य लागत ₹162.97 प्रति घंटा थी। यंत्र का बी.इ.पी. 77.84 घंटा प्रति वर्ष तथा पेबैक पीरियड 1.89 साल निकाला गया।

CHAPTER-I

INTRODUCTION

Leafy green vegetables are an important part of a healthy diet. These type of vegetables are enrich in vitamins, minerals, carbohydrates, fats, important proteins, vitamins, essential amino acids, and fiber but having very low in calories (Sharma *et al.*, 2006). Eating a diet rich in leafy greens can offer numerous health benefits including reduced risk of obesity, heart disease, high blood pressure and mental decline. The leaves of a large number of wild and cultivated plants are used as vegetables in various parts of India. Many types of leafy vegetables available here which are grown in bed they are spinach, red spinach, amaranths, fenugreek leaves etc.

Now horticultural crops are widely growing to meet the consumer demand, so it is necessary to do all the operation in time. After maturity of the leafy vegetables in time harvesting is important because after this stage the market value of the green leafy vegetables will be reduced. Chickpea leaves also used as green leafy vegetable in India. Fifty one types of leafy vegetables were eaten by the tribal and local people of Chhattisgarh (Chauhan *et al.*, 2014). Leafy vegetables play a major role in the nutritional requirement of the tribal and local population in remote parts of the Chhattisgarh (Chandravanshi *et al.*, 2018). Leafy vegetables were quick growing crops that are harvested 4-6 weeks after sowing. Dieticians recommend daily consumption of at least 116 g of leafy vegetables in a balanced diet (Dhaliwal *et al.*, 2017).

Chickpea was cultivated in 106 lakh ha in India at 2017-18. The country harvested a record production of more than 111 lakh tonne at the ever highest productivity level of 1056 kg ha^{-1}. Chickpea producing states in India are Madhya Pradesh (29.37%), Maharashtra (20.03%), Andhra Pradesh (15.48%), Rajasthan (9.73%), Karnataka (9.63%), Uttar Pradesh (6.42%), Gujarat (3.57%) and Chhattisgarh in ninth position (Anonymous, 2011). In Chhattisgarh cultivation area, production and productivity of chickpea in 2010-2011 was 2.519 lakh ha, 2.415 lakh tonne and 891 kg ha^{-1}, respectively, where it was increased 3.18 lakh hectare, 3.20 lakh tonne and 1010 kg ha^{-1}, respectively in 2017-18. The green leaf in early stage of the chickpea was also important for farmers of Chhattisgarh as remunerative value. Green leaves harvested from chickpea are known as nipping. This is one of the key practices for the improvement of yield as well as yield contributing factors. It is also helpful to improve the number of branches, pods and growth rate of the chickpea crop (Singh and Diwakar, 1995). Some major and widely cultivated leafy vegetables in Chhattisgarh are shown in Fig. 1.1.

Chickpea (*Chana*)

Red amaranthus (*Lal*)

Fenugreek (*Methi*)

Spinach (*Palak*)

Fig 1.1 Different types of major leafy vegetables grown in Chhattisgarh

Harvesting of leafy crops is done manually either by hand picking or by small tools like sickle in India. Green leafy vegetables are harvest manually by hand. The harvesting process of spinach, amaranthus, fenugreek and chickpea like vegetables is normally a time consuming by manual harvesting. It was also noted that due to improper harvesting and unavailability of tools and machinery the capacity of the harvesting is very low and hence it reduces the quantity as well as quality of the produce. This happens due to the lack of skills of workers. Quality is decreased due to more time required for harvesting. The quality and life of all leafy vegetables after harvesting is affected by a pre-harvest factors like its harvesting time and proper methodology used for harvesting.

Harvesting of green leafy vegetable crops are normally a time consuming and tedious operation in manual harvesting. Nipping of chickpea leaves are done in continuously bending posture by female workers which causes the drudgery to workers and very tedious and time consuming operation. Manual methods also make injuries to the plants due to compressive action by finger. Many time the plants is unable to undergo the process of rejuvenation. Therefore it is proposed to develop a mechanical green leafy crop harvester to reduce drudgery, time of operation, labour requirement and cost of operation. The machine should cover more width as compared to manual methods. It reduces the compaction on the field and improves the aeration of soil. The developed machine should reduce the injuries or damage and spot the heads as minimum as possible. To achieve this goal following steps are taken under consideration:

1. To study crop geometry of selected leafy crops *viz.* chickpea, amaranthus, spinach and fenugreek.
2. To study the status and associated problems of existing harvesting/nipping techniques of selected leafy crops.
3. To design and development of leafy crop harvester.
4. Performance evaluation of the developed machine.

CHAPTER-II

REVIEW AND LITERATURE

Leafy vegetable is one of the most important crop in India. Various researchers worked on the various properties and different harvesting techniques used for the leafy vegetables. The works are reviewed to identify various problems inccurred during leafy crop harvesting and find out their solution to design an efficient leafy crop harvester. Many parameters affect the performance of harvester *viz.* agronomical parameters of crop, engineering properties of leaves and design parameters of the machine which are reviewed and written below in this chapter. After design and fabrication of machine some operational parameters also taken into consideration to evaluate the performance of developed leafy crop harvester which also reviewed in this chapter.

2.1 Biometrics of Leafy Crop

Information about biometrics of leafy crop was very important to design an leafy crop harvester. Biometrics of leafy crop give the idea to decide the size and required components of the machine. Leafy crop grown in flat land is reviewed and their outcome presented in this section.

Aziz (2000) conducted an experiment in which they grown chickpea without irrigation on calcareous floodplain soil at Bangladesh. Nipping was taken as treatment for experiment that was done at 30, 45, 60 or 75 days after emergence. Maximum number of branches was measured at nipping at 30 days, bus statistically similar result was observed nipping at 45 days. Yield was found maximum 2394 kg ha^{-1} in which nipping done at 30 days.

Svirskis (2003) studied the amaranthus during season of 1998-2001 at Lithuanian Institute of Agriculture. The study was conducted with 13 varieties of amaranthus and collect information about yield contributing factors like sowing time, seed rate and row spacing. It was found that maximum yield was about 9.5 t ha^{-1}.

Khan *et al.* (2006) observed the nipping effects on yield and yield components, a three year study (1995-1998) was conducted with chickpea variety Karak-1. Experiment was conducted in growing season with total 8 nipping at 20 days interval by using plot size 4×1.2 m which consists four rows chickpea at row and plant spacing 30 cm and 20 cm, respectively. The gathered data set were statically analyzed by randomized block design and they found significant results of trails in number of productive branches per plant, number of pods plant, 100 seeds weight and yield (kg ha^{-1}). But non-significant result also observed in number of seeds per pods. It was conclude that nipping at last week of December to the end of January was observed to be best for improving yield and extra feed for cattle.

Soltani *et al.* (2006) worked to collect quantitative information regarding leaf area development in chickpea. Information from four fields existing at different locations were measured by gathering data of genotype, planting date and plant thickness across four area season blends to evaluate fundamental impacts of temperature, photoperiod and plant population density on plant leaf area in chickpea in well irrigated field. A close relationship was found between the fraction of senesced leaves per plant and the same fraction on the main stem. It was found that the average leaf size was about 4 cm^2 when nodes were 10 on the main stem and it stabilized at 10.8 cm^2 when there were 21 nodes on the main stem. It was found that the prediction of leaf area of chickpea was possible with the help of number of nodes in main stem, where plant density and date of sowing not affect the leaf geometry.

Acharya *et al.* (2006) studied the agronomy of the fenugreek which was new legume crop in North America. They observed that fenugreek was positively affecting the economics and environment of the agriculture. It was able to grow easily in any diversity of world so very less maintenance and changes were required for those crops which also help for soil conservation. Leaves and seed of the fenugreek were widely used in medical field and animal feed.

Acharya *et al.* (2007) studied about *tristar* an annual forage legume cultivar of fenugreek developed by Agriculture and Agri-Food Canada (AAFC) Research

Centre, Lethbridge. Plant characteristics were measured during study. *Tristar* was transplanted at 6 cm height after 3 weeks of seeding. At 50% bloom the plant height was measured about 40 cm and stem length at maturity period was about 60 cm.

Bouhssini *et al.* (2008) investigate the effects of different date of planting, varieties and insecticides on chickpea leaf infestation and the parasitoid *Opiusmonilicornis F.* were studied. A Field experiment was conducted at International Center for Agricultural Research in the Dry Areas, Syria. It was found that significant damage occurred in leaf of chickpea planted in spring season as compared to winter planted chickpea. There was a significantly higher number of damaged leaflets on the local cultivar, as compared with an improved variety (Flip 82–150, '*Ghab* 3'), at both planting dates and both years. It was analyzed that chickpea leaf miner effectively managed by integrating different pest management options such as winter sowing chickpea and the use of tolerant cultivars.

Acharya *et al.* (2008) studied the status and opportunities of fenugreek as alternative crop in semi-arid region of North America. It was widely used in India as spices and medicinal herb all over the world. New technologies were adopted to improve the production of the fenugreek to gain profit beef and milk production in Canada.

Baloch *et al.* (2010) investigate the appropriate nipping technique as well as to sort out combination of spacing and nipping. An experiment was conducted during 2008-09 with chickpea variety NIFA-2005. Nipping operation done at four different crop growth stages *viz.* nibbling (topping), harvesting at 4 levels, harvesting at ground level and control (no nipping) with rows spacing 40 and 50 cm apart. It was observed that nipping was a profitable practice for chickpea growers. Nipping or cutting back chickpea at various levels would enhance yield and yield contributing parameters of that crop. Study revealed that a case in favor of nipping that not only increased yield but also supplied fodder at times when there was scarcity of green forage in the area.

Ebert *et al.* (2011) reported important information about leafy vegetable amaranthus which was the widely consumed vegetable in the lowlands of Africa and Asia. Amaranthus was the highly nutritional food consist protein, calcium, iron, vitamins A, C and K, riboflavin (B2), niacin (B3), vitamin B6, and folate (B9). It required raised bed for suitable growth and yield, the beds were 90 cm wider with height 20 cm during dry and 30 cm during rainy season. Amaranthus was sown by direct seeding (*A. tricolor*) or by transplanting (*A. cruentus, A. dubius*) in the field. Suitable seed rate for amaranthus was about 1-1.5 g m^{-2} resulting plant density about 100-400 per m^{-2}.

Islam *et al.* (2011) studied the effect of chemical and organic fertilizers on plants and soil properties in Gazipur district (Bangladesh). An experiment was conducted with eight treatments, the treatments were poultry manure (PM) 5 t ha^{-1} (T_1), cow dung (CD) 10 t ha^{-1} (T_2), household waste (HW) 10 t ha^{-1} (T_3), PM 2.5 t ha^{-1} + reduced RDF (recommended dose of fertilizer) (T_4), CD 5 t ha^{-1} + reduced RDF (T_5), HW 5 t V + reduced RDF (T_6), 100% RDF (T_7) and control (T_8). The 100% RDF treatment (T7) gave the highest radish yield, however identical yield was obtained with T_5 and T_6 treatments. The maximum yield of stem amaranthus and Indian spinach was obtained with T_4 and T_6 treatments, respectively.

Mehrafarin *et al.* (2011) reviewed the different morphological characteristics and agronomical parameters of fenugreek. It was consumed in different regions for different purpose like medicinal uses, making food, roasted grain as coffee-substitute (in Africa), controlling insects in grain storages, perfume industries etc. Morphological parameters reported of fenugreek that were stem diameter (05.1 cm), leaf (1.5-45 cm × 0.8-1.5 cm), no. of pods per plant (2-8), seeds (10-20 per pods of size 3-5 mm×2-3 mm), leaf length (16.90-37.4 mm), leaf width (11.32-18.63 mm), leaf thickness (0.23-0.35 mm), no. of leaves before flowering (7-23), fresh weight of plant (23.9-44.41 g), dry weight percent of plant (0.7-0.14%) etc. Cultivation parameters like depth of sowing (1-2cm), method of sowing (broad casting and drilling), spacing (10-40 cm but highest yield at 20 cm), seed rate (17-25 kg ha^{-1}) and irrigation required (250 m^3 ha^{-1}) also observed.

Kakani *et al.* (2012) worked on the agronomics parameters of the fenugreek which extensively cultivated as annual herb. It was very adaptable crop, it grown effectively both tropical and temperate region upto 2000 m above from the sea level. Grown in wide variety of soil and it was resist upto 8.4 pH and give better result in neutral soil with pH 6-7. Fenugreek was a cool season grown, it was cultivated Oct-Nov in plain region of the India, whereas it grown March-May in hilly areas depending upto the altitude. Amount of seed required about 20-25 kg ha^{-1}, the crop geometry should be 25–30 cm × 10–12 cm. The fenugreek crop has been reported to absorb both macro as well as micronutrients. The crop removes N, P and K in the ratio of 2:1:1 from the soil, in the uptake order of 10, 3.5, 8.2 kg, respectively. Irrigation required 12-15 days of breaks which depend on the soil, growing season and weather condition.

Nasir *et al.* (2012) conducted an experiment during 2011-2012 to evaluate the effect of mechanically dried bio-slurry on cabbage growth, productivity, and soil health in terms of nutrients availability at field conditions. The evaluation of biometric characteristics of cabbage crop was main part of the study. The parameters observed were plants density per meter square area, plant height (inches), the leaves intensity per plant and root depth of cabbage plants (inches).

Snehlata and Payal (2012) presented an overview of legume crop fenugreek. In India, fenugreek was used as green leafy vegetable and also as spice. It was grown in semi-arid region, it also tolerated for frost and low temperature so it also cultivated in cold season and areas. It grows suitably in soil having pH about 5.3-8.2 in plant spacing about 8-10 cm. two to three weeding required during one season which can be done 20-25 DAS and second weeding can be done 45-50 DAS. It required 4-6 irrigations mainly depend on the climate with first irrigation at the time of thinning and subsequent irrigation was given at an interval of 20-25 days. Fenugreek leaves contain moisture, protein, fat, minerals, fiber and carbohydrates about 86.1%, 4.4%, 0.9%, 1.5%, 1.1% and 6% respectively. It also consists calcium, iron, phosphorous, carotene, thiamine, riboflavin, niacin and vitamin C.

Golaszewska *et al.* (2014) investigate the effect of agronomical parameters on the content of chlorophyll, the biometric characteristics and seed quality of fenugreek. Non significant effect on plant parameters of potassium fertilizer and inoculation, but it was significantly affect the seed weight per plant. Under the high dose of the potassium $K_{2.5}$ and $K_{3.75}$ seed weight was about 10% more, but 19.3% less with inoculated seeds compared to non-inoculated ones. Water deficiency affects many factors like reduced the height of plant about 15.5%, decrease the seed per pods about 20%, decrease the seed weigh about 28% and decreases harvest index by 13.2%.

Khan *et al.* (2014) worked on production and post harvest constraints of fenugreek (*Trigonellafoenumgraecum* L.), they studied fenugreek had 16 chromosomes and was a diploid (2n) annual legume plant. It was producing in various ecological regions of the word. Purpose of growing was different according to different agricultural zone like vegetable, animal food, spices and also as medicinal herb. Unluckily the awareness was less on production, storage practices and post-harvest processing of the fenugreek. It was investigate that the agronomical practices to get maximum yield, such as plant spacing, irrigation, fertilizer application, weeds, diseases and harvesting practices. Best period for 3-4 harvesting in a season was sown in October whereas only 1-2 harvesting can be done when it sown in mid of November.

Praveen *et al.* (2014) conducted field study on amaranthus (*Amaranthus sp* (*L.*)) at the University of Burdwan at August 2012 with eight genotypes of *Amaranthus* sp. Significantly changes for all the traits except leaf length in 60 days of different genotypes was observed in study. He found leaf per plant at 60 day after sowing and number of branches per plant at 90 days after sowing was useful character for the improvement of amaranthus breeding programme.

Vidyashankar (2014) worked on market of fenugreek which was legume and cultivated in different zones of the world as spices and medicinal herb. In global market India was the major producer of fenugreek and a large portion of it consumed within country. Like other food products productivity, sustainability and safety of foods were principal task in fenugreek production.

Garrido *et al.* (2015) worked to analyze the effect of harvesting time and delay in operation on spinach. Experiment was conducted by taking two parameters with their three levels i.e. times of the day for harvest (8:30, 13:00 and 17:30 h which were noted as H_1, H_2 and H_3, respectively) and times of delay before processing (3, 24 and 48 h as DP_3, DP_{24} and DP_{48}, respectively) were studied as independent parameters. In winter season harvesting timing not much affect for processing, where harvesting in morning give better results in spring. It was conclude that baby spinach stand without affecting its quality for at least 48 h.

Gupta *et al.* (2015) conducted an experiment at Dr. Panjabrao Deshmukh Agricultural University, Akola during 2015 to collect information about effect of green and white shade nets (50%) on spinach production. Agricultural farmers were facing difficulties due to climate change because of their traditional methods. Shade net cultivation was a good recommendation to avoid these problems for short duration valuable crops. Green leafy vegetable *viz.* spinach for experiment was selected for study. It was observed that the average temperature about 2-3°C for green shed which was less than white net temperature 4-5°C, and relative humidity inside green shade was 5-6% greater than the white shade net. The height of plant in green shade and white shade net was observed to be 15.9 cm and 14.6 cm respectively.

Kumar *et al.* (2017) analyzed the effect of sowing time, spacing and nipping on growth and yield of chickpea (*Cicerarietinum L.*) under irrigated condition during *rabi* season of 2016-17 at Instructional cum Research Farm, IGKV, Raipur, Chhattisgarh. The field had clay soil with neutral soil reaction, low nitrogen percentage, medium in phosphorus with high potassium content. The treatments evaluated of four sowing time *viz.*, first week of November (D_1), third week of November (D_2), first week of December (D_3) and third week of December (D_4) in main plot and three spacing *viz.*, 30 cm (S_1), 40 cm (S_2) and 50 cm (S_3) in sub plot and three nipping *viz.*, no nipping (N_1), one at nipping 30 DAS (N_2) and one nipping at 40 DAS (N_3) in sub-sub plot. The test variety was JG-130. The results of the experiment indicated that the growth parameter *viz.*, plant height, number of branches plant^{-1} (34.96), dry matter accumulation plant^{-1} (40.18 g), number of nodules plant^{-1} (45.93), dry weight of nodules plant^{-1} (0.72 g) and leaf area index (4.86) were maximum at 3rd week of November sowing time.

Jabeen *et al.* (2017) worked on spinach beet at Shalimar during *rabi* in 2016-17 to observe the outcome by using bio fertilizers and organic manures. Nine numbers of treatments were selected for experimental study by using statistical design (RCBD).The treatments comprised of organic manures *viz.*, farm yard manure, sheep manure, vermin compost, mustard cake and two types of bio-fertilizers namely Azospirillum and PSB, including RFD (recommended fertilizer dose) as control. Yield contributing parameters like plant height, weight of leaf blade, weight of leaf petiole, seedling emergence per cent, seedling root length, seedling shoot length and seedling vigour index were measured. Yield parameters like number of leaves (10.97, 9.37 and 7.09), leaf area (20.10, 64.10 and 104.30 cm2), leaf yield per plant (17.62, 29.27 and 29.26 g) and per hectare (58.73, 97.58 and 97.88 q) were measured maximum in vermin compost @ 3 tonnes ha^{-1} + bio fertilizers @ 5 kg ha^{-1}.

Khan *et al.* (2017) analyzed the effect of nipping in chickpea. He conducted an experiment by using eleven *Desi* and nine *kabuli* total twenty chickpea genotypes with two treatments (nipped and control). He made nipping twice at 20-25 days of interval and observed that nipping was significantly affecting the crop characteristics in all genotypes. It was observed that there was highly significant interaction between chickpea genotypes and nipping which shown that, various genotypes of chickpea responded in a different mode of nipping.

Basha *et al.* (2018) had undertaken an experiment at Regional Agriculture Research Station, Nandyal, Andhra Pradesh during Rabi 2017-18 on vertisols to estimate of growth and yield parameters of chickpea cultivars amenable to mechanical harvesting. The present investigation was carried out with six chickpea cultivars (GBM 2, NBeG-47, CSJ 515, HC 5, Phule G 08108 and BRC 1) sown at two different plant geometry (30×10 cm and 22.5×10 cm) in split plot design replicated thrice. Significantly higher number of branches (8.8) was observed under 30 x 10 cm (33 plants m^{-2}) when compared to 22.5 x 10 cm (44 plants m^{-2}) (7.7). Higher plant height (46.9 cm) lower days to 50% flowering observed with NBeG 47. Higher test weight (30.9 gm) was observed in NBeG 47. Higher seed yield was observed in GBM 2 (1474 kg ha^{-1}) and is at par with NBeG 47 (1346 kg ha^{-1}), Phule G 08108 (1374 kg ha^{-1}) and BRC 1(1348 ha^{-1}).

Chandrawanshi *et al.* (2018) conducted an experiment to collect information about morphological characteristics of *Amaranthusdubius* Mart. (*Khedha*) during *rabi* season (2014-15 and 2015-16) at the Dept. of horticulture, IGKV, Raipur. First they conducted a survey to collect information about leafy vegetable consumed by local and tribal people of Chhattisgarh. After that they conducted a comparative experiment by taking 25 genotypes and check variety CO-1 of *Amaranthusdubius* Mart. (*Khedha*) by using randomized block design with three replications. The morphological parameters taken were stem pubescence, stem pigmentation, leaf shape, leaf pubescence, leaf pigmentation, leaf colour intensity and fiber content. The obtained data expressed maximum fibre content in variety of CO-1 (15.67%) followed by genotype IGKB-2014-51 (15.50%) and IGKB-2014-53 (15.13%) was observed.

Singh *et al.* (2018) surveyed the some district of Uttar Pradesh and West Bengal to analyze the environment and ecology of *basella* species. *Basella* species were a nutritional vegetable and it can be cultivated in any agricultural region of the world without much effort. The habitat, growth stage, length of the whole plant and the number of primary and secondary vines were noted. Similarly, soil samples were collected from study area and physicochemical and biological characterizations were done according to the standard procedural protocols; soil pH and EC were measured by using a pH meter (CyberScan-500) and water holding capacity, bulk density, available nitrogen, available phosphorus, available potassium, microbial biomass carbon, microbial biomass nitrogen and soil organic carbon were measured accordingly.

Gnyandev *et al.* (2019) conducted an experiment to see the effect of nipping, growth regulating factors in chickpea varieties (A-1 and ICCV-2) during *rabi* 2007 and 2008 at University of Agricultural Sciences, Dharwad. Proper maintenance was essential during growing of crop like thinning, intercultural operation and plant protection. Nipping was done 30 DAS and plants were sprayed by different foliar sprays and observations (seed yield, number of pod, number of seeds per pod, test weight *etc*.) were measured at 60 days after transplanting and at harvesting time. It was observed that plant growth was enhanced due to nipping operation and all the observed all the seed yield parameters was found significantly different in plants nipped (N1) at 30 DAS. The number of pods per plant (46.04), pod yield per plant (18.22 g), seed yield per plant (12.65 g), per plot (1.02 kg) and per ha (28.50 q) were more with nipping treatment.

Guimaraes *et al.* (2019) studied to identify the sorghum varieties that had growth and grain yield potential under saline conditions. An experiment was conducted in 2016 at a greenhouse of Pernambuco, Brazil. The plants were cut above 10 cm from the ground and the following biometric parameters were evaluated: plant height, stem diameter, number of leaves, and length and width of the leaf. The plants were separated in stems, leaves, panicles, grains, and roots to determine their fresh weights; then forced-air circulation oven used at 60°C until constant weight to determine their dry weight. The fresh weight of the grains was used to calculate the grain yield per plant.

Tripathi (2019) worked on organically cultivated chickpea in the central Uttar Pradesh. He conducted an experiment to see the effect of plant biometrics, genotypes and nipping on yield and other parameters of chickpea during *rabi* 2011-12 and 2012-13 under irrigated conditions. Pods per plant, weight of pods and 100-seed weight etc. yield enhancement parameters were significantly affecting by plant spacing that was maximum at 45 cm than 30 cm and 60 cm. All the considered parameters were highly dependent of the row spacing and nipping methods. It was conclude that the wider row spacing with nipping system was profitable for farmers in chickpea. Grain yield obtained 2178 kg ha^{-1} at 45 cm of row spacing.

Choudhary *et al.* (2020) worked on different varieties of chickpea to examine the influence of seed rate and nipping during winter season 2016-17 and 2017-18. Nipping practices show a significant effect on growth and yield of chickpea. Higher dry matter, leaf area index, chlorophyll content, net assimilation rate, seed and straw yield was observed at 45 days after sowing than the control, nipping at 30 DAS and 60 DAS.

Rathod *et al.* (2020) conducted an experiment to analyze the yield and quality of spinach in controlled environment of hydroponic structure at Akola during Feb-April, 2019. Hydroponic structure was dimensioned 1400 mm × 970 mm ×1800 mm (length × width × height). Statistical analysis of biometrics parameters and yield parameters were done in OPSTAT software by using randomized block design. Hydroponic structure by using white, green and uv-polyethylene was giving better result in many parameters *viz.* plant height, number of leaves and stem diameter than open field. Maximum yield was observed at green hydroponic structure and yield was also 2 times more in all hydroponic structure than open field farming.

Sanbagavalli *et al.* (2020) stated that nipping contribute very important role to improve the yield contributing factors. It was a maintenance practice to improve the productivity. Nipping can be done in two ways either by clipping manually or by spraying growth retardants such as mepiquat chloride, chlormequat chloride and maleic hydrazide.

Shabina *et al.* (2020) worked on 30 different genotypes of amaranthus to analyze the different biometric characteristics and yield contributing parameters at COA, Vellayani during 2016-18. Maximum yield was observed 125.93 g per plant in genotype Madhur local (A22) and least incidence of leaf blight.

Singh *et al.* (2020) studied to assess the extent of adoption for scientific package of practices of chickpea among the chickpea growers of the Banda district. Total 120 respondents from eight villages of four blocks were randomly selected. Most of respondents were adopted various practices *viz.* nipping at 25-30 DAS (95.83%), chemical method of spraying quinolphos or indoxacarb to control heliothis (95.83%) and irrigation at the time of branching and flowering (93.33%) and Majority of respondents were found to be not adopted the various practices like seed treatment (89.17%), proper spacing (81.67%), seed rate (71.67%), recommended dose of fertilizer (83.33%) and basal application of sulphur (95.83%). Therefore, farmers should educate about package and practices of chickpea by training or demonstration. Maximum plant population was observed at spacing 30×10 cm.

Teggellie *et al.* (2020) conducted frontline demonstrations on farmer fields in adopted villages by Krishi Vigyan Kendra, Kalaburagi to study the effect of nipping on seed yield of pigeonpea. It was observed that nipping of the terminal bud in between 45 to 50 days of crop growth stage significantly reduced the height of the plant and increased the number of primary and secondary branches and pods per plant. It was found that nipping operation in pigeonpea was improved the yield about 19.59, 17.39 and 14.37 per cent during 2016, 2017 and 2018 respectively. The average production of pigeon pea due to nipping practice was observed to be 13.24 q ha^{-1} over check plot i.e. 11.28 q ha^{-1}.

Sun *et al.* (2021) stated that fenugreek was a natural vegetable found from Iran to India, and it was currently growing in different agricultural zone of the world. Conventionally, it was using as medicinal plant which was helping humans for different diseases and beneficial for bone and muscles, respiratory system, gastro-intestinal system, female reproductive system, cardio-vascular system, endocrinology and hepatic. Traditional and modern growing techniques of fenugreek was helping the encourage the sustainable production in long term and wide range.

Antisha and Priyadharsini (2017) green leafy vegetables form a part of everybody's diet specially the vulnerable group which includes children, adolescents, pregnant, nursing and aged people where in their requirements for vitamins and minerals are higher. Contamination of heavy metal in greens due to agricultural practices, environmental changes pollution and use of pesticides result in the contamination posing serious health issues. The heavy metal contamination of *Arakeerai* (*Amaranthusdubius*) cultivated from three different sites of Coimbatore was tested for chromium, zinc and lead contamination using standard procedure. Result revealed a contamination of chromium and zinc irrespective of the site of cultivation. Presence of lead was found to be below the deductible levels.

2.2 Engineering Properties of Leaves of Leafy Vegetable Crop

Engineering properties of leaves of leafy crop and standard methodology to find out was reviewed and discussed in this section. Engineering properties helpful to design various components of the machine.

Zewdu (2007) measured terminal velocities for both tef grains and straws using the suspension velocity method. The terminal velocity of tef grains increased linearly from 3.08 to 3.96 m s^{-1} with increase in moisture content from 6.5% to 30.1% wet basis (wb). Straw of different size and nodes (nodes at middle, at end and nodes free) were tested to evaluate the terminal velocity. Highest terminal velocity was observed with nodes at end. Terminal velocity was observed 3.69-2.13 and 3.08-1.70 m s^{-1} for node at middle node and node free straw respectively, whereas at the end-node straws the terminal velocity measured 3.32-5.40 m s^{-1} as the length of straw increased from 1 to 10 cm. Drag coefficient for tef grain decreased with increases in moisture content.

Azadbakht *et al.* (2015) studied on the needed energy for cutting canola stems in different levels of cutting height and moisture content. Experiment was conducted in the farm of Gorgan, Iran to evaluate the fabricated device after calibration, which was working on the principle of conservation of energy. Device was tested at different moisture content and cutting height, and it was found that highest energy was required at 10 cm cutting height with 25.5% (wb) moisture content that was 1.1 kJ. Also the minimum cutting energy was 0.76 kJ in 11.6% (w.b.) moisture content and 30 cm cutting height. Blade velocity was 2.64 m s^{-1} in cutting moment.

Kushwaha *et al.* (2015) developed a mathematical model for angle of repose and bulk density using RSM. The developed model followed by numerical optimization of responses using desirability functions. The two parameters bulk density and angle of repose were found to be most critical physical parameters for tea leave on free flow behavior during processing. The study also includes the effect of size of cut leaf and moisture content of tea leaves on the bulk density and slide angle of repose.

2.3 Leafy Crop Harvester

Many researchers work on the development and evaluation of various types of leafy crop harvester. Their contribution in development of leafy crop harvester is discussed in this section.

Hood *et al.* (1986) developed a harvester for leafy vegetable. The developed machine consists of stationary blades and rotatable discs. A pair of opposing, rotatable belts was used for lifting and transport of the material. It was adjustable through pressure pulleys, for proper gripping pressure on the products. A product orienting section in which the products are transformed from a vertical to a horizontal disposition.

Bowen (1989) designed a vegetable harvester mounted on a tractor. The cutting mechanism, pneumatic transport system and a collection box on a common frame. It was movable vertically relative to the tractor on which it was mounted to adjust the height of the cutting blade. It also raises the collection box to a height whereby it produces discharge through a bottom opening into a larger receptacle. The common frame was mounted on a telescopic slide frame, which in turn was pivotally mounted at its lower end to the conventional three point hitch of a tractor.

Fischer *et al.* (1990) developed a mobile harvester of leafy produce, had two harvesting sections with a cutter located forwardly for severing the produce from the ground. A continuous belt having a large number of openings moves in a closed path presenting an upwardly facing surface. A low pressure plenum underneath the belt provides a vacuum attraction to the belt upwardly facing for picking up severed produce. An enclosure over the belt protects against wind removal of produce leaves from the belt. The two harvesting sections were individually adjustable for proper height above the ground.

Nevarez *et al.* (2000) developed a leafy vegetables harvester for lettuce. Which consist a conveyer/cutter assembly is located on one side of the harvester centerline and has a width nearly exceeding the width of a single width bed. The wheels on each side are separated by somewhat more than the width of a double bed. The driver and engine was located on the other side of the centerline. Such a harvester can cut Single width beds, or can cut double width beds by making a first pass in one direction and a second pass in the other direction. An improved single conveyer/cutter assembly was disclosed along with a method of harvesting and processing leafy vegetables to reduce the amount of debris and unwanted material in the harvested leafy vegetables.

Groot *et al.* (2002) invented a harvester particularly suited for harvesting baby greens. The harvester generally comprises a chassis with wheels that travels in the furrow between raised beds, a sorting belt assembly on a floating header. The floating header rides on the top surface of a raised bed and is articulated so that the floating header can move independently of the chassis to follow the contours of the raised bed so that the cutting assembly could cut a uniform height. The sorting belt assembly includes a series of belt for collecting and sorting the cut baby greens at the easiest and most effective time to do so, immediately after the baby greens are cut and before the baby greens were clumped in storage bins or in other storage containers. The invention further includes a method of using the harvester of the invention in which the forward momentum of the harvester and the density of the crop are used to assist the cut product onto the collection belt.

Hegazy *et al.* (2011) designed a new harvesting prototype for cutting and collecting different types of aromatic and medical plants. It was observed that the main components of the experimental harvester were: engine with travelling mechanism, cutting unit and conveyor unit connected with storage tank. They observed that the working time taken by the machine to collect sage was higher than the time taken to collect rosemary and winter savory by 16 and 12%, respectively, where average values of fuel consumption for sage, rosemary and winter savory were 0.32, 0.27 and 0.30 kg kW h^{-1}, respectively. Machine working efficiency varied from 28.5 to 36.9 m^2 min^{-1} for all plants. Best working efficiency value obtained by using machine with rosemary. There were increasing in harvesting losses for sage and rosemary by 15.4 and 14% compared to winter savory, also number of transferred plants in case of winter savory was high and gave best transfer efficiency by 89.2%.

Nang *et al.* (2015) developed a vegetable harvester in order to reduce the production cost of head lettuce production. The harvester consists of a cutting component to slice the lettuce head at the desired location and a lifting component that transports the harvested produce from the cutting site onto elevating conveyor and trimming station. A cutting component with reciprocating blade was proposed. Laboratory tests were performed to verify ability of reciprocating blade to slice lettuce stump at forward cutting speed of 0.1 m s^{-1}, reciprocating stroke of 18 mm, and different reciprocating frequencies of 2, 4 and 6 Hz. In addition, power requirement for reciprocating the cutting knife as slicing two lettuce stumps was measure. Tests in lettuce fields were also conducted at different working speed to investigation the cutting and lifting performances of the harvester mounted with the reciprocating-blade cutting component. The results of laboratory tests indicated that the cutting component could smoothly cut lettuce stumps and the maximum cutting torque and cutting power requirement were 0.73 Nm and 27.7 W, respectively at 6 Hz reciprocating frequency. Field test results showed that the harvester could cut and lift the lettuce heads without damaging and blemishing the produce at working speed of 0.04 m s^{-1} and the commercial head percentage was 94.5%. At higher working speed of 0.08 m s^{-1}, the head damage rate was 12.8% reducing the percent of commercially accepted heads to 87.2%.

Younis *et al.* (2012) modified a leafy crops harvester prototype depending on the leafy crops characteristic like crop height leaves surface area crop stems. The prototype included frame, conveyor, collection box, and transmission system. Results provided the suitability of the modifying prototype to transportation and collecting leafy crops, the suitability of the modifying prototype was judged through the removal percentage, un-damaged percentage and losses percentage.

Kolgiri *et al.* (2019) reviewed to optimize design of harvester for farming vegetables. They recorded that farming of lettuce, spinach, and baby leaf type a vegetable harvesting was done by manually through bottle-neck work. A prototype of leafy harvester was developed to reduce the time and money. The developed harvester consists of the cutting blade, which cut the vegetable head at desired location. It was lifted in a container by using conveyor belt. Cutter and transport belt was drive by the electric power. A 12 V DC motor was used for cutting and lifting. There was a provision to position the cutter height according to the, type of vegetable.

Williams *et al.* (2019) stated that as labour requirements in horticultural become more challenging, automated solutions were becoming an effective approach to maintain productivity and quality.

Singh *et al.* (2020) studied and analyzed that harvesting of vegetable *viz.* spinach and coriander were mostly done by traditional methods and cut crops were gathered by hand and kept in loose or in bundle. Harvesting was generally done 4-6 times for a season that takes too much time, labour and cost. Bending posture of harvesting was also uncomfortable posture for the worker. To overcome all that problems a rotary cutter was developed to cut and lay the cut crop in windrow. That consist a 250W geared DC motor, two 12V-12 Ah batteries, power transmission and cutting unit. A worker with the developed cutter provided output of 145 m^2 h^{-1} for green spinach and 153 m^2 h^{-1} coriander. The leftover leaves rate after manual and machine cut per m^2 area was 0.35 and 1.4% respectively. Time taken in collection of cut crop by the developed cutter and making bundle manually was incorporated in getting overall output with this system was found 2.56 times more than traditional system of harvesting the crops. That equipment provides powered mechanical aid in cutting operation to avoid squatting or sitting or changing posture while performing this activity which further helped in reducing drudgery of farm worker with increased output.

2.4 Design of Leafy Crop Harvester

2.4.1 Design of blade

Nakano (1976) worked on self-propelled tea plucking machines. A reciprocating type of cutter which gives less fragmentation of leaves was selected. Best result was found at 25-30 mm pitch of knife, 30 mm length of knife, 30 mm cutting angle at 10° and 20-30 mm cutting pitch. Suction and blowing unit used to blown and suck the plucked shoots. It was observed that suction nozzle of 80 mm of width with curved tip with 25 mm radius of curvature was found more suitable and effective. With that nozzle, the minimum air flow capable of sucking leaves was 8- 12 m s^{-1}, and a distance of 50-60 mm between the suction nozzle and plucking surface gave a good result. The pair of the suction nozzles was placed 50 mm above the cutter bar. By using two units of turbo fun, plucked leaves were sucked into a suction cylinder through suction nozzles, and the leaves, which fall down on the metal-net belt equipped inside the cylinder, are blown into net bags by the use of the exhaust of the fun. As the cutters were adjusted by hand to come right onto the plucking surface, two operators are needed.

Watson *et al.* (1982) worked on the tea leaf plucking machine and results obtained from two small plucking machines were reported. Mechanical harvesting was done twice a week where hand plucking one time on a weekly round. The knapsack machine was found to be more efficient than the machine transmit power through throttle cable. Outputs of 215 kg Green Leaf per day with 25 - 35% coarse material was obtained. When labour for picking out coarse material was considered the output of acceptable leaf was 28 kg per laborer which was comparable to hand plucking. Sorting operation required after machine harvesting so labour requirement was same for both machine harvesting and hand plucking for per kg of tea. Machine harvesting resulted in a 30-40% decline in green leaf yields, decreased pruning weights and poorer recovery after pruning.

Celik (2006) developed a manual push type mower by using 25% extra powered engine than the required power of mower to reduce the problem during operation and it work suitable in all forward speed, forage density, and ground topography conditions of the field. Worm gear unit was used because of its compact size and transmit power at negligible loss. Grass density was taken into consideration to reduce clogging during cutting. Vibration in cutter bar was reduced by balanced crank, cutting height was adjusted by using skids both side. A standard width cutter bar knife of 76.2mm was selected for dense and tall forage. It was mainly consisted of six main components including the cutting, transmission, power, handling, frame, and transporting units. Two cycle engine that produced 1.47 kW at 7000 rpm provided power for the cutting unit. Two skids were attached to the cutter bar unit, one on each side, to control cutting height. The total mass of the mower was 41 kg. It was observed that the effective field capacity 0.11 ha h^{-1}, 10 L h^{-1} fuel consumption, 0.875 field efficiency, 2.24 t h^{-1} effective wet grass harvesting capacity, 4.43 L t^{-1} wet grass specific fuel consumption, and 64 mm cutting height.

Chavan *et al.* (2015) designed a manually operated reaper machine by focusing to design a machine which would be ease to harvest a wide variety of crops. The operating, adjusting and maintaining principle were made simple for effective handling by unskilled operators. After field evaluation they observed that the developed manual operated reaper was highly labor saving which required only 20 man-h ha^{-1}. Cost of operation of developed reaper was observed to be ₹ 1250.4 ha^{-1} and which was as compared to the traditional method that was ₹ 2000 ha^{-1}.

Teref (2017) designed and developed a manually engine operated reaper machine. He researches various problems in harvesting and gathered data from previous works and set a goal to design a suitable harvester for customers. Design steps consist: concept generation, product ideas, and alternative solution using digital logical approach for conceptual design, analysis and selection. The product architecture and configuration finally introduced in the embodiment design after the selection of final concept. Developed reaper for grain harvesting was evaluated against the technical and economical criteria's can be carried out to be suitable with the most Ethiopians low farmers capacity.

Fadavi *et al.* (2017) conducted an experiment to evaluate the wheat crop harvester in West Azarbaijan province of Iran. Efficiency of harvester measured in both laboratory (CATIA, V5) and field. Sensors and wooden were used to gather data for statistical analysis by using (SPSS19 software). In response surface method, central composite design was used to modeling and finding optimal levels of mentioned factors; at the optimum condition, minimum combine header loss were reported for reel Index 1.1.

Prem *et al.* (2017) studied that reaper was most important for timely harvesting of field crops. Many types of manually operated harvesters were available but traction developed from ground wheel was not sufficient to cut and convey the crop. Available self propelled and tractor mounted reapers were uneconomical for small and marginal farmers, it was also found not environmental friendly. It was conclude that an eco-friendly and economical harvester with less power requirement was required for farmers.

Ogunlowo and Olaoye (2017) designed a guided horizontal conveyor rice harvester which consist slider crank mechanism to convert rotary motion into reciprocating motion and deliver power to cutter bar, transmission system, crop reel and conveying system. Uses of combine harvester in Nigerian farms were generally problematic because of segregation. Developed machine was tested on the rice field of National Cereals Research Institute (NCRI), Moor plantation, Ibadan. Experiment was conducted by using factorial design by taking three independent parameters engine speed (1200, 1400 and 1800 rpm), ecology (irrigated and rainfed-lowland) and moisture content (18.3% and 21.2%) with two replication of each on dependent parameters field capacity, field efficiency, harvesting efficiency and operational losses. It was observed that moisture content was significantly affecting cutting efficiency and operation losses, while the ecology had a significant effect only on the field capacity and field efficiency. The concluded that harvesting efficiency was maximum 97.2% at moister content 21.2% at engine speed of 1200 rpm.

Vignesh and Kumar (2018) worked to design a manually and mechanically operated reaper machine. The operating, adjusting and maintaining principle were made simple for effective handling by unskilled operators. Developed automatic operated reaper was working continuously after modification which was given more efficiency than before. Conveying system was worked satisfactory, which was able to reduce the harvesting losses and clogging. Because of continuous work the efficiency of machine increased about 59% than previous machine, which was saving more labour and time. Field efficiency of the modified machine was observed more than 66%.

Umale *et al.* (2018) stated that after maturity of the crop timeliness harvesting operation play an important role in cultivation. In India farmers were using manual harvesting i.e. done by sickle. That makes harvesting time consuming and laborious operation. They analyzed the tractor front mounted reaper which was powered by tractor PTO. The machine was evaluated in various varieties of crops and the problem occur during operating reaper was also observed. The field capacity of the reaper was observed to be 0.29 ha h^{-1} and it was also observed that the 88 man hour required to harvest per hectare of crop including collection and bundling which required 50% less time than the manual harvesting method.

Mule *et al.* (2018) designed and developed a soybean harvester for small farmers had land holding <2 acres. The machine was powered by 3 hp petrol engine, which give scissoring type motion to the cutter bar by the help of pulley and gear arrangement. Machine was fabricated by use of locally available parts. After performance it was observed that the developed harvester was much economical than the manual harvesting method. The developed harvester was suitable for small farmers and it was found efficient, effective, compact and economical.

Assefa (2018) designed a manually operated wheat crop reaper for broad bed furrows. It was observed that the conventional methods of harvesting taking more time and cost. Mechanical method using combine harvester also costly for small farmers. To overcome all that problems they developed a manually operated reaper. Reaper consists gear drive, belt-pulley and gear system to transmit power from engine to cutter bar. To reciprocate the cutter bar unit slider crank mechanism was used which give scissoring action to cut wheat crop. Lugged belt was used to collect the cut crop. It was observed that the less effort required by working with developed machine in the field.

Nisha and Saravanakumar (2019) developed a cutter bar testing rig for measurement of required cutting force for finger millets cutting. To design harvester and efficient use of the power source it was essential to observe the cutting force of crop. To achieve that objective the developed a testing rig for reciprocating cutter bar. Testing rig consist a frame, cutter bar assembly, transmission unit, load measurement unit (load cell, load indicator) and transmission unit to observe the required cutting force for finger millets at different cutter bar speed. The average cutting forces was observed about 3.75 kg for finger millets cutting, and it was verified by using pendulum testing rig.

Tang *et al.* (2019) In order to reveal the reason of stem cutting in rice harvesting by combine harvester front header, stem cutting principle of the front header was developed. Based on the structural models and the parameters of each part of header, the first eight-order constrained model simulation analysis was carried out to obtain the vibration response frequency. +e front header was produced and used to be tested for restraint experimental model in the rice field.

The rice stem cutting state of the header cutter was analyzed by carrying out the vibration test of the no-load rotation state and rice harvesting state in the field. According to the cutting diagram of the stalk in the header, the angle of the cutting surface and length distribution of the short stalk were analyzed with compound state of forward and vertical vibration. The results showed the mean and variance amplitude of front header were similar to length distribution of the short stalk. The mean length 23.60 mm of the repeatedly cut stems was inextricably linked to the up and down vibration amplitude 25.36mm of the header. The stem cutting surface angles 38°, 44°, and 62° were for different forward speed and cutting areas on the cutting diagram. The above studies reveal the intrinsic nature between header vibration and length distribution of the cutting stem.

Lakshmi *et al.* (2019) stated that, the harvesting was the important part in the agricultural cultivation. Modern harvesting technology was increasing day by day but the cost of the harvesting machines was high. The developed harvester was found low cost manual crop harvesting machine for small farmers having less land holding. Developed machine consist cutter bar which was taken power from the wheels of the vehicle itself. The cutting motion to the rotary blades was obtained through the bevel gears (or) crown wheel and pinion arrangement. It was estimated that the productivity of the work improved, the developed machine was able to reduce the time and operation cost of harvesting.

Charwak *et al.* (2019) developed an economical crop harvesting machine with simple mechanism. It was observed that harvesting was a serious problem because of its cost, timeliness operation and work force requirement. That problem would be solved by adopting mechanical harvesting methods. Farmers were adopting reapers, combine harvester which are uneconomical for small farmers to adopt. The developed and fabricated a machine which consists two mechanisms one was a crank and slotted lever mechanism for reciprocation of cutter blade over stationary cutter blade and that mechanism was used to convert rotary motion into linear motion. Second was collecting mechanism which consist chain sprocket and motorcycle chain. Machine was powered by 7.5 HP, 3200 rpm 2 stroke petrol engine. By using V-Belt power was transmitted to bevel gear box. Bevel gear box was used to change direction of drive by 90 degree in the gear system. One end of that output shaft was connected to crank and slotted lever mechanism which converts rotary motion of shaft into reciprocating motion of cutter blade. Reciprocating cutter blade slides over fixed blade and creates scissoring action responsible for cutting the crop and other end was connected to the collecting mechanism.

Myo *et al.* (2019) developed an agricultural reaper machine based on reaper machine. They studied the design of reaping mechanism of paddy reaper with engine power 3.729 kW and input speed 3600 rpm with an average operating speed of 29.5 m min^{-1}. Reaping gear box was designed according to the required gear ratio, module, face and no. of teeth. Chain drive also designed by calculating number of links, sprocket size and number of teeth. It was working well by combination of man and machine power. To complete harvesting in the field one man was taken normally 5 days but with the help of developed machine it was reduced and only one fourth of the day required to harvest one acre.

Tefera and Aschenaki (2019) developed a low cost and ease to operate solar operated multi-crop (*viz.* wheat, barley, Teff and rice) harvester at Ethiopia. Design steps included review of previous works, data collection, analysis of machine components, and visual 3D model by using CATIA, drawing and fabrication of prototype. The prototype of solar grain harvester has one hp DC motor, 2.4 m^2 solar panel, four-wheel vehicle and cutter assembly. Working width of machine was 600 mm, working at 0.5 m s^{-1} with field capacity of 0.1 ha h^{-1}. It was saving the time, cost of operation in ecofriendly way.

Sinha and Jogdand (2019) developed a low cost manual drawn wheat crop harvester for small scale farmers. The machine consist cutter bar, crop row divider and lifter, star wheel, transmission system and ground wheel. To reciprocate the cutter bar crank mechanism was used which was power by ground wheel. After field performance actual field capacity was observed to be 0.048 ha h^{-1} and field efficiency was 71.20%.

Zareishahamat *et al.* (2019) reported that lack of mechanization in harvesting operation was result annually about 0.2 million ha of farms were not harvested in Iran. To overcome that problems and losses a 4.85 kW engine operated with working width of 1 m was designed, fabricated and evaluated. They observed that forward speed of the machine significantly affect the field efficiency of machine and crop losses. When machine operational speed increased it increase crop losses and decrease the field efficiency. The forward speed of 0.5 m s^{-1} had the lowest crop losses and was less exhausting and had the maximum energy saved compared to 1 and 1.5 m s^{-1}. The forward speed of 0.5 m s^{-1} had the best result. Results of cost analysis showed that the total operating cost of machine was ₹ 1472.95/- per hectare. The cost of manual harvesting was ₹ 11341.72/- per hectare. The minimum justified ownership area for the machine was 1.3 ha which was appropriate for agricultural systems with small farms.

Chavan *et al.* (2020) worked to help the small farmers by developing an efficient harvesting machine to reduce the cost, labour and efforts. Different types of crops, harvesting, power source, cost of machine and cost of operation was considered to evaluate its performance. Easy of operation make it adoptable, which would be also suitable for unskilled person. The computer software CATIA was used to make a 3D model of reaper, after analysis required components were collected and assembled.

Alemu *et al.* (2020) developed a cereal crop reaper from cost effective and locally available materials. First a prototype CAD model was developed by taking various design consideration, which was analyzed by software. The designed reaper was manually guided and powered with diesel engine for cutting cereal crop stems. Power transmission unit consist belt-pulley arrangement to transmit the power, bevel gear to operate slider crank mechanism to reciprocate the cutter bar. Reciprocating cutting blade was sliding over fixed bar and created scissoring action between cutter blades which results cut crops stem. Integrating mechanism consist of flat belt with collecting lugged plates bolted on it to convey the crop.

Balaji *et al.* (2020) designed and fabricate crop reaper attachment by targeting the small scale farmers had land holding < 2 acres. Machine was compact and able to cut two rows in one pass. Scissoring type of action was done by reciprocating cutter bar the machine. The cutter assembly works on scotch and yoke mechanism. Power was transmitted from power tiller by pulley and gear box unit to the cutter. CAD model was designed by using CATIA V5. Windrowing system also provided in that machine. Locally available parts were used to fabricate that compact harvester that makes it easily maintainable. After field evaluation of the machine it was observed the cost of harvesting considerably lower than the manual harvesting method.

2.4.2 Blade mechanism

Reza (2007) studied the impact force requirement of paddy stem cutting. A pendulum type impact shear test apparatus was designed and constructed to measure the energy required for cutting paddy stem. Experiment were carried out to determine the optimum values of blade bevel angle, oblique angle, tilt angle and blade cutting velocity for cutting paddy stem of *Sepidrood* variety. The results show that blade bevel angle of 28°, oblique angle of 30°, tilt angle of 35° and blade velocity of 2.24 m s^{-1} are optimum.

Baneh *et al.* (2012) designed a cutting head for a portable brush cutter and for harvesting four Iranian rice varieties, two varieties of high yielding named Khazar and Fajr and two varieties from local varieties named Binam and Hashemi. Cutting head consisted of a circular saw blade with 24 cm diameter and 2 mm thickness. Designed blade had 136 teeth with 0° rake angle, 30° clearance angle and 6 mm pitch. A simple windrowing system made from aluminum sheet was designed and constructed. The cutting head installed on existent brush cutter and test was conducted in field conditions. Cutting energy and critical blade speed was computed for each type of variety. Maximum power consumption of about 1.132 kW was obtained for *Khazar* variety. Results also showed that rice losses of the portable reaper were lower than manual harvesting and field capacity of machine was 4.20 times greater than manual harvesting.

Allameh *et al.* (2016) observed cutting energy requirement for rice stem was a momentous touchstone in design or optimization of cutting mechanism on harvesting machines. Various parameters such as physical and mechanical properties of a plant stem and blade shearing components were effective on the cutting energy requirement. Specifying these parameters and their impacts on the cutting energy would be especially important in the assessment of each cutting mechanism efficiency and total energy utilization. By using a test-rig pendulum displacement cutting apparatus, specific cutting energy for single stem cutting of rice stem was identified. The experiments were analyzed in a factorial arrangement laid out in a completely randomized design (CRD) with three replications in order to examine the effects of rice cultivars. There were significant differences among cultivars in the view of specific cutting energy so that the highest and lowest values belonged to *Hashemi* (29.29 kJ m^{-2}) and *Khazar* (16.81 kJ m^{-2}), respectively. When blade velocity increased from 1.5 to 2.5 m s^{-1}, specific cutting energy raised about 77%. Blade cutting and bevel angles were not solely influential on the specific cutting energy but they interacted with rice cultivar and impacted it. Optimum specific cutting energy obtained at cutting and blade bevel angles of 30 and 30 degrees, respectively.

Shushilendra *et al.* (2016) studied to investigate the effect of blade type, cutting velocity and cross sectional area of stalks on cutting energy, cutting force and specific energy required for cutting of chickpea stalks. A pendulum type impact test rig was designed and developed to measure the cutting energy. The bundled chickpea stalks were fitted firmly in the stalk holder to replicate stalks stand in the field. Two types of blades viz., smooth edge and serrated types were used for the present study. The results showed that the cutting energy, cutting force and specific energy requirement were decreased as the cutting velocity increased for both type of blades whereas these values were increased as the cross sectional area of chickpea stalks increased. Among the two types of blades used for experiments, serrated type blade required less cutting energy, cutting force and specific energy as compared to that of smooth edge type blade at all cutting velocities and diameters of stalks.

Gharakhani *et al.* (2017) reported that the damaging effect of stones on their blades was one of the challenging problems of the cutter-bars. The problem was much bigger during harvesting short plants. One of the valuable but short height crops was lentil, which can grow well in stony fields. Lentil in most countries especially in West Asia and North Africa (WANA) was harvested by hand. In order to overcome the problem of blades damaging, a new mechanism was designed and fabricated. Each blade has its own safety mechanism and so can show flexion independently. The harvester was tested at different forward speeds, knife speeds and carousel speeds. The impacts on both product losses and cutting height were evaluated. The obtained data was analyzed by design expert software and two quadratic stepwise models with the R^2 of 0.9505 and 0.9046 were obtained for losses and cutting-height, respectively. The results showed that forward speed has the greatest impact on both of losses and cutting height.

Rostek and Homberg (2017) worked on cutting blade of lawn clippings. It was found that abrasive lawn clippings, often wear out within hours which results in high expensive for re-sharpening. As the cutting blade was subjected to wear conditions, the less wear resistant layer wears faster than the relatively more wear resistant harder layer. As a result, the more wear resistant layer was always exposed at the tip of the blade and determines its geometry. As the hard layer's thickness was almost the same within the part, the cutting edge remains unchanged and provides constant performance in service.

Zhang *et al.* (2019) worked on to optimizing the cutting blade for crop harvesting and size reduction. The effect of blade sliding cutting angle and stem level on cutting energy of single rice stem investigated using a cutting apparatus that combined with texture analyzer. The cutting energy was determined for four blade angles. The results showed that the average cutting energy was the highest for cutting stem upper level and the lowest for cutting stem lower level. It was found that the peak cutting force per unit stem area decreased with blade sliding cutting angle increased. However, the least average cutting energy was 9.12 J mm^{-2} of 45° sliding angle when cutting without counter support blade and 32.3% less than that of 60° sliding angle. When cutting with counter support blade, the cutting energy per unit stem area varied from 6.57 to 12.54 J mm^{-2} as the sliding angle varied from 0° to 60°, whereas the peak cutting force per unit stem area varied from 2.46 to 0.98 N mm^{-2}. It was concluded that the optimal sliding cutting angle was 45° without support blade and 30° with support blade, respectively. The experiments on rice stems indicated that optimization of sliding cutting angle and stem level have a significant effect on cutting energy savings. Also this study emphasized the need to further investigate the effect of the case of more moisture content and cutting speed on the cutting energy to help in selection of optimum cutting speed and harvesting time.

2.4.3 Conveyor

Verbeek *et al.* (1982) invented an improved conveyor belt for agricultural machinery and industrial purpose. A conveyor belt comprising a web woven from an extruded nylon cord and had a polyvinyl chloride coating with a plurality of trans verse, spaced, vinyl slats heat sealed thereto. Preferably, the vinyl slats comprise an inner core or rigid vinyl and an outer main body of less rigid vinyl, and the rigid core has a T-shaped cross-section and the outer main body has an inverted T-shaped cross-section with a slot of corresponding shape to the inner rigid core for receiving same, and the inner core is secured to the outer main body with a polyvinyl chloride solvent.

Ashraf *et al.* (2007) designed and evaluated fruit and vegetable grader by using locally available material. Conveyor system, grading unit and take-away conveyor were mounted in the main frame. Optimization of the grader was done at 3 conveyor speed 10, 15 and 20 m min^{-1} on 6, 9 and 12 t h^{-1} crop load, respectively. Transmission system was developed to change the speed 25, 50 and 75 rpm for different feed rate. Damage was found at grading speed 75 rpm (20 m min^{-1}) with maximum grading errors. Cost of operation or grading charges of evaluated about ₹ 4 per 100 kg of product.

Rahman and Razali (2012) designed a conveying system with robotic arm. Base of conveyor was made up by using mild steel and aluminum profile and sensors were attached to recognize glass to stop the conveyor. Robotic arm was made up by plastic material which consist four servomotors (3 for its joint and 1 for gripping mechanism), and optical sensor was provided to detect the moving object. Basic stamp programming in the sequence and reflective theory was used in their convector system. Simulation analysis was done by using Solid Works (CAD software).

Ananth *et al.* (2013) worked on design and selection of conveyor belt. Belt conveyor was used because of its good carrying capacity, long length transportation, easy in design and construction, less maintenance and reliability. A proper belt conveyor was designed by considering speed of belt, width of belt, selection of motor, details of belt, diameter of shaft, transmission system by using standard model calculation.

Bebic and Ristic (2018) worked for efficient controlled speed conveying system by considering drive units and mechanism. It was observed that at constant speed of operation belt tension varies within same limits. Optimization of conveyer speed done to design an efficient system with minimum electricity consumption at different feed rate of material. By using algorithm an under stressed belt conveying system designed with minimum cost of operation and higher efficiency.

Kumar and Gangil (2019) worked on design of conveyor belt by using fabric material. In industries to convey the material long distance generally belts were used, which was the main component to carry the materials. Carcass material provide generally in the rubber belt for enhance the strength. Different layering material *viz.* carcass, pineapple fiber and banana fiber were analysed by using CAD software CATIA V5 and ANSYS 15.

Tupkar *et al.* (2020) found belt conveyor as one of the essential instruments for material handling in industry. It was mostly utilized in transportation of mass materials like grain, salt, coal, sand etc. Transient dynamic was the key to decide whether the design was rational in technique, safe and reliable in running, economically feasible. It was very important to study dynamic properties, improve efficiency and reduce cost of belt conveyor. In this paper, we discussed about the parameters and simulation program used for dynamic analysis of belt conveyor.

Colijn (2020) observed that many belt conveyor users who decide that detailed engineering of their loading points was a waste of time come to regret that decision after the conveyor was installed. Poorly designed equipment at belt conveyor loading points can cause excessive material spillage, create belt training problems, and shorten belt life. A right selection of conveyor was very important.

Pati and Majumdar (2020) designed a belt conveyor system for industrial purpose. In industries many mode of transportations were available like truck, pipelines, conveyor belts etc. a good material handling system was essential for efficient and safe work. It was analyzed that the belt conveying system was more suitable than the other modes of transportation for material handling. The life of conveyor system was found very good, power consumption was lower for handling coal than other selected modes. Inclination upto 20° from the horizontal was found best for transporting coal.

3.4.4 Blower

Pan (1999) studied the modes of flow and properties of material on pneumatic conveyor. Three modes of transportation was observed *viz.* (a) diluteto fluidized dense-phase, (b) dilute-phase, unstable-zone and slug-flow and (c) dilute-phase only. Flow of material was mainly depending on the bulk density, permeability, air retention and de aeration. This all factors were mainly depend on particle size, size distribution, density and shape. Bulk solid materials were divided into 3 groups PC_1, PC_2 and PC_3based on loose-poured bulk density and median particle diameter. A good accuracy was found when various test results with the observed flow modes were superimposed on the developed flow mode diagram.

Klasek (2006) worked on separation of biomass by using terminal velocity. Separation techniques that segregate by particle density and aerodynamic differences use terminal velocity properties as exemplified by classifiers and cyclones. By using a vertical air duct terminal velocity was observed 3.0-9.5 m s^{-1}. Measures of particle density for the node and inter node samples differed by about 52.6% for wheat, and from 39.3 to 61.9% for switch grass, and from 0.4 to 27.6% for com rind, and between 40.1 to 81.9% for com pith. In the low moisture level particles, the 2.5 cm lengths proved to have the least difference (-30.0%). Corn pith with a high moisture content (43% w.b.) had a greater node and inter node terminal velocity difference (-141.5%) than did the com rind. For all three species, except for wet com rinds, the terminal velocity of nodes and inter nodes differed significantly (P<.0001).

Ghafori *et al.* (2011) worked on pneumatic conveying of corn and barley by interact physical and conveying properties to design a pneumatic conveyor. Physical properties of corn and barley were determined and incorporated with air velocity to analyze the effect on pressure drop, power consumption and mechanical damage of seeds. Pneumatic characteristics of fabricated pneumatic conveying system were observed at seven air velocities. Pressure drop was observed nonlinear for corn seed with change in air velocities, where barley seed was increased linearly. Power requirement was nonlinearly increased by for both corn and barley seeds. Mechanical damage was increasing linearly for both seeds. Least pressure drop was observed at air velocity 20 and 15 m s^{-1} for corn and barley, respectively with conveying capacity of 15 t h^{-1}.

Gherman *et al.* (2012) studied the centrifugal blower in which mass flow rate was regulated by using mobile ante. A centrifugal blower 3D model was analyzed by taking different components such as rotor, stator and scroll to check out the losses by each parts. The geometry of the stator also optimize to improve the efficiency. The wall function was not predicted accurately at the separation and reattachment points. To overcome those problems impeller had the averaged y+ nearly 1, to properly capture the separation flows near leading edge at off-design regimes.

Jang *et al.* (2013) evaluate the performance of centrifugal blower by using optimal design method. Two different shape of volute casing was used to improve the performance of blower. Eddy viscosity was evaluated by SST turbulence model, where boundary condition interference between rotational and stationary domains was observed by stage method. It was obseved that that blower efficiency and pressure was improved by 0.5 and 1.6%, respectively that the compared one. They found that efficiency of blower more affected by casing height than casing width.

Myaing *et al.* (2014) designed and analysis a centrifugal blower with the help of simulation. Simulation was done for backward curved impeller by SOLIDWORKS software and theoretical result was compared. By using backward curved impeller air stream, temperature and pressure distribution also analyzed by computational fluid dynamics (CFD). The model consist diameter of shaft, diameter of hub, vane inlet, width of inlet, vane angle, outer diameter and outlet width. Various parameters were calculated *viz.* impeller inlet width, outlet width, inlet vane angle, outlet vane angle, inlet diameter, outlet diameter and number of vane about 43 mm, 22 mm, 34°, 50°, 260 mm, 600 mm and 12 , respectively.

Wagh and Panchaghade (2014) analyzed the mass flow rate of centrifugal blower at outlet for different widths of impeller by using computational fluid dynamics (CFD) analysis. This CFD analysis was advanced tool generally used for industrial purpose. CAD model was designed by using ProE WF2 software. Three different types of impeller width 17, 20 and 21.5 mm at the tip was designed by using CAD software. It was observed that the CFD result was validate for impeller with tip width about 17 mm and based on this flow rate was calculated. Suitable correlation between CFD and model was finally obtained.

Aremu *et al.* (2016) investigate the effect of moisture content on the terminal velocity of the popcorn to find out the air stream velocity range for particular moisture to separate the desirable product. No significant effect of moisture content was observed on terminal velocity, which was varies 6.88-7.82 m s^{-1} at moisture content from 20 to 60% (wb). Terminal velocity of popcorn was increased linearly with moisture content. The obtained data was help to design of material handling equipment by using pneumatic system.

Tare *et al.* (2016) analyzed the impeller of centrifugal blower by using finite element analysis at blower manufacturing company. Blower creates pressure beside the path and obstruction by duct, damper and other system components. Blowers were commonly used for ventilation, conveying, cooling system and boilers. Company was using M.S. material for manufacturing blowers which had corrosive problem that was reducing the life of blower. Blower weight was also high that creating vibration. These problems were solved by changing the material of blower. To reduce the corrosion problem SS316L material was used that was decreased about 93.7%. Three materials MS, SS and SS316L were analyzed by using FEA to overcome the weight with suitable strength and SS316L (food grade steel) of 32.93 kg weight was selected.

Baloni *et al.* (2017) designed and developed a centrifugal blower by using explicit design methodologies and tracing unified design to get better design point performance. In this method minimum assumptions required that was based on fundamental concepts. This parametric study was also carried out for the effect of design parameters on pressure ratio and their interdependency in the design. The code is developed based on a unified design using C programming. Numerical analysis is carried out to check the flow parameters inside the blower. Two blowers, one based on the present design and other on industrial design, are developed with a standard OEM blower manufacturing unit. A comparison of both designs is done based on experimental performance analysis as per IS standard. The results suggest better efficiency and more flow rate for the same pressure head in case of the present design compared with industrial one.

Abubakar *et al.* (2019) developed a terminal velocity measurement device for seed. Main components of the machine were frame, motor elbow, regulator, impeller, anemometer and measuring column. Three different seeds *viz.* paddy, sorghum and beans were evaluated by developed machine. Terminal velocity of paddy, sorghum and beans were 6.95±0.37, 4.71±0.24 and 10.98±0.27ms^{-1}, respectively. Machine efficiency was evaluated about 70.06%.

Kshirsagar *et al.* (2020) designed and optimize centrifugal blower with the help of computational fluid dynamics (CFD) analysis by using SOLIDWORKS software. Study was carried out to improve the efficiency of the blower which was observed about 84%. Static and model analysis was done by Finite Element Analysis by using mild steel.

Vasundhara *et al.* (2019) developed and evaluate the machine to measure terminal velocity of sorghum grain. Aerodynamic characteristics of the food grains/seeds were very important for harvesting, handling, pneumatic conveying, and separation. It was also good for design and selection of components. Apparatus for terminal velocity measurement was developed by using locally available material such as Mild steel sheet, galvanized iron sheet, motor, blower and speed controller. The developed machine was 41.3×30×141.9 cm of weight about 19.5 kg, which was tested at different moisture content *viz.* 8.96, 14.37, 17.29, 20.69, 23.22, 25.03, 27.56 and 29.15% (wb). The terminal velocity for sorghum grain was observed about 8.83, 9.11, 9.28, 9.32, 9.46, 9.54, 9.62 and 9.71 m s^{-1}, respectively.

2.4.5 Design of machine

Resnic *et al.* (1995) worked on manual handling jobs in industries. Pushing and pulling tasks had become increasingly common as the result of the introduction of a variety of carts and other materials-handling assistance devices. In order to predict the peak performance of workers in these tasks, and the biomechanical stresses that can result from them, the exertions involved in cart pushing were studied. Four subjects of various strengths pushed carts with loads from 45 to 450 kg at several heights. Peak push forces reached 500 N for male subjects and 200 N for female subjects. Strong subjects moved a 45 kg cart at velocities of 1.1 m s^{-1} and a 450 kg cart at velocities of 0.8 m 8. Weaker subjects moved the carts at velocities of 0.5 and 0.4 m s^{-1}, respectively. Calculated static compression forces at the L5/Sl spinal disc were consistently above the MOSH Action Limit of 3400 N for strong subjects when the cart load reached 225 kg.

Jung *et al.* (2005) studied on manual vehicles focused on the factors of wheel diameter and swiveling, handle height, load weight, moving direction, motion phase, and floor type, employing biomechanics, psychophysics, and work physiology as usability criteria. As a simple solution to alleviate problems associated with manual material handling, manual vehicles, such as carts, trucks, wheelbarrows, etc., were often provided to operators. The ergonomic recommendations are made for each factor. Most studies had been performed on four-wheeled carts and focused on wheel design, handle height, load weight, moving direction, motion phase, and floor type. Biomechanics, psychophysics, and work physiology have been used to help understand usability. The systematic classification of manual vehicles was necessary to make specific ergonomic recommendations for special-purpose manual vehicles.

Woo *et al.* (2013) observed that product design process without considering the strength of the user can cause the excessive burden on musculoskeletal system of human body. It was important to know the push and pull strength exerted by human when designing so that exerted force does not exceed the safety limits. Since the muscle strength will vary depending on the body posture, the design of product should consider the characteristics of body posture. Effects of forearm postures on the push and pull strength was investigated on study. Maximum isometric push and pull strength of left, right and both hands were measured according to forearm postures with pronation, neutral and supination. For the study, 66 male and 30 female undergraduate students were participated as subjects.

All subjects were normal and healthy with no clinical history. The push strength of male and female were observed to be 93.3% and 85.4% of pull strength. It showed that the strength of one-hand was 72.1~81.0% of the strength of two-hands, and the strength of left hand was 93.1~95.8% of the strength of right hand. The strength of female was 62% of the one of male. It was found that the strength with pronation 90° was reduced up to 20% compared to the strength with neutral posture. It was observed that push and pull strength of male and female were reduced when forearm was rotated extremely.

2.5 Performance Evaluation

Singh (2006) estimate the mechanization index and their impact on production and economics of cultivation. The standardized regression coefficient has revealed that irrigation (42%) and farm power (32%) significantly contributed in increasing the yield. They revealed that the human labour cost was largest in wheat crop cultivation, which was the most highly mechanized crop in India. Analysis also showed that 78.5% farm power was contributed by the mechanical sources, the mechanization index based on cost of use of machinery was 14.5%. The crop-wise mechanization index varied from a lowest value of 8.22% in sorghum and paddy to a highest value of 30% in wheat. It was also revealed that the states had higher mechanization indices incurred a lower cost of cultivation of the wheat crop on quintal basis due to increased yield.

Patil *et al.* (2011) conducted an experiment to evaluate the performance of the self-propelled reaper for wheat (WH 147 and HD 2189) by using RNAM test code. Straight line method was used to estimate the cost of operation. To evaluate the performance of machine field capacity, speed of operation, working width, losses and height of stubble after harvesting were observed. They found the header loss 0.85%, conveying loss 3.1% and total machine loss about 3.95% respectively. The cost of operation and field capacity were calculated ₹ 677.50 ha^{-1} and 0.13 ha h^{-1} respectively.

Maughan *et al.* (2013) evaluated the performance of a mower-conditioner used to harvest miscanthus, and modifications to the disk head were made to allow the machine to operate more efficiently. It was also hypothesized that the harvest energy requirement of the mower-conditioner in miscanthus could be reduced by increasing the blade oblique angle. Blades with oblique angles of 20° and 30° were manufactured and fitted to the disk mower-conditioner. When combined with data collected from a real-time yield sensing system, the data collected regarding the machine performance resulted in point-specific and overall machine energy consumption information. The 30° oblique angle resulted in a 27% reduction in the energy requirement, with an energy consumption of 13.5 MJ Mg^{-1} as compared to 18.5 MJ Mg^{-1} for the conventional straight (0°) blades. Overall life of the angled blades as well as the feasibility was also examined of their application on other crops harvested by disk mower-conditioners, such as hay and forage.

Shilpa *et al.* (2017) worked on mechanization, cost and returns of manual and mechanical harvesting and threshing of chickpea. Selection of the experiment location, farmers and machine owner were selected according to multistage sampling method. Total number of sample was selected for study was 90 (60 chickpea growing farmers and 30 machine owners), and farm budgeting and tabular analysis was used to evaluate the gathered data. It was analyzed that about 70% of farmers harvested chickpea engaging human labour and threshed it with machine and other 30% of the farmers were using machine both for harvesting and threshing operation. On an average both states together, total human labour, bullock labour and machine hours utilized in the study areas was found to be 33.66 man days, 5.39 pair days and 4.69 hours, respectively. Although the quantities of inputs used were less per acre, the total expenditure incurred on these inputs was more in case of Maharashtra (₹ 13,443.88 ha^{-1}) when compared to Madhya Pradesh (₹ 12,133.73 ha^{-1}). The net profit of mechanical harvesting and threshing over manual harvesting and machine threshing was ₹ 2613 and ₹ 3044 in Maharashtra and Madhya Pradesh, respectively.

Patel *et al.* (2018) evaluate the performance of self-propelled reaper binder for harvesting of wheat crop. The harvesting was found too much labour demanding operation and labour scarcity during wheat harvesting was also one of the major problem. To do the all work in proper time it was essential to adopt mechanical methods in cultivation, which also help to reduce the cost and increase production. To evaluate the performance of self-propelled reaper binder various parameters *viz.* actual field capacity, field efficiency, operational speed and fuel consumption were taken under consideration, which was observed 0.17 ha h^{-1}, 78.49 per cent, 2.55 km h^{-1} and 1.12 l ha^{-1} respectively. The cost of operation and losses were observed to be about 3235.11 ha^{-1} and 25.42 kg ha^{-1}, respectively.

Bheda *et al.* (2019) evaluate the performance of leafy harvester in coriander. The major components of the machine include the cutting unit (reciprocating cutter bar), the slider crank mechanism, the reel, conveyor, storage crate and the frame. Experiments were conducted in the coriander field by varying crank speeds (200, 300 and 400 rpm) by accelerator throttle of engine and forward speed ranges (0.9-1.2, 1.3-1.6 and 1.7-2.0 km h^{-1}) in different nine combinations. The highest effective field capacity was found to be 8.6×10^{-3} ha h^{-1} for the combination of crank speed at 200 rpm and 1.7-2.0 km h^{-1} of forward speed. The highest field efficiency and cutting efficiency were found to be 87.29% and 96.28% respectively with the combination of crank speed of 400 rpm and forward speed of 0.9-1.2 km h^{-1}. Cost of operation of the leafy harvester was found to be ₹ 1907.79 ha^{-1}.

2.6 Inference

Outcome of the review related to our research work is presented here:

- It was observed that the harvesting of leafy crop generally done by manual method, mechanization status of leafy crop harvesting also found negligible. The manual process of leafy crop harvesting was found time taking process.
- In chickpea 2-3 nipping is required for higher growth and yield, but nipping operation done only by hand plucking, too much labour and time required for nipping operation in chickpea.
- Now days many varieties of the leafy vegetables available, which required more than three harvesting.
- It was also recorded by various researchers that with the increase in the forward speed the header loss decrease. It was also observed that with the increase in the cutting height the header loss increases.

CHAPTER-III
MATERIALS AND METHODS

This chapter deals with the materials and methods used for design and development of leafy crop harvester. Before designing of the machine a study was conducted on the geometry and crop parameters of the leafy vegetables. The machine was designed for harvesting leafy crop and to reduce the problem occurs during harvesting.

The present study was conducted at research farm of Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur. The leafy vegetables were grown in the flat or check basin methods. The leafy vegetable cultivation is usually done either in *badi* or in midland situation. The soil in the area is suitable for various types of crops. In present study four leafy vegetables *viz.* chickpea, amaranthus, fenugreek and spinach were take. As the area of these leafy vegetables is prominent leafy vegetable of the area.

3.1 Geometry of Leafy Crops *viz.* Chickpea, Amaranthus, Fenugreek and Spinach

A purposive survey was conducted to know the practice involved in harvesting of leafy vegetables from the crops. Biometrics of crop, different problems occurred during traditional harvesting operation.

3.1.1 Biometric properties of leafy crop

It was essential to know the agronomical parameters of leafy crop to design a harvester. The agronomical parameters of selected crops were measured and (amaranthus, spinach, fenugreek and chickpea) are described below:

a. Plant height:

Plant height was measured with the help of a steel ruler having least count of 1 mm. The randomly selected 10 plants were measured from ground to top of plant at maturity as given in Fig 3.1 to Fig 3.4.

b. Stem diameter:

The stem diameter was measured with the help of a vernier caliper having least count of 0.01mm. The measurement was taken place at randomly selected 10 plants in each plot. It was done at the three points of the stem and the thickest part was noted for study as given in Fig 3.5 to Fig 3.6.

c. Numbers of branches:

Number of branches was counted in whole plants. The branches were divided into primary and secondary according to its position. The branches near to the main stem are called as primary whereas the branches appeared from the primary are termed as secondary branches. Both primary and secondary branches were counted together to determine the total number of branches in a plant.

d. Plant population:

The plant population in unit area was measured with the help of a square frame having 1 m^2 area. The frame was placed diagonally along the line of planting to count number of plants per unit area.

e. Spacing:

It was the distance between two continuous plants. Row to row and plant to plant spacing of the different leafy crops were measured by the help of measuring scale with least count of 1 mm at the field.

f. Number of harvesting:

The total number of harvesting in a season was termed as number of harvesting. Number of harvesting varied from crop to crop. Harvesting may either do by manual nipping, or plucking.

g. Period of harvesting:

Harvesting of leafy crop was done in a specific interval period from day after sowing. It varies from crop to crop.

3.1.2 Engineering properties of leaves of leafy crop

Engineering properties like bulk density, angle of repose, crushing resistance and terminal velocities were measured to develop different components like cutting, blowing, conveying and storage unit with proper mechanism in the machine as follows:

Fig. 3.1: Height measurement of chickpea

Fig. 3.2: Height measurement of spinach

Fig. 3.3: Height measurement of fenugreek

Fig. 3.4: Height measurement of green amaranthus

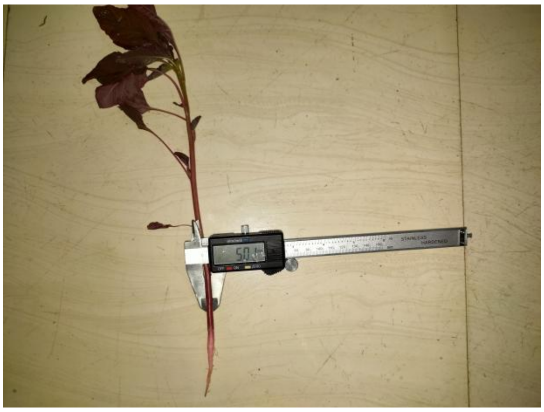


Fig. 3.5: Stem diameter of red amaranthus

Fig. 3.6: Stem diameter of chickpea

3.1.2.1 Bulk density

The bulk density was calculated as the mass of leaves divided by the container volume (Singh and Goswami, 1996; Baryeh, 2002). A metallic cube box of known dimension 20×20×20 cm^3 was used to measure the bulk density of leafy crops (Fig 3.7 to 3.10). The box was completely filled by leafy vegetables up to the top followed by three times tapping and weight was taken with an electronic balance having least count of 1 g. The bulk density was calculated by using the Equation 3.1 (Kushwaha *et al.*, 2015).

$$\text{Bulk density, } (\text{kg m}^{-3}) = \frac{\text{Weight of leafs (kg)}}{\text{Volume of box (m}^3\text{)}} \quad \ldots (3.1)$$

3.1.2.2 Angle of repose

Angle of repose of the leafy crop harvester was measured with free fall method by making a heap of leafy crop as shown in Fig. 3.11. Then height and radius of the heap of leafy crop was measured and angle of repose was calculated with the help of Equation 3.2. Empty box method was also tried but it was not applicable for harvested leafy crop for that size of box as shown in Fig. 3.12.

$$\alpha = \tan^{-1}\left(\frac{h}{L}\right) \quad \ldots (3.2)$$

Where,

α = Angle of repose, degree;

h = Height of the heap, mm;

L = Radius of the heap, mm.

3.1.2.3 Coefficient of static friction

Coefficient of the friction of cut leafy vegetable was measured by inclined plane method. The leafy crops were kept horizontal on the plate of the instrument and the slope was gradually increased. The angle at which impending slip occurred was measured. The value of coefficient of static friction was used to decide the inclination of rods of soil separator and calculated by using Equation 3.2:

$$\mu = \tan\emptyset \quad \ldots (3.2)$$

Where,

μ = Coefficient of static friction;

$\emptyset$= Angle of rolling resistance, degree.

Fig. 3.7: Measuring bulk density of chickpea

Fig. 3.8: Measuring weight of chickpea for density

Fig. 3.9: Measuring bulk density of amaranth green

Fig. 3.10: Measuring bulk density of amaranth red

Fig. 3.11: Measuring angle of repose of chickpea by free fall method

Fig. 3.12: Measuring angle of repose of leafy crop by empty box method

3.1.2.4 Terminal velocity

Terminal velocities were measured by using suspension velocity method (Zewdu, 2007). Leafy vegetables were cut at difference sizes to know the desired terminal velocity. A circular duct made of transparent glass was used to observe the suspension of the leaf which was placed in wire mesh/net as shown in Fig. 3.13. Air was supplied from the bottom side by centrifugal blower. And an anemometer is placed over the duct to measure the velocity of air. In a particular velocity the leaves were comes in suspension, that time we measured the velocity of air that was terminal velocity for particular sample.

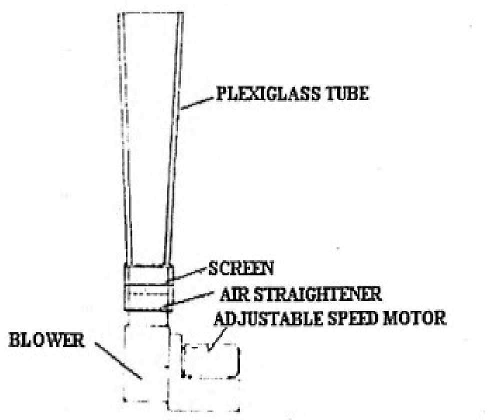


Fig 3.13: Vertical air tunnel for measurement of terminal velocity of leafy crops (Sacilink *et al.*, 2003)

3.1.2.5 Crushing resistance

The most important factor for blade design is cutting strength of the leafy vegetables. Cutting strength of the leafy vegetable was measured by using texture analyzer (Stable Micro Systems, United Kingdom, machine model number TA-Hdi). The texture analyzer is used in determining different physical properties of fruits and vegetable crops. Stem of leaves placed in the base plate such that the point of crushing was on the center of the stem after that 500 kg force was vertically applied at speed of 0.2 mm $s^{-1}$with the help of load cell. The rupture distance was kept as 4 mm and force was measured in compression. After setting of the machine stem of leaves were crushed for each sample by crushing probe and peak force was measured by computer.

3.2 Identification of Associated Problem in Leafy Crop Harvesting

Harvesting of leafy crop is analyzed in field. Various parameters like labour requirement, time of operation, times and period of operation and fatigue occurred during harvesting were analyzed. Different harvesting method i.e. manual hand plucking (Fig 3.14), by using sickle (Fig 3.15) and by using tea leaf harvester was performed in field to identify the associated problems.

3.2.1 Harvesting methods

Harvesting of leafy crop is generally done by manual harvesting. Harvesting method adopted for different leafy vegetables is described here. Nipping operation of chickpea in India done by manual hand plucking method, which was found uneconomical and time consuming operation. Amaranthus (*chulai*, *lal bhaji*), fenugreek and spinach were harvested by sickle and sometime whole plant uprooted from the field.

3.2.2 Effect of different harvesting methods on growth parameters of leafy crop

Four different methods were used to observe the effect of different harvesting methods on the growth parameter on selected leafy crop. Two factors were selected i.e. number of harvesting and methods of harvesting with their 3 and 4 levels, respectively. Observe data from twelve (3×4) treatments with their three replications were statistically analyzed using Split Plot Design with the help of OPSTAT statistical package developed by HAU, Hisar. Details of independent and dependent parameters are given in Table 3.1 and this all parameters were tested for all selected leafy crop individually.

Fig. 3.14: Manual plucking

Fig. 3.15: Mild steel sickle

Dependent parameters were included number of branches, plant height and yield. Number of branches and plant height were measured 10 Days after each harvesting. Yield of the leafy crop was determined just after harvesting. Dependent parameters were measured as described in section 3.1.1.

Table 3.1: Dependent and independent parameters at various levels for testing growth parameters of different harvesting methods

S.No.	Factors	Levels
Independent parameters		
1.	No. of harvesting	1. First harvesting (D1) 2. Second harvesting (D2) 3. Third harvesting (D3)
2.	Methods of harvesting (M)	1. Manual hand harvesting/nipping (M1) 2. Harvesting with mild steel sickle (M2) 3. Harvesting with fiber blade (M3) 4. Harvesting with stainless steel blade (M4)
Dependent parameters		
	1. Number of branches 2. Plant height 3. Yield	

3.2.3 Overall Discomfort Rating (ODR)

The overall discomfort rating during harvesting and threshing operation experienced by the selected sample was estimated by the point on the psychophysical rating scale i.e. 0 to 10-point rating scale which shows that 0 is no comfort to 10 as extreme discomfort. A scale of 70 cm length having 0 to 10 digits marked equidistantly (Fig. 3.16 and Fig. 3.18) and Table 3.2. At the ends of each trial, subjects were asked to point their overall discomfort rating on the scale. The overall discomfort ratings given by each of the subjects were added and averaged to get the mean rating.

3.2.3.1 Body part discomfort score (BPDS)

Body diagram as shown in Fig. 3.17 divided in to 27 numbers of regions for the localization of different Body part discomfort score, on the basis of Corlett and Bishop Technique. The body diagram chart used during the experiments. The body part discomfort score of each subject was the rating multiplied by the number of body parts corresponding to each category. The subjects were asked to locate the body parts with respect to degree of discomfort in the order as extremely heavy, very heavy, moderately heavy, heavy, light and very light.

The Borg Scale Rating (≥ 5) is considered as the 'break point' or, in other words, as the point where the participants rated their discomfort as strong. Thus, in this study, this point was considered as the point where the participants started to feel the discomfort in their relevant body parts. Body part discomfort score was measured for different leafy crop harvesting methods adopted in Chhattisgarh i.e. manual plucking and harvesting with sickle as presented in Fig. 3.14.

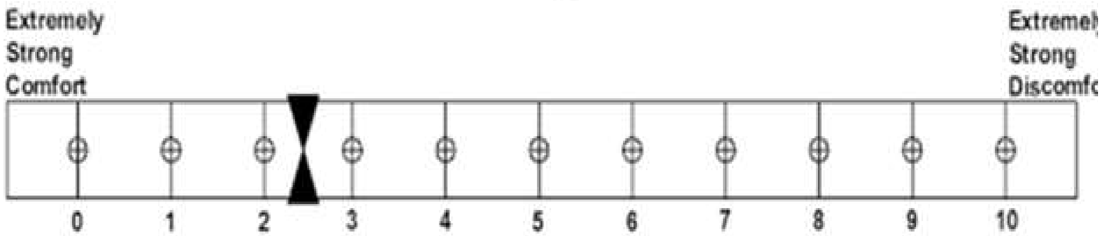
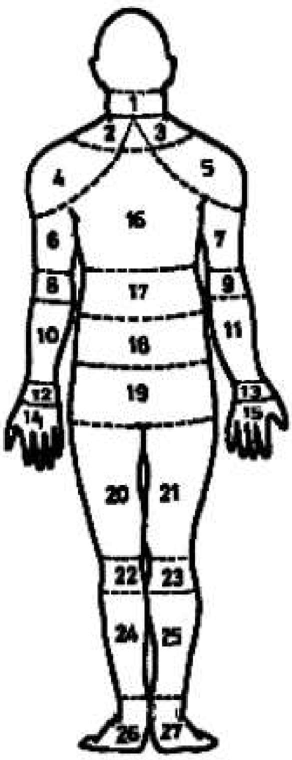


Fig.3.16: Visual analogue discomfort scale for assessment of overall body discomfort (*Borg ,1982*)

1. Neck
2. Clavicle left
3. Clavicle right
4. Left shoulder
5. Right shoulder
6. Left arm
7. Right arm
8. Left elbow
9. Right elbow
10. Left forearm
11. Right forearm
12. Left wrist
13. Right wrist
14. Left palm



15. Right palm
16. Upper back
17. Middle back
18. Lower back
19. Buttocks
20. Left thigh
21. Right thigh
22. Left knee
23. Right knee
24. Left leg
25. Right leg
26. Left foot
27. Right foot

Fig. 3.17: Body map showing different region for knowing BPDS (*Corlett and Bishop, 1978*)

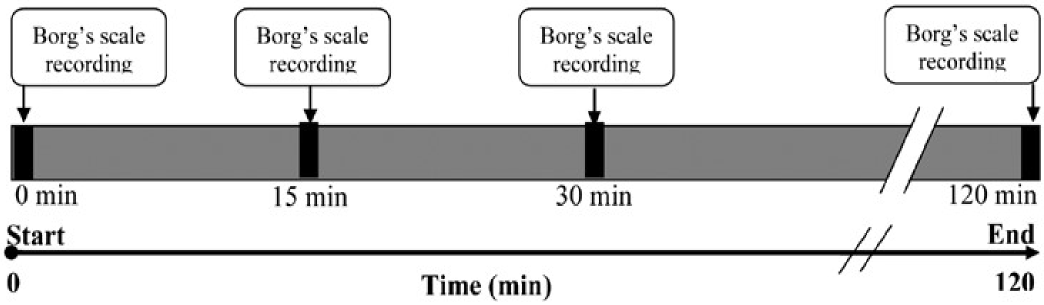


Fig 3.18: Schematic schedule of measurement including:
1) The total period of time; 2) Borg's scale recording at every 15 min time period.

Table 3.2: Borg CR10 scale for assessment of overall body discomfort rate

Scale	Scale Rating	Perceived Exertion	Note
0	Nothing at all		Subjects don't feel any exertion whatsoever, e.g. no muscle fatigue, no breathlessness or difficulties breathing.
0.3	-	-	-
0.5	Extremely weak	Just noticeable	
0.7	-	-	-
1	Very weak		Very light. As taking a short walk at your own pace.
1.5	-	-	-
2	Weak	Light	
2.5	-	-	-
3	Moderate		Is somewhat but not especially hard. It feels good and not difficult to go on.
4	-	-	-
5	Strong	Heavy	The work is hard and tiring, but continuing not terribly difficult. The effort and exertion is about half as intense as 'Maximal'.
6	-	-	-
7	Very strong		Is quite strenuous. Subject can go on, but really have to push himself/herself and are very tired.
8	-	-	-
9	-	-	-
10	Extreme strong	Maximal	An extremely strenuous level. For most subjects this is the most strenuous exertion they ever experienced.

BORG G. 1998. Borg's perceived exertion and pain scales, Illinois: Human Kinetics Publishers, Champaign, 49 p.

3.3 Design of Leafy Crop Harvester

Leafy crop harvester has been designed as a functional and experimental unit for chickpea, fenugreek, amaranthus and spinach harvesting. Before designing of leafy crop harvester, the performances of existing leafy vegetable harvesters were evaluated and associated problems were identified and biometric data of leafy crop was collected. After that manual push type harvester was considered for harvesting leafy vegetables. Then soil parameters during harvesting, engineering properties of leaf were also studied. Anthropometric data was collected to design a suitable machine for operator.

Harvesting is suitable with reciprocating cutter bar, so engine operated reciprocating cutter bar is considered for harvester. To design leafy vegetable harvester biometric characteristics of plants, physical and engineering properties of leafy vegetables also considered. Different components of leafy vegetable harvester are mechanically designed to withstand in any operating condition. A field test also conducted to analyze the performance of machine. The design and selection of appropriate harvester component involves following steps and basic information required parameters:

- Collection of anthropometric data
- Design of leafy crop harvester
    - Frame
    - Design of blade
    - Selection of blowing unit
    - Selection of power source for blade and blower
    - Design of conveyor
    - Storage tank

Leafy crop harvester has been designed based on the engineering and physical properties of the crop.

3.3.1 Anthropometric data

Anthropometry is essential for successful agricultural equipment design. In anthropometry physical measurement of human body dimensions were recorded to achieve best performance and efficiency of the man-equipment system along with better comfort and safety of the operator. It was collected from farm workers involved in agricultural activities as shown in Fig 3.19. Anthropometric data from other studies were also reviewed for designing of the various part of the harvester. The following parameters to be measured during study as given in Table 3.3.

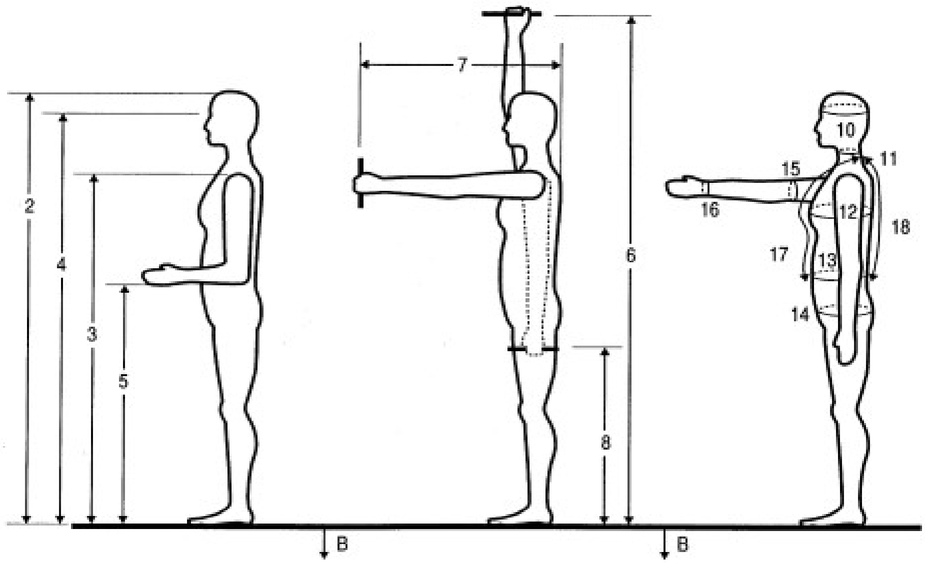


Fig 3.19: Schematic diagram of anthropometric measurements in the standing position

3.3.2 Design of components of leafy crop harvester

3.3.2.1 Design of cutting blade

Estimation of force required to push the machine according to (Compbell, 1990) the power of useful work done by human being was determined by Equation 3.3:

$$P = 0.35 - 0.092\log(t) \qquad \ldots (3.3)$$

Where,

P = Power in horse power; and

t = Time in minute.

Assuming the time of work as four hours, power developed by a man is calculated by formula 3.4:

$$P = 0.35 - 0.092 \log(4 \times 60)$$

P = 0.131 hp = 0.098 kW

Table 3.3: Body parts for anthropometric data measurement

S No	Particulars	Unit	Measured by instruments
01	Weight	kg	Digital weighing balance
02	Stature (Base to vertical height)	mm	Measuring tape
03	Shoulder height (Base to arm height)	mm	Measuring tape
04	Eye height (Base to eye)	mm	Measuring tape
05	Elbow height	mm	Measuring tape
06	Arm overhead reach	mm	Measuring tape
07	Arm reach forward	mm	Measuring tape
08	Arm reach down	mm	Measuring tape
09	Arm span	mm	Measuring tape
10	Head circumference	mm	Measuring tape
11	Neck circumference	mm	Measuring tape
12	Chest circumference	mm	Measuring tape
13	Waist circumference	mm	Measuring tape
14	Hip circumference	mm	Measuring tape
15	Upper arm circumference	mm	Measuring tape
16	Wrist circumference	mm	Measuring tape
17	Front chest length arc	mm	Measuring tape
18	Back length arc	Mm	Measuring tape

To determine the push force following Equation 3.5 is used,

$$\mathrm{P} = \frac{\mathrm{Push} \times \mathrm{Speed}}{75} \quad \ldots (3.4)$$

$$\mathrm{Push} = \frac{75 \times \mathrm{P}}{\mathrm{Speed}} \quad \ldots (3.5)$$

Let speed of operating the machine was 2.5 km h^{-1} or 0.7 m s^{-1}. Therefore, from equation,

$$\mathrm{Push} = \frac{75 \times 0.098\ \mathrm{kW}}{0.7} = 10.5\ \mathrm{kN}$$

Torque generation

$$\mathrm{hp} = \frac{2\pi \times \mathrm{N_g} \times \mathrm{T_g}}{4500} \quad \ldots (3.6)$$

Where,

N_g = rpm of ground wheel; and

T_g = torque developed by the ground wheel.

$$V = \frac{\pi \times D \times N_g}{60} \quad \text{... (3.7)}$$

V = Operating speed of machine, take 0.7 m s^{-1}; and

D = Diameter of ground wheel.

It is taken, D = 0.5 m putting these values in Equation 3.7,

$$N_g = \frac{60 \times 0.7}{\pi \times .5}$$

= 26.73

Putting this value in Equation 3.6, we got

$$T_g = \frac{4500 \times 0.098 kW}{2\pi \times 26.73}$$

= 2.63 kN m ≈ 18.54 kg cm

3.3.2.2 Determination of forces acting on the cutter bar

The total resisting force (F) acting on the cutter bar is the sum of all the forces acting on the knife (Sharma and Mukesh, 2010).

$$F = F_c + F_f + F_i \quad \text{... (3.8)}$$

Where

F = Total resisting force on cutter bar, N or kg;

F_c = Average resistance to cutting, N or kg;

F_f = Frictional force N or kg; and

F_i = Inertia force of knife section, N or kg.

3.3.2.3 Cutting force in the cutter bar

The resistance to cutting for cereal crops was estimated by assuming that the plants were uniformly distributed in rows and leafy crops will be cut by engine powered machine. The total cutting force (F_c) on the cutter bar was determined by using formula given by Equation 3.9 (Sharma and Mukesh, 2010).

$$F_c = \frac{EF_tZ}{X_c} \quad \text{... (3.9)}$$

Where,

FC = Total cutting force in cutter bar, N;

E = 1.25 N cm cm^{-2} for wheat crop and 2.0 N cm cm^{-2} (for paddy);

Ft = Knife load area for single stroke cutter. It is calculated, 48 cm^2;

Z = Number of knife section in the cutter bar is 16 for 80 cm cutter bar; and

X_c = Displacement of knife, start to end of cutting equal to 3.75 cm for the designed knife section.

$$F_c = \frac{2 \times 48 \times 16}{3.75}$$

= 409.6 N

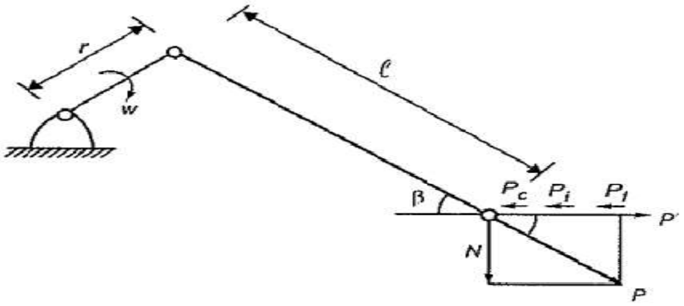


Fig 3.20: Forces acting on cutter bar

3.3.2.4 Inertia force in cutter bar

The inertia force acting on the cutter bar is governed by the mass (Mk) of reciprocating cutter bar, it is calculated by Equation 3.10 and Fig. 3.20.

$$F_i = M_k r \omega^2 \left(1 - \frac{x}{r}\right) \qquad \text{... (3.10)}$$

Where,

M_k = mass of knife section, kg;

r = radius of crank, cm;

ω = angular velocity, rad s^{-1}; and

x = length of stroke, cm.

At initial and final points of stroke, F_i would be maximum. So,

$$F_i = M_k r \omega^2$$

$$F_i = 0.2 \times 0.01875 \times 26.67^2 = 26.67 \text{ N}$$

3.3.2.5 Frictional force in the cutter bar

The frictional force (F_f) acts on the knife slides over the finger bar and was given by (Sharma and Mukesh, 2010).

$$F_f = F_{f1} + F_{f2} \quad \text{... (3.11)}$$

F_{f1} = Force due to weight of cutter bar;

F_{f2} = Force caused by normal component of force exerted by connecting rod on the knife.

$$F_{f1} = M_k \times f \quad \text{... (3.12)}$$

f = 0.2- 0.3, take average of it 0.25

$F_{f1} = M_k \times f = 2 \times 0.3 = 0.6$ N

$$F_{f2} = \left[\frac{(F_c + F_{imax} + F_{f1})\tan\theta_b}{(l - f\tan\theta_a)}\right] \times f \quad \text{... (3.13)}$$

Angle $\theta_a$and$\theta_b$was maximum and minimum at 0 and 180°.

So putting tan0° =tan 180°= 0 this F_{f2} term would be zero.

$$F_{f2} = \left[\frac{(F_c + F_{imax} + F_{f1})\tan\theta_b}{(l - f\tan\theta_a)}\right] \times f$$

F_{f2}= 0

$F_f = F_{f1} + F_{f2} = 0.6 + 0 = 0.6$ N

Therefore, total resisting force (F) acting on the cutter bar is calculated using Equation 3.12.

$F = F_c + F_f + F_i$= 409.6 + 26.67 + 06 = 436.87 N

Market available selected cutter bar dimension is presented in Fig. 3.21 and 3.22. Travelling path of two adjacent knife edges during several consecutive strokes in selected cutter bar is depicted in Fig. 3.23 assuming the speed of cutter bar as 1 m s^{-1} and travelling speed as 0.7 m s^{-1} (if speed is 1 km h^{-1}). The surface described by the moving knife edges partly coincide, and partly leave gaps which show that vegetable blades, growing on the surface of such gaps, were not cut by knife during their single stroke. The shaded area given in Figure 3.23 is the area of cut by the reciprocating blade. The vegetables grown on these surfaces were cut during one knife stroke and the rest in next consecutive (back) stroke of the knives. The magnitude of the surface of the gaps depends, with a given mean speed of knife edges, on the speed of their forward motion, the faster the cutter bar travels over the field, the greater the gaps left behind, where twice run of knife in same surface in unnecessary.

3.3.2.6 Selection of power source

Leafy vegetable harvesting is a very important operation. These types of crops and vegetables were generally harvested by hand plucking/nipping methods or by using either a sickle or sharp knife. The present design was done with the use of manual pushed trolley. The trolley consists of four towed wheel.

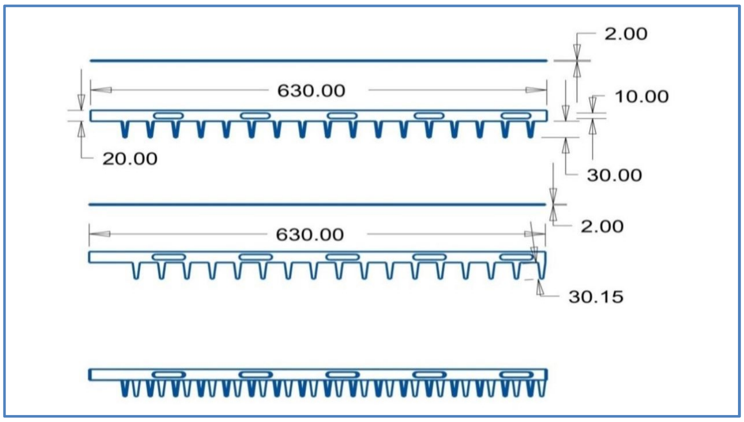


Fig. 3.21: Dimension of cutter bar blade

Fig. 3.22: Blade used for leafy crop harvester

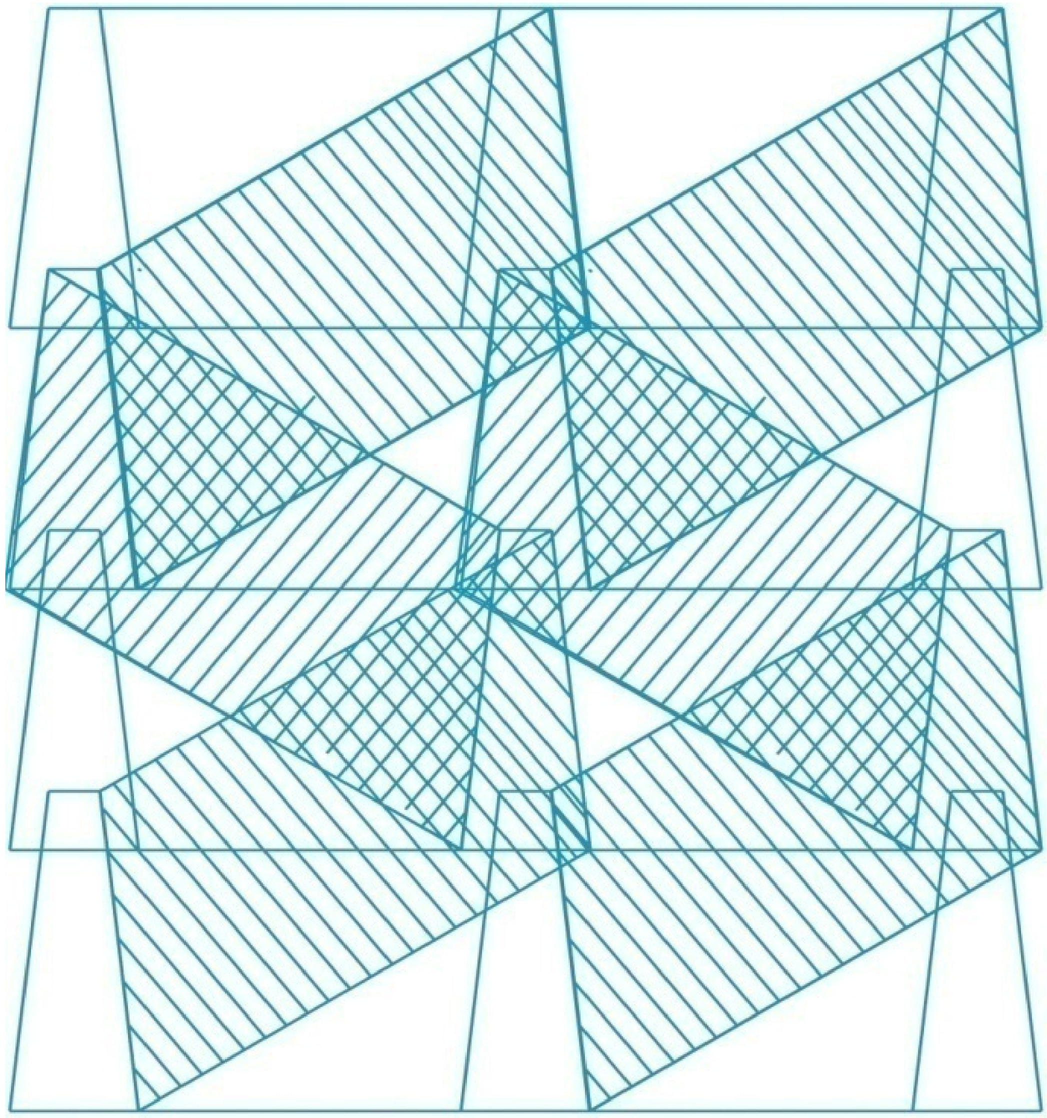


Fig. 3.23: Path of two adjacent knife edge

3.3.2.6.1 Power requirement for the machine

The power required to overcome the resistance to motion of cutter bar (P) was determined by Equation 3.14 (Sharma and Mukesh, 2010)

$$P = F \times V_k \qquad ... (3.14)$$

Where,

P = Power, W;

F = Resistive force equal to 436.87 N; and

V_k = Knife speed, ms^{-1} (i.e. 1 ms^{-1}).

Hence $P = F \times v = 436.87 \text{ N} \times 1 \text{ ms}^{-1} = 436.87 \text{ W} = \frac{436.87}{746} \text{ hp} = 0.59 \text{ hp}$

3.3.2.6.2 Power requirement for blower

The design of the blower was based on the terminal velocity required to blow the cut leaves of leafy crop on the conveyor. The details of the blower unit were discussed in section 3.3.2.7.1.

Assuming the power requirement to operate the cutter bar as well as blower was about 0.8 hp i.e. 0.21 hp for blower operation. Taking factor of safety 20% more power of the designed power a 1 hp 2-stroke petrol operated engine was selected. The specification of the petrol engine is given in Table 3.4.

Table 3.4: Specification of engine

S.No.	Particulars	Value
1.	Model	KK-3209
2.	Power	1.0 hp
3.	Stroke	2
4.	Fuel	Petrol
5.	RPM	7600

3.3.2.7 Conveying/blowing

A conveyer unit was provided in the machine to convey the cut leaves to the collecting tray. After cutting of leafy crop a blower and conveyor unit was used to convey it to storage unit. Blower unit was provided to push cut leafy crop in to conveyor just immediate after cut.

3.3.2.7.1 Selection of blower

The blower unit was selected on the basis of the aerodynamic properties of the leaves of leafy crop. It helps to convey leaves from the cutter bar to the surface of the conveying belt with the help of air stream ejected from the blower with the help of eight small pipe outlets. Selection of blower was done according to required terminal velocity and pipe available to create stream for blowing harvested leaf. The aerodynamic property of leaves was firstly measured as described in the section 3.1.2.4. The terminal velocity was observed about 2.5-3.54 m s^{-1}. To maintain high terminal velocity total 8 numbers pipe of circular opening of 7.07 cm^2 were selected to cover complete width of the cutter bar. These pipes were connected in main stream of the blower. The required flow rate of the blower was calculated by using following formula written in Equation 3.15.

$$Q = A \times V_t \quad \text{... (3.15)}$$

$$Q = \frac{7.07}{10000} \times 3.54$$

$$Q = 3.54 \times 10^{-3}\ m^3 s^{-1}$$

Efforts are taken to select plastic materials to overcome the weight of machine. The blower selected was made up of plastic. Detail CAD drawing and dimensions of impeller and casing of selected blower is presented in Fig. 3.24 to 3.26.

3.3.2.7.2 Design of conveyor

Frictional properties of the leaves of leafy crop were considered for selection of material for conveyor. Coefficient of friction and angle of inclination was measured for canvas, rubber, cotton, jute and fiber as described in section 3.1.2.2. A canvas cloth conveying material was selected due to it more resistance to flow than other material.

Length of the conveying belt was calculated by the formula given in Equation 3.16 (Sahay and Singh, 1996) and shown in Fig. 3.27. The center distance between the upper and lower shafts was kept at 850 mm. The diameter of the two shafts was taken as 25 mm. The length of the roller shaft was selected as 530 mm.

The conveyer was made by using a canvas cloth of having width of 510 mm. The cloth was taken slightly more than 510 mm to make its strength more by stitching and folded sidewise about 50 mm from both side. It provides more grip as well as strength to the conveyer belt. The long side was overlapped about 60-70 mm. Total length of the conveyer belt was determined by using formula (3.16):

$$L_b = \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d_1 - d_2)^2}{4x} \quad \text{... (3.16)}$$

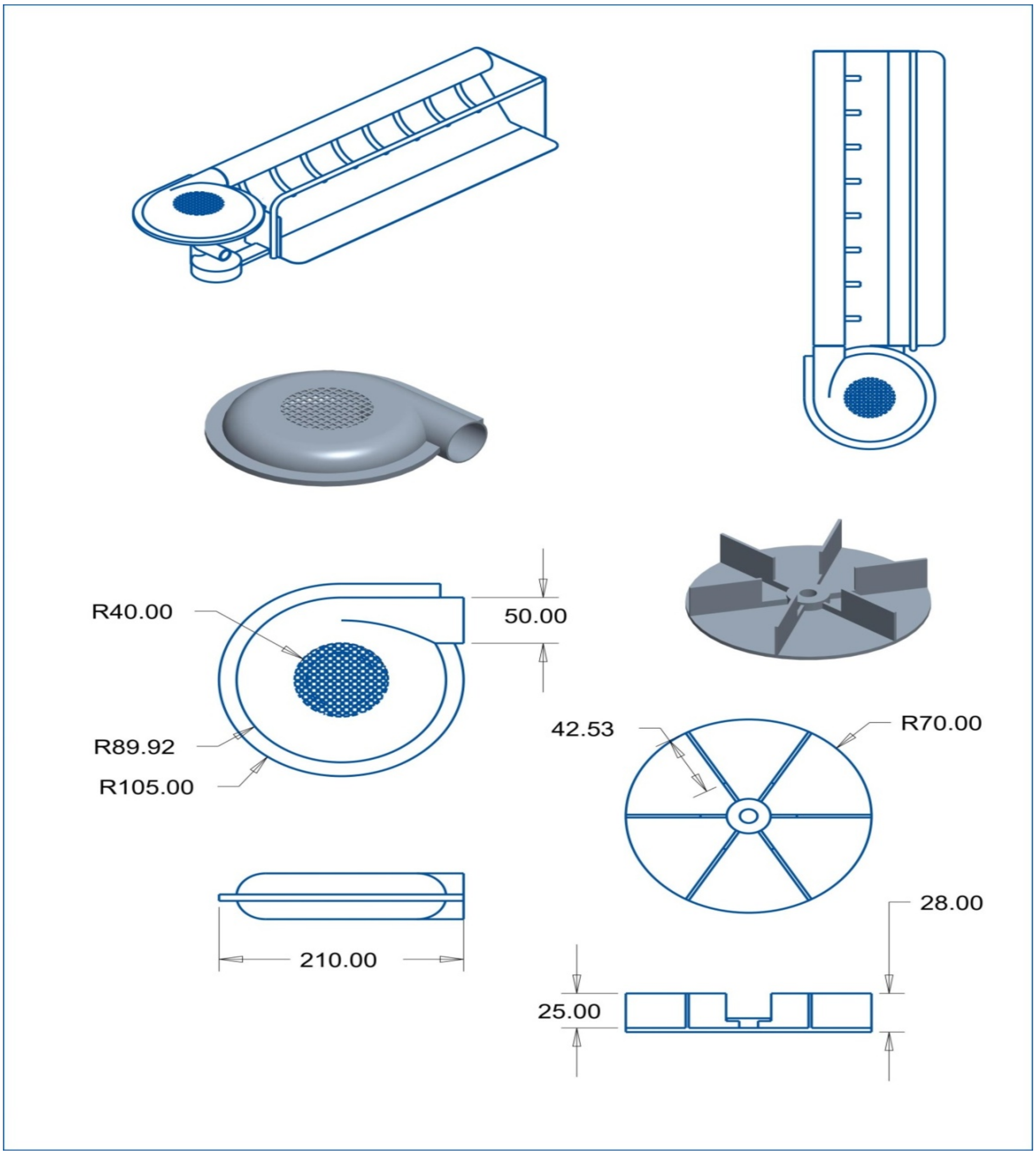


Fig. 3.24: Dimensions of impeller and casing used in blower

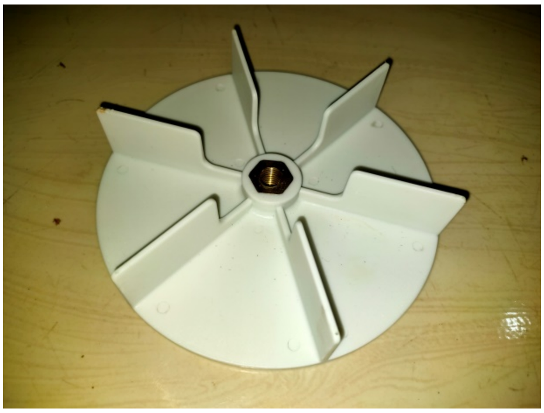


Fig. 3.25: Impeller

Fig. 3.26: Blower

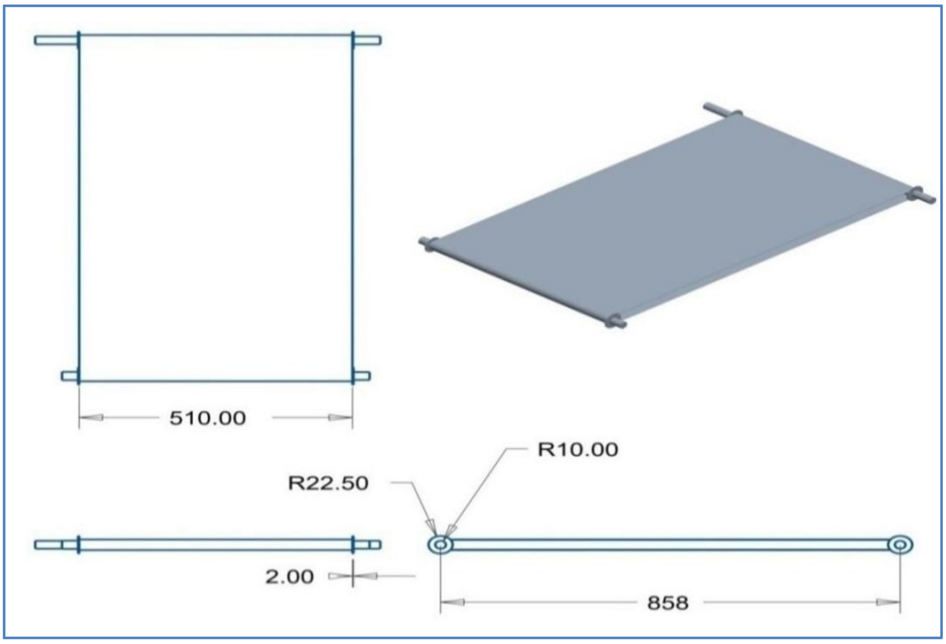


Fig. 3.27: Dimensions of canvas conveyor

Where,

L_b = Length of belt;

d_1 = Diameter of driver roller shaft i.e. 25 mm;

d_2 = Diameter of driven roller shaft i.e. 25 mm; and

x = Center distance between shaft i.e 850 mm.

Putting the values of the various parameters in Equation 3.16, the length of belt was calculated as follows:

$$L_b = \frac{\pi}{2}(25 + 25) + 2 \times 850 + \frac{(25 - 25)^2}{4 \times 850}$$

L_b= 1778.54 mm

3.3.2.8 Transmission system

3.3.2.8.1 Design of power transmission system

Power transmission system was designed to operate the conveyor of the machine. The power is supplied from the ground wheel to the conveyer belt. Power transmission unit consists of a chain drive and gear drive. Chain drive was fitted between wheel shaft and mediate shaft, which was selected because of its positive motion without slippage. Mediate drive unit was used to change the rotation of motion. Mediate drive unit shaft/pin consists of both gear and chain sprocket. Chain sprocket in mediate drive unit was taking power from ground wheels shaft and transmit it to conveyor shaft by gear system. The arrangement of the transmission system is shown in Fig 3.28 and 3.29.

3.3.2.9 Selection of shaft

Both the rotary and twisting force were acting on the wheel shaft. Diameter of the shaft was calculated by considering equivalent bending moment and torque acting on the shaft by using Equation 3.17 and 3.18.

$$T_e = \frac{\pi}{16} \times \tau \times d^3 = \sqrt{(K_m \times M)^2 + (K_t \times T)^2} \quad \ldots (3.17)$$

$$M_e = \frac{\pi}{32} \times \sigma_b \times d^3 = \frac{1}{2}\left[K_m \times M + \sqrt{(K_m \times M)^2 + (K_t \times T)^2}\right] \quad \ldots (3.18)$$

Where,

T_e = Equivalent twisting moment; N mm;

M_e = Equivalent twisting moment; N mm;

T = Torque; N mm;

M = Bending moment; N mm;

d = Diameter of shaft, mm;

τ = Allowable stress, N mm^{-2};

σ_b = Maximum tensile or compressive stress, N mm^{-2};

K_m= Combined shock and fatigue factor for bending, 1.5; and

K_t = Combined shock and fatigue factor for torsion, 1.5.

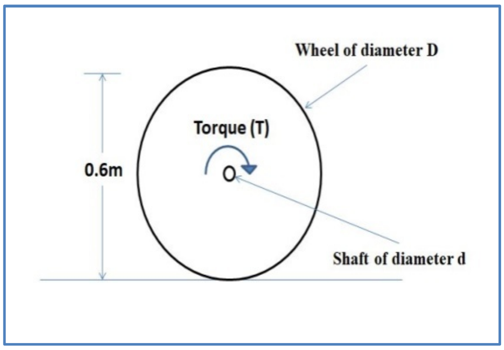


Fig. 3.28: Torque acting on wheel shaft

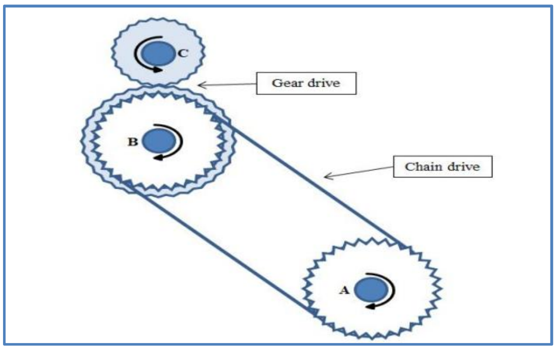


Fig. 3.29: Layout of transmission system

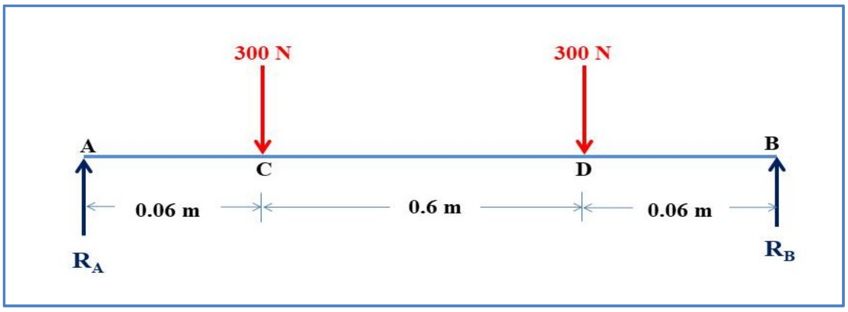


Fig. 3.30: Free body diagram of wheel shaft

Torque (T_A) acting on the wheel was already calculated i.e. 18.54 kg cm. Shaft was designed by using cost iron with tensile strength (S_{yt}) about 400 MPa (Budynas and Nisbett, 2011). Shear strength (S_{ys}) was taken $0.5 \times S_{yt}$ i.e. calculated about 200 MPa. Torsional stress and bending stress of the material was measured by taking factor of safety 2.5 with following Equation 3.19 and 3.20 (Bhandari, 2005). Concept of transmission system and free body diagram of wheel shaft of machine is shown in Fig. 3.28 to 3.29.

$$\sigma_A = \frac{S_{yt}}{2.5} \quad \text{... (3.19)}$$

$$\tau_A = \frac{S_{ys}}{2.5} \quad \text{... (3.20)}$$

$\sigma_A = \frac{S_{yt}}{2.5} = \frac{400}{2.5} = 160$ MPa = 1631.55 kg cm^{-2}

$\tau_A = \frac{S_{ys}}{2.5} = \frac{200}{2.5} = 80$ MPa = 815.77 kg cm^{-2}

Reaction force was measured by consider all forces in equilibrium condition as shown in Fig. 3.30. Then it writes as given below.

$$R_A + R_B = 300 + 300 = 600 \text{ N} \quad \text{... (3.21)}$$

Taking moment about A to measure reaction force R_B,

$M_A = 0$

$M_A = -P_1 \times 0.06 - P_2 \times 0.66 + R_B \times 0.72$

$M_A = -300 \times 0.06 - 300 \times 0.66 + R_B \times 0.72$

$R_B \times 0.72 = 216$

$R_B = 300$ N

Then, putting the value of R_B in Equation 3.21 to find out R_A,

$R_A + 300 = 600$ N

$R_A = 300$ N

Shear force at different point of frame,

$F_A = 300\ N$

$F_C = 300 - 300 = 0\ N$

$F_D = 0 - 300 = -300\ N$

$F_F = -300 + 300 = 0\ N$

Bending moment at different point of frame,

$M_B = 0$

$M_D = 300 \times 0.06 = 18\ Nm$

$M_C = 300 \times 0.66 - 300 \times 0.6 = 18\ N\ m$

$M_A = 300 \times 0.72 - 300 \times 0.66 - 300 \times .06 = 0\ Nm$

Max 18 N m = 183.55 kg cm

Bending moment diagram prepared by using Beam HPS (android software) by considering acting force on shaft is shown in Fig. 3.30.

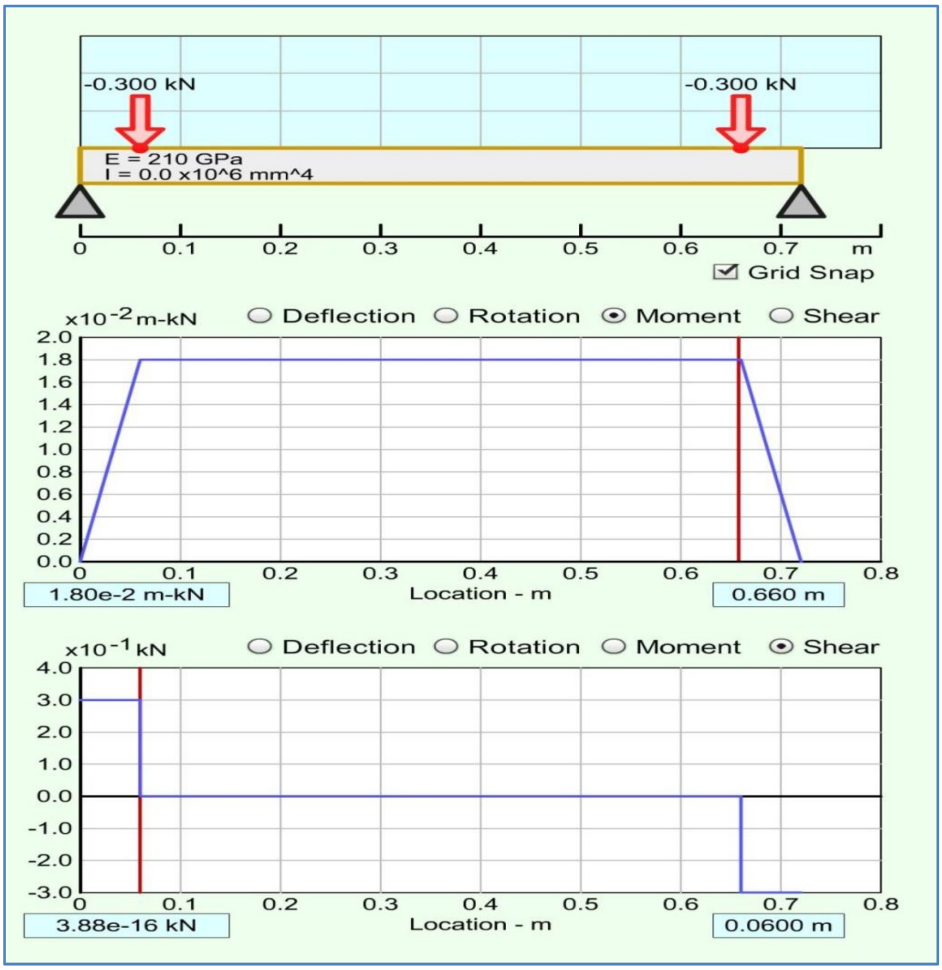


Fig. 3.31: Bending moment and shear diagram of wheel shaft

Putting the values of maximum torque 18 N m and bending moment 2.63 N m in Equation 3.17 and 3.18,

$$\frac{\pi}{16} \times 80 \times d^3 = \sqrt{(1.5 \times 18 \times 10^3)^2 + (1.5 \times 2.63 \times 10^3)^2}$$

d_a = 12.02 mm

$$\frac{\pi}{32} \times 160 \times d^3 = \frac{1}{2}\left[1.5 \times 18 \times 10^3 + \sqrt{(1.5 \times 18 \times 10^3)^2 + (1.5 \times 2.63 \times 10^3)^2}\right]$$

d_a = 11.20 mm

Shaft-B was used to transmit the power between ground wheel and conveyor shaft-C. Shaft-A and shaft-B were connected by chain drive with velocity ratio 1:1 having 17 teeth sprocket in both shafts. We know that following relationships as given in Equation 3.22.

$$\frac{2\pi N_A T_A}{60} = \frac{2\pi N_B T_B}{60} \quad \text{... (3.22)}$$

We know that $N_A = N_B$, then

$T_A = T_B$=18.54 kg cm

Only torsional stress was considered because bending stress was very small in this shaft and diameter of shaft was determined by Equation 3.23.

$$T_B = \frac{\pi}{16} \times \tau \times d_B^3 \quad \text{... (3.23)}$$

$$18.54 = \frac{\pi}{16} \times 1570.36 \times d_B^3$$

d_B = 0.39 cm

To drive the conveyor shaft-C gear drive was used having velocity ration 1.56 by taking 39 teeth gear in shaft-B and 25 teeth gear in shaft-C. Rotation of shaft-A was already measured 26.73 rpm, so $N_A = N_B$ = 26.73 rpm. Rotation of shaft-C was calculated by using following formula.

$$N_B G_B = N_C G_C \quad \text{... (3.24)}$$

$$N_C = N_B \times \frac{G_B}{G_C} = 26.73 \times \frac{39}{25} = 41.70 \text{ rpm}$$

Torque on shaft-C was measured by using relationship given in Equation 3.25,

$$\frac{2\pi N_B T_B}{60} = \frac{2\pi N_C T_C}{60} \quad \text{... (3.25)}$$

$T_C = T_B \times \frac{N_B}{N_C} = 18.54 \times \frac{26.73}{41.70} = 11.88$ kg cm

Diameter of shaft-C was measured by using Equation 3.26.

$$T_C = \frac{\pi}{16} \times \tau \times d_C^3 \quad \text{... (3.26)}$$

$$11.88 = \frac{\pi}{16} \times 1570.36 \times d_C^3$$

$d_C = 0.34$ cm

Based on availability in market and FOS shaft-A, shaft-B and shaft-C were taken of diameter 25 mm as shown in Fig. 3.32.

3.3.2.10 Chain drive

The chains are mostly used to transmit motion and power from one shaft to another, when the distance between the centers of the shafts was short for agricultural machinery. In this case bush roller chain was used to transmit power.

Distance between the shafts was 170 mm where we used two sprockets of 24 teeth, and standard chain was used of pitch 9.525 mm. as shown in Fig. 3.33. The length and numbers of links of chain was calculated by using following formula (Khurmi, 2005).

$$L = \frac{p}{2}(T_1 + T_2) + 2x + \frac{\left[\frac{p}{2}\mathrm{cosec}\left(\frac{180^\circ}{T_1}\right) - \frac{p}{2}\mathrm{cosec}\left(\frac{180^\circ}{T_2}\right)\right]^2}{x} \quad \text{... (3.27)}$$

$$k = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2\pi}\right]^2 \frac{p}{x} \quad \text{... (3.28)}$$

Where,

L = Length of chain;

k = No. of links in chain;

p = Pitch of chain;

T_2 = No. of teeth in driven sprocket;

T_1 = No. of teeth in driver sprocket; and

x = Distance between shaft.

$$L = \frac{9.525}{2}(24 + 24) + 2 \times 170 + \frac{\left[\frac{9.525}{2}\mathrm{cosec}\left(\frac{180^\circ}{24}\right) - \frac{9.525}{2}\mathrm{cosec}\left(\frac{180^\circ}{24}\right)\right]^2}{170}$$

L = 568.6 mm.

$$k = \frac{24 + 24}{2} + \frac{2 \times 170}{9.525} + \left[\frac{24 - 24}{2\pi}\right]^2 \frac{9.525}{170}$$

k = 59.70 ≈ 60 links

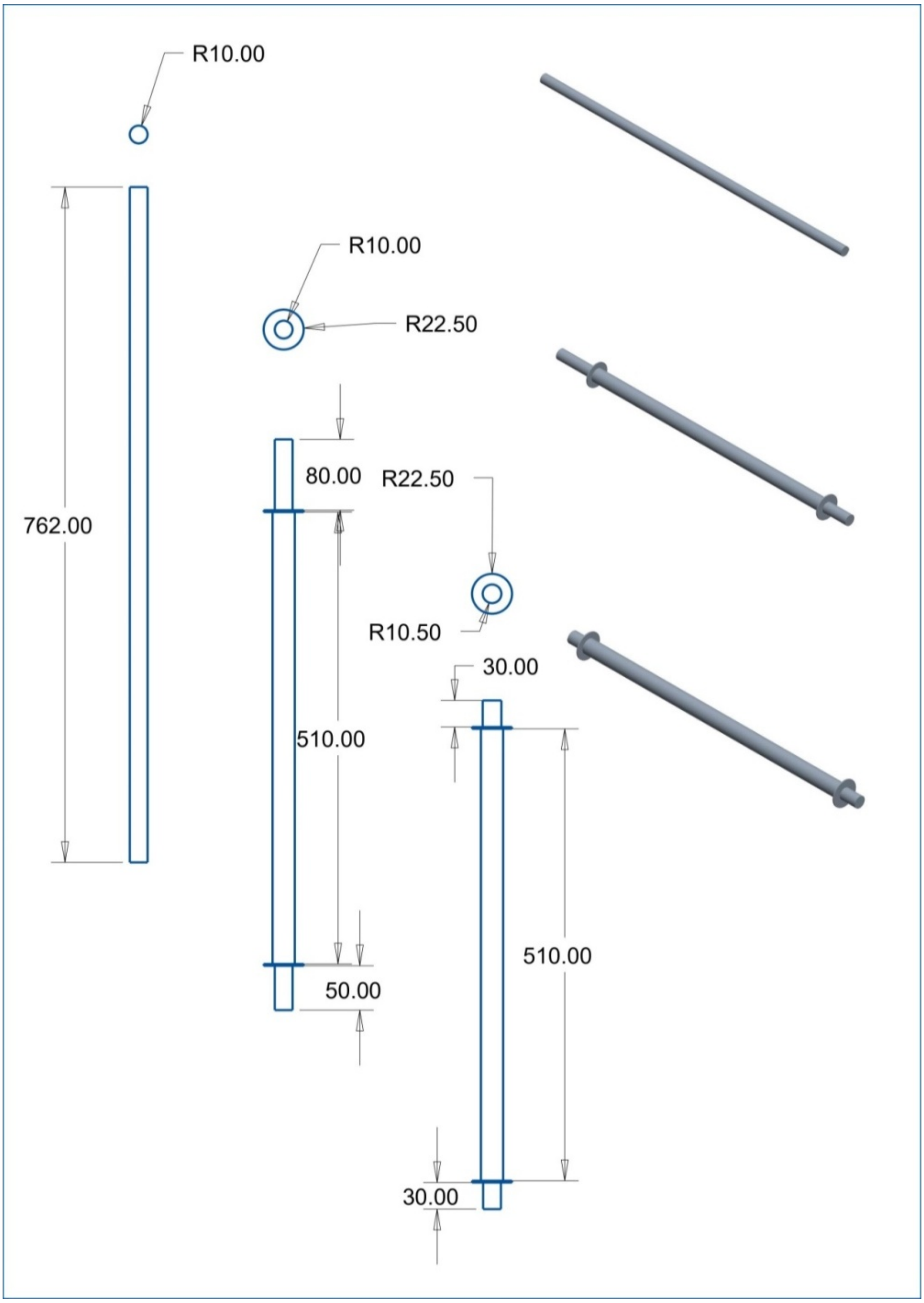


Fig. 3.32: Dimensions of all shaft used in leafy crop harvester

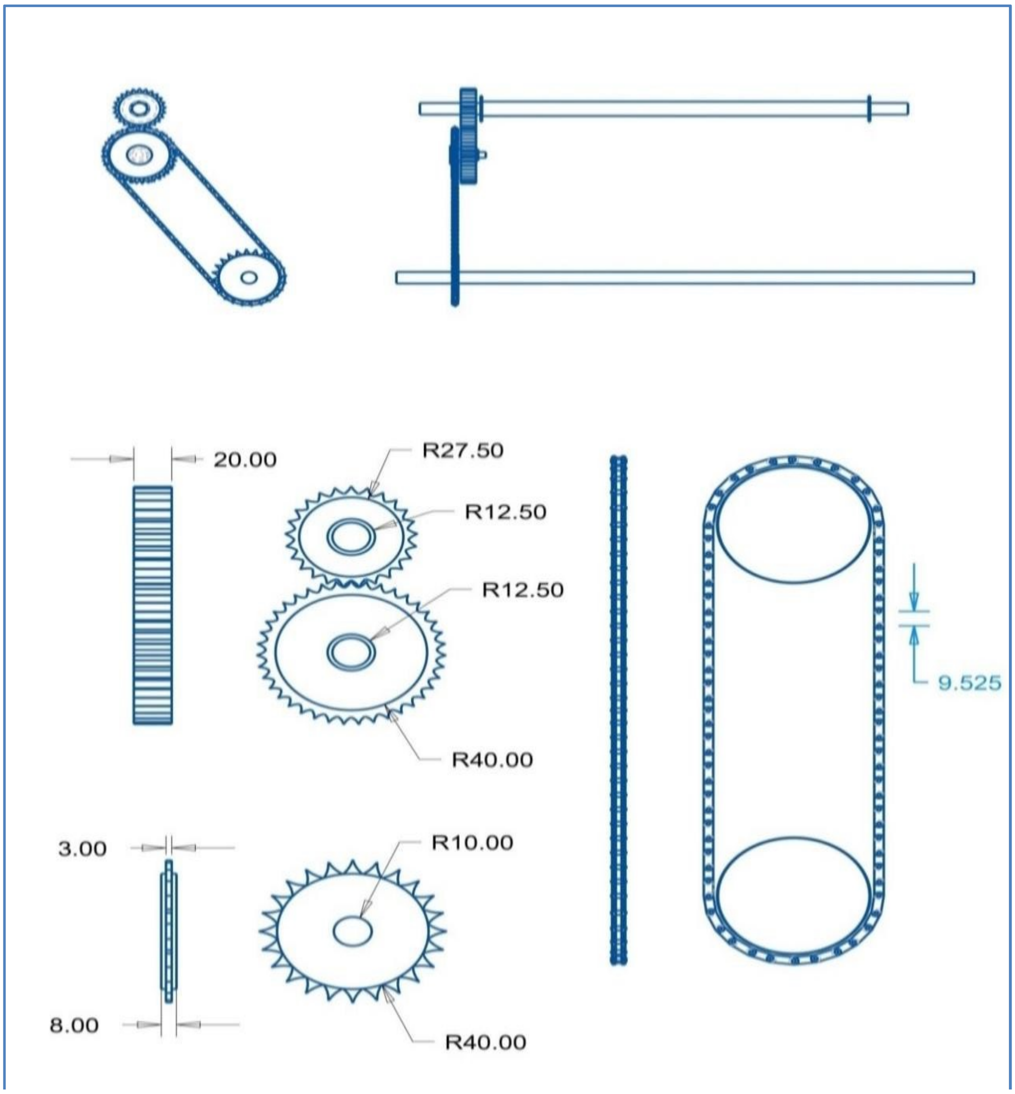


Fig. 3.33: Dimensions of chain and sprocket

3.3.2.11 Gear drive

Gear drive was used to drive the conveyor opposite to the direction of motion. It was observed that the canvas belt conveyor was working suitable at speed 15-20 mm s^{-1}. The rotary power of the conveyor was taken from the ground wheel and the rotary motion obtained was calculated by using Equation 3.29.

$$\text{Forward speed } (\text{m s}^{-1}) = \frac{\pi \times D \times N}{60} \qquad \ldots (3.29)$$

Where,

D = Diameter of wheel, m; and

N = Rotation of wheel shaft, rpm.

Forward motion and wheel diameter was assumed 0.27 m s^{-1} (1 km h^{-1}) and 0.60 m, respectively. Rotary motion of wheel shaft N_w was calculated by using Equation 3.29.

$$0.27 = \frac{\pi \times 0.6 \times N}{60}$$

N_w = 8.59 rpm

Roller of conveyor was selected of 25 mm. So the required rpm of roller (N_r) to move the conveyor at peripheral velocity 15-20 mm s^{-1} was calculated using equation 3.29.

$$\frac{15}{1000} = \frac{\pi \times 0.025 \times N}{60}$$

N_r = 11.45

Required gear ration between driver and roller shaft is calculated below,

$$\frac{N_r}{N_w} = \frac{11.45}{8.95} = \frac{1.33}{1}$$

Gear available in market of 39 teeth and 25 teeth were selected for driver and driven shaft, respectively which give the velocity ration of 1.56. So the peripheral velocity of the conveyor belt again calculated as given below.

$$\text{RPM of roller} = \text{RPM of driver shaft } (N_w) \times \text{velocity ratio}$$

RPM or roller = 8.59 × 1.59 = 13.66

Peripheral velocity of the roller calculated using equation 3.29.

$$\frac{\text{Roller peripheral velociy (mm s}^{-1})}{1000} = \frac{\pi \times .025 \times 13.66}{60}$$

Roller peripheral velocity = 17.88 mm s^{-1}

The selected gear was giving suitable peripheral speed, hence it selected for gear drive which is shown in Fig. 3.34 and bearing used is given in Fig. 3.35.

3.3.2.12 Wheel

Wheel was required to give forward motion as well as reduce the physical effort during harvesting and transporting the machine. For front side two small rubber wheels of diameter 20 cm and for rear side two steel rimed rubber tyre wheels of diameter 60 cm were selected. Conceptual drawing and selected wheels are shown in Fig. 3.36 to 3.38.

3.3.2.13 Collection unit

Collection or storage unit was mounted just behind the conveyor belt. Harvested leafy crop comes through belt conveyor and drop in this storage tank. Capacity of the tank was calculated by bulk density of leafy crop and available space for 5 kg capacity. The volume of the tank was calculated about 0.06 m^3 where weight depends on the density of the different leafy crop. Dimensions and different 3D view of storage tank is presented in Fig. 3.39.

3.3.2.14 Design of frame

It was a structural design, based on the various component and their positions on the machine. A structural frame considered to mount all the component of leafy crop harvester as shown in Fig. 3.40. Selection of material was very important to withstand the entire load during operation.

Fig. 3.34: Gear

Fig. 3.35: Bearing

Fig. 3.36: Front wheel

Fig. 3.37: Rear wheel

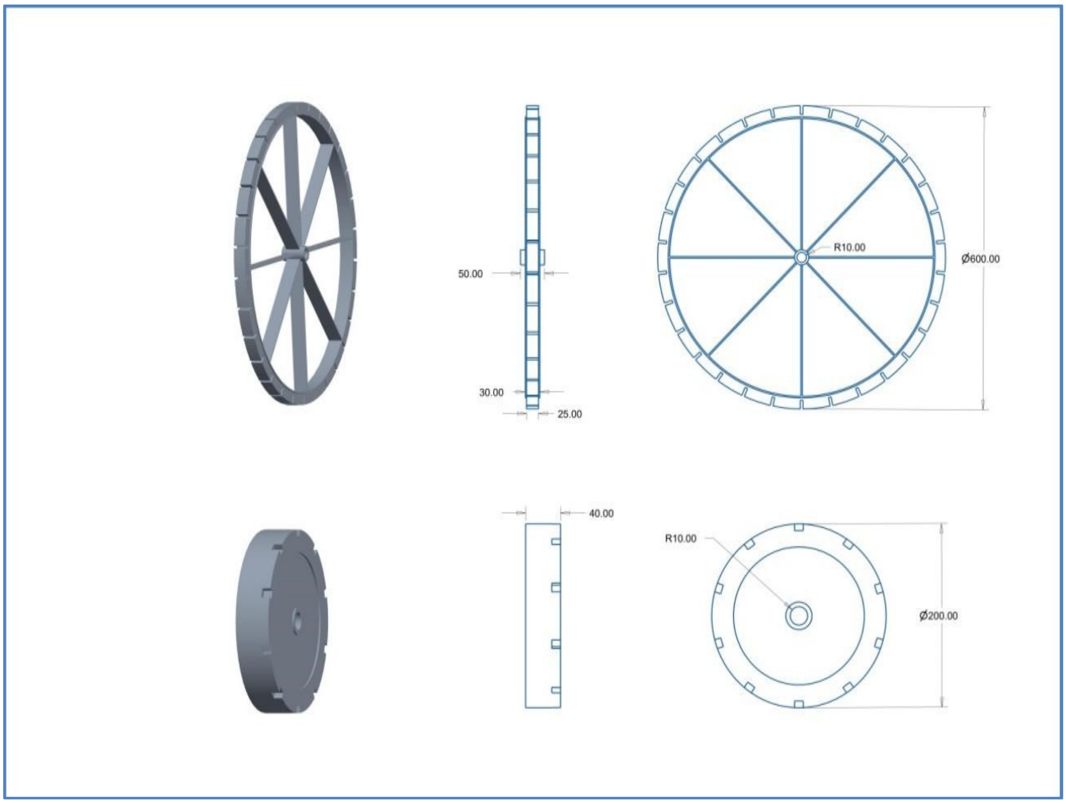


Fig. 3.38: Dimensions of front and rear wheel of leafy crop harvester

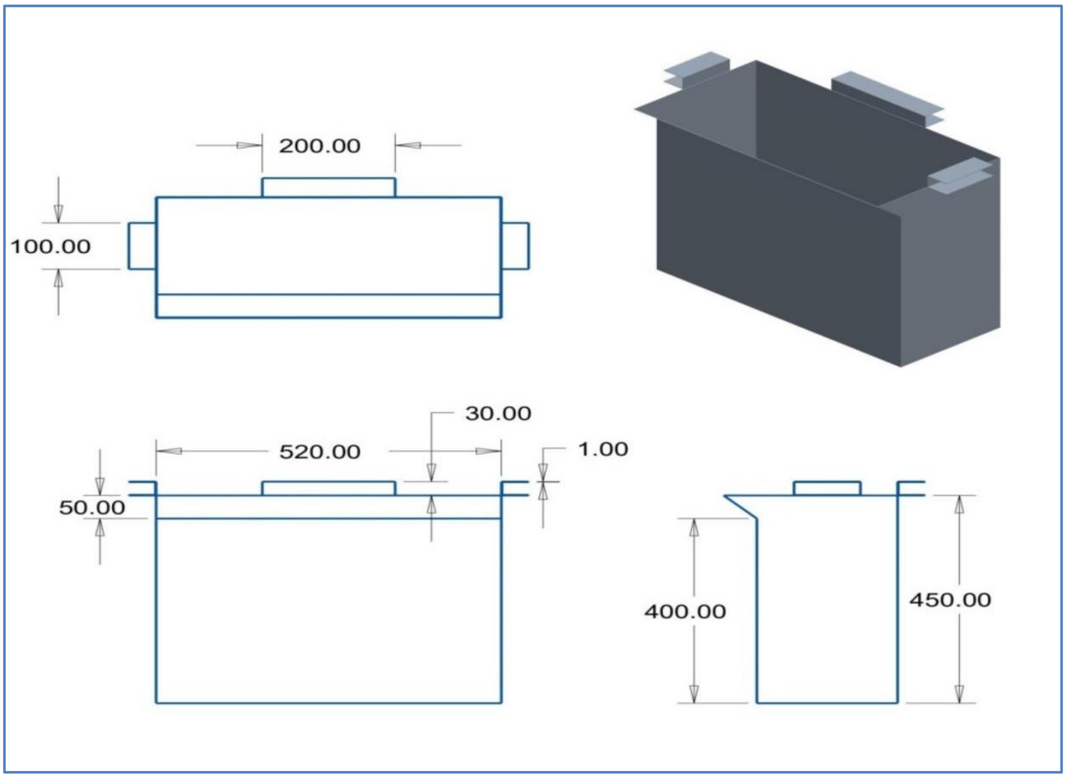


Fig. 3.39: Dimensions of storage tank of leafy crop harvester

Table 3.5: Various loads and their magnitude

Load	Parameter	Magnitude
P_1	Sum of weight of harvesting unit and conveyor shaft-1. (it was considered point load at C)	150 + 22 = 172 N
P_2	Weight of conveyor shaft-2 at D	25 N
P_3	Weight of vegetable stored in tank. (it was taken center of the storage tank as point load)	50 N
P_4	Weight of vegetable conveyor. (considered uniformly distributed over conveyor.	4 N m^{-1}

Various loads were applied in the frame. Frame was considered two dimensional and various loads i.e. P_1, P_2 and P_3 were applied at point C, D and E, respectively, where load P4 was considered uniformly distributed load applied 0.95 m length from C to D point. Reaction force R_A and R_B were considered at A and B, respectively. Magnitude of load is described in Table 3.5 and presented in Fig 3.40. All the force were taken in Newton (N) as share force and bending moment diagram was prepared by using Beam HPS (android software) as shown in Fig. 3.41.

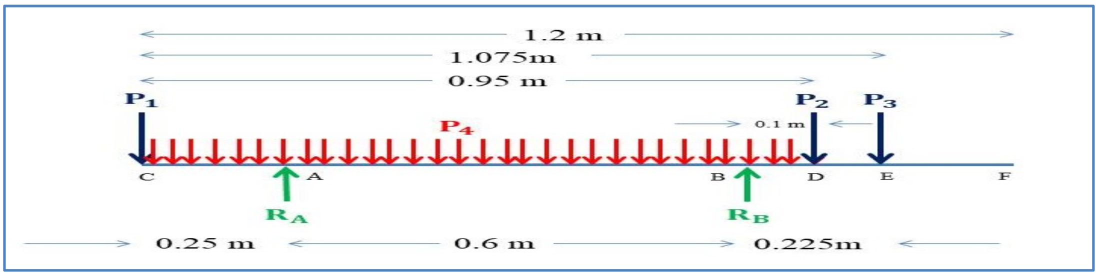


Fig. 3.40: Two dimensional free body diagram of frame with various load

Reaction force was measured by consider all forces in equilibrium condition. Then it writes as given below.

$$R_A + R_B = P_1 + P_2 + P_3 + P_4 \quad \dots(3.30)$$

$$R_A + R_B = 172 + 25 + 50 + 3.8$$

$$R_A + R_B = 250.8N \quad \dots(3.31)$$

Taking moment about A to measure reaction force R_B,

$$M_A = 0$$

$M_A = -P_1 \times 0.25 + P_4 \times 0.225 - R_B \times 0.6 + P_2 \times 0.7 + P_3 \times 0.825$

$R_B \times 0.6 = 16.61$

$R_B = 27.68$

Then, putting the value of R_B in Equation 3.30 to find out R_A

$R_A + 27.68 = 250.8$ N

$R_A = 223.16$ N

Shear force at different point of frame,

$F_C = -172$ N

$F_A = -172 - 0.25 \times 4 + 223.16 = 50.16$ N

$F_B = 50.16 - 0.6 \times 4 + 27.44 = 75.44$ N

$F_D = 75.44$ N $- 0.1 \times 4 - 25 = 50.04$ N

$F_E = 50.04 - 50 = 0.04 \approx 0$

$F_F = 0$

Bending moment at different point of frame,

$M_F = 0$

$M_E = 0$

$M_D = 0.125 \times 50 = -6.25$ Nm

$M_B = -50\ (0.125 + 0.1) - 25 \times 0.1 - 0.1 \times 4 \times 0.05 = -13.77$Nm

$$M_A = -50(0.6 + 0.1 + 0.125) - 25 \times 0.7 + 27.68 \times 0.6 - 4 \times .7 \times 0.35$$
$$= -43.12 \text{ Nm}$$

$$M_C = -50(0.95 + 0.125) - 25 \times 0.95 + 27.68(0.85) - 4 \times 0.9 \times 0.45$$
$$+ 223.16 \times 0.25 = 0$$

Maximum bending moment was determined at point A about 43.12 N m as given in Fig 3.41. To fabricate the frame 35×3 mm angle section as given in Fig 3.42 was considered and bending stress was determined by bending Equation 3.31. Bending stress was taken about xx axis of the section.

$$\frac{\sigma}{y} = \frac{M}{I} \qquad \text{... (3.32)}$$

Where,

σ = Bending stress, kg cm^{-2};

M = Bending moment, kg cm;

I = Moment of inertia of section, cm^4; and

y = Distance of neutral axis from xx axis.

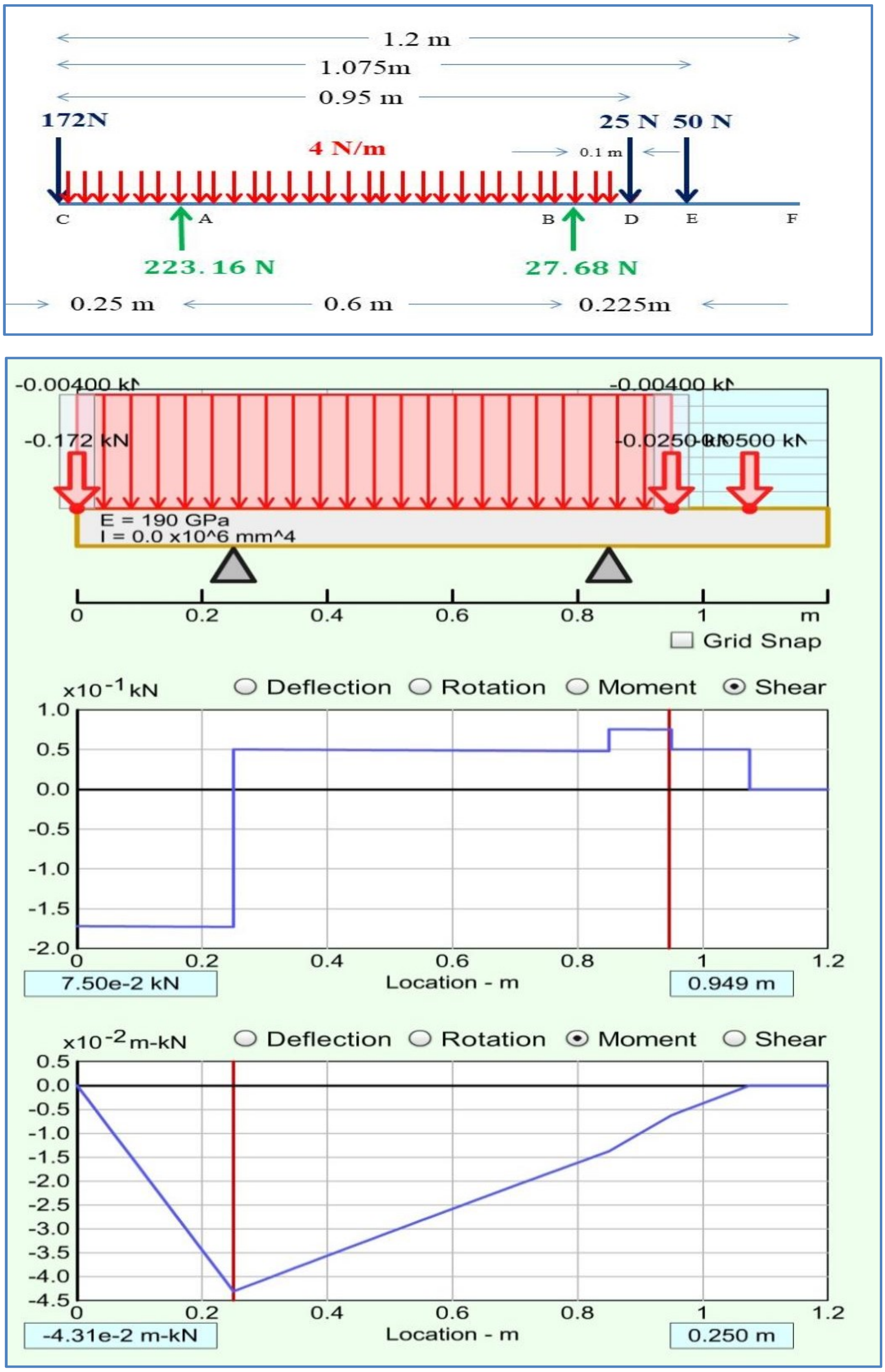


Fig. 3.41: Shear force and bending moment diagram

Units of forces and dimension were converted in kg and cm respectively.

Bending moment M = 43.12 N = 439.82 kg cm

Moment of Inertial = 23628.96 mm^4 = 2.36 cm^4

Distance of neutral axis from xx axis is evaluated using Equation 3.33 by considering L- shape angle in two sections as described below and given in Fig. 3.43 and 3.44.

$$A_1 = 35 \times 3 \qquad A_2 = 32 \times 3$$

$$y_1 = \frac{3}{2} + 32 \qquad y_2 = \frac{32}{2}$$

Then,

$$y = \frac{A_1 \times y_1 + A_2 \times y_2}{A_1 + A_2} \quad \text{... (3.33)}$$

y = 25.14 mm

y = 2.51 cm

Putting all the values in Equation 3.31 to find out the bending stress on material

$$\sigma = \frac{M \times y}{I} \quad \text{... (3.34)}$$

$$\sigma = \frac{439.82 \times 2.51}{2.36}$$

$$\sigma = 467.77 \text{ kg cm}^{-2}$$

Shear stress was observed to be 467.77 kg cm^{-2}, and then stainless steel was selected of yield tensile strength 510 MPa (5200.55 kg cm^{-2}). Then factor of safety was taken as for sufficient strength to the frame for all type of unknown factors during field operation.

Selection of material and size of frame was most important part of the machine. This was decided by considering required width of cutting and components used for operation. Main frame of the machine of dimension (1600×800×1100 mm) was fabricated by using stainless steel angle 35×35×3 mm. It consist harvesting, blowing, conveying and storage unit with handle.

Frame was fabricated by using many pieces of stainless steel angle. Stainless steel was cut two pieces length 1700 mm, two pieces of 1200 mm, 4 pieces of 600 mm, 4 pieces of 250 mm. Basic structure of frame was fabricated by joining all these pieces by weld joint. Some holes and capsule holes also made by drill machine for bearings. To mount the engine another plate was welded right corner of the frame. Attachment was made front of the frame for holding the cutting and blowing unit. Details of the frame are given in Fig 3.45.

3.3.2.15 Handle

Handle was attached behind the machine which was connected with the frame. Various anthropometric parameters were used for design of the handle. Elbow height was considered to decide the height of handle, whereas diameter of handle (35 mm) was decide based on grip diameter. Anthropometric parameter of male workers is given in Appendix-B.

3.3.2.16 Analysis of frame

To determine the magnitude of stress and strength of various loads on frame a finite element analysis test was conducted. Computer software ANSYS 2021R1 was used for finite element analysis. Static structure and fixed support is presented in Fig. 3.46 and 3.47, respectively.

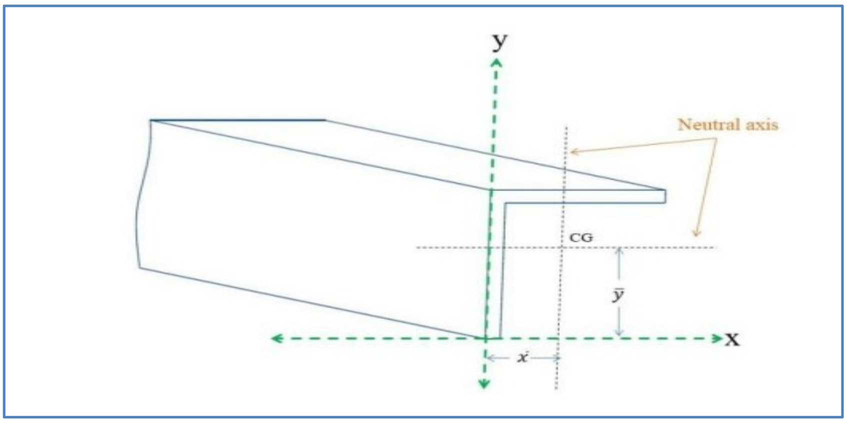


Fig. 3.42: Section of angle

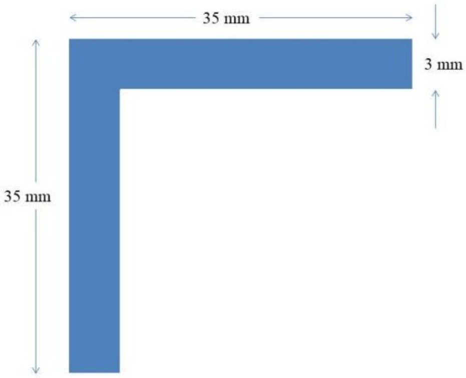


Fig. 3.43: Dimension of angle

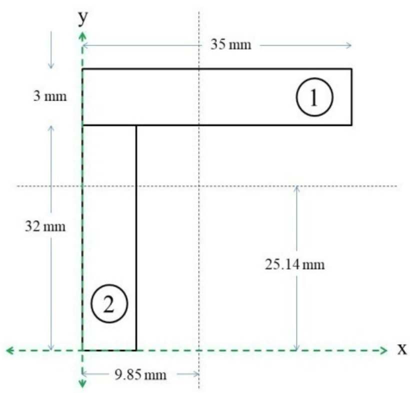


Fig. 3.44: Section of angle

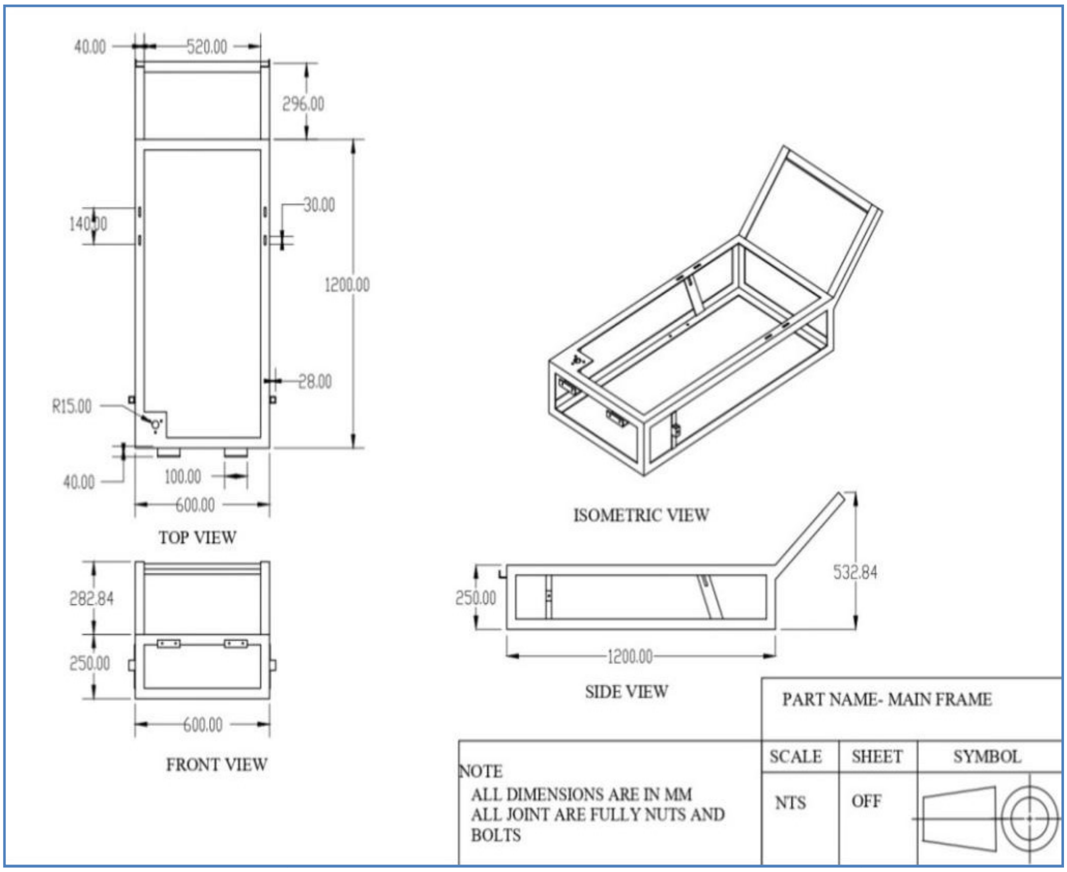


Fig. 3.45: Dimensions of leafy crop harvester frame

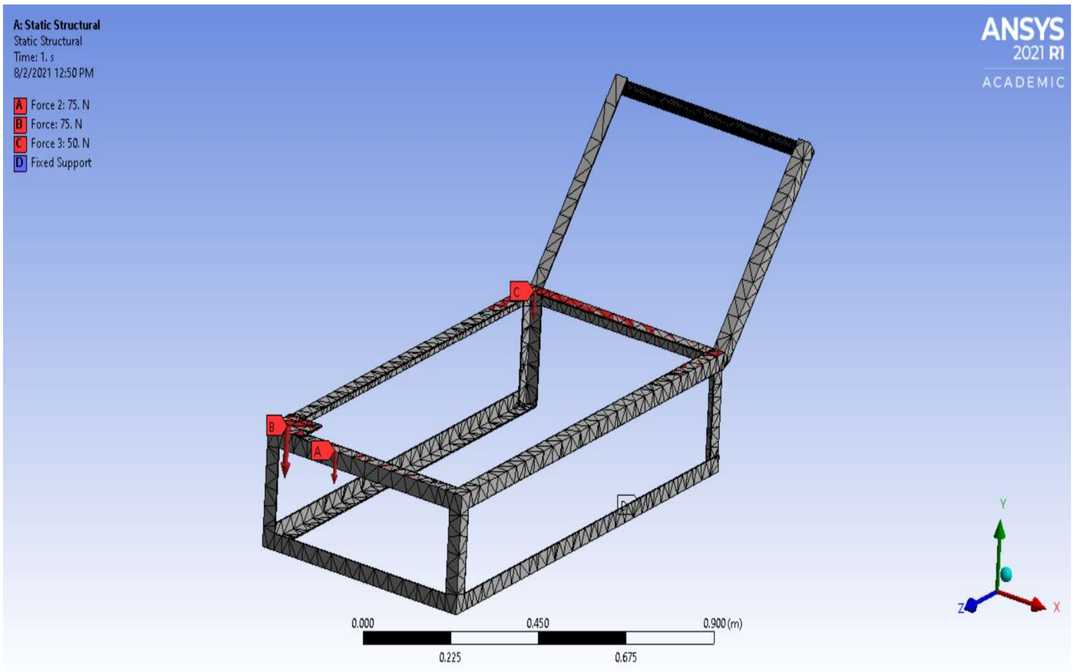


Fig. 3.46: Load on the frame at different places

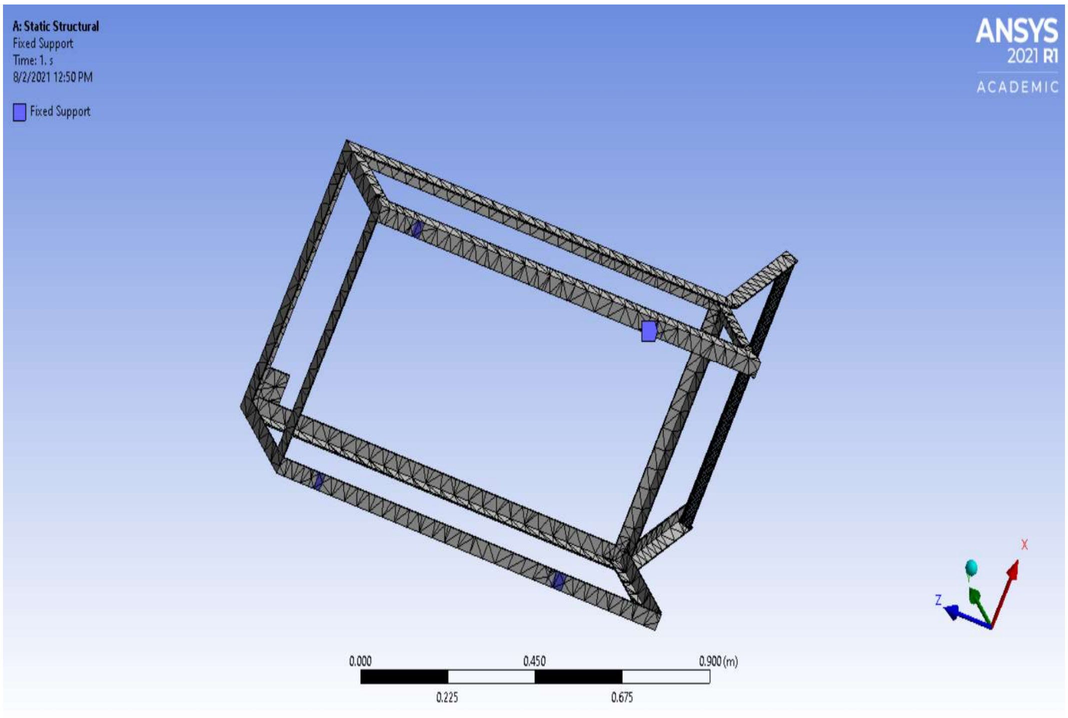


Fig. 3.47: Fixed point of frame for strength analysis

Fig. 3.48: Visual model of leafy crop harvester

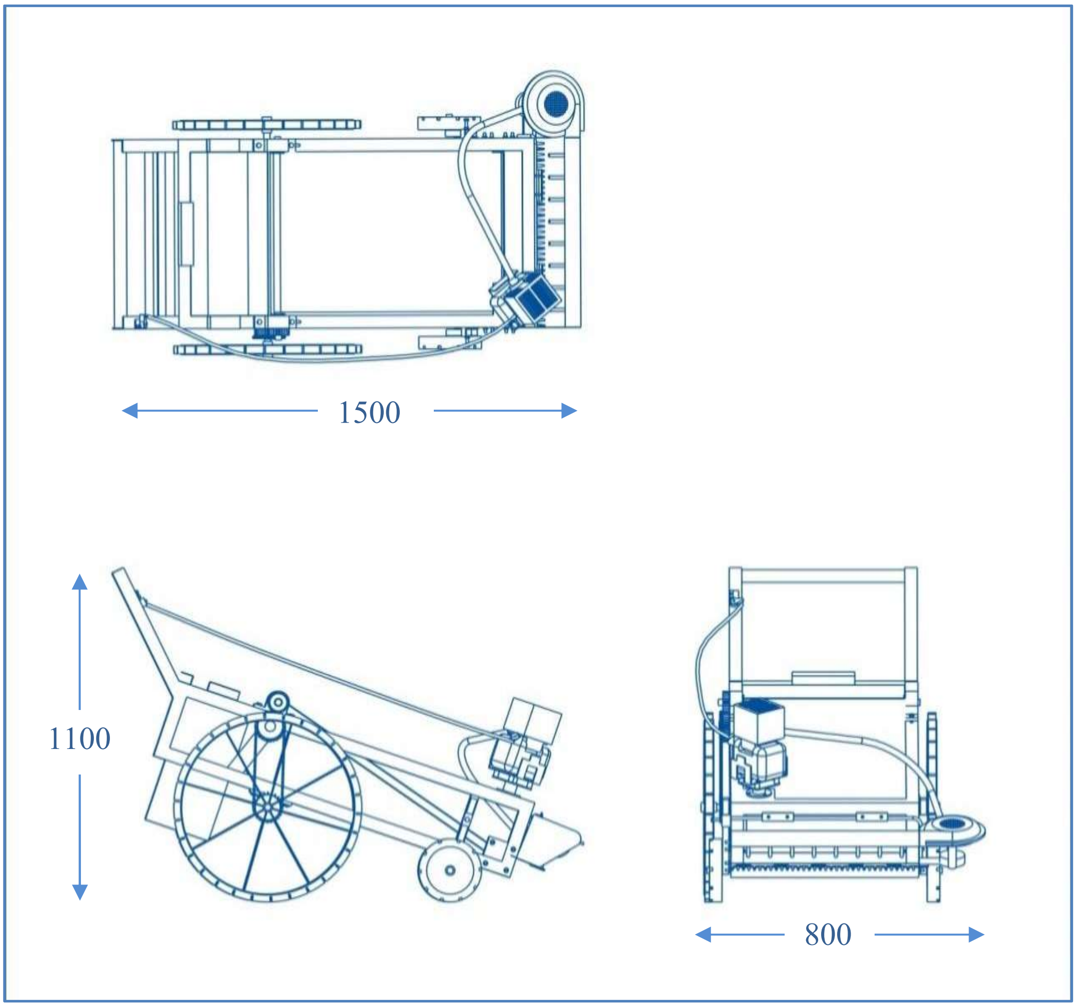


Fig. 3.49: Overall dimension of developed leafy crop harvester

3.3.3.17 Fabrication of leafy crop harvester

After design calculation and consideration of components a 3D model was developed by using CREO-Parametric 4.0 to visualize the designed leafy crop harvester as shown in Fig. 3.48 and 3.49. After creation of 3D model by attaching all the components of harvester in their desired position design of leafy crop harvester was finalized.

Leafy crop harvester was designed to reduce time consumption and drudgery involve in leafy crop harvesting. Various components of the harvester were fabricated and assembled in desired position. Fabrication of different parts is shown in Fig. 3.50 to 3.54 and specification of developed prototype leafy crop harvester is given in Table 3.6.

Fig. 3.50: Angle used for frame

Fig. 3.51: Frame of machine

Fig. 3.52: Arrangement of shaft

Fig. 3.53: Fabrication of wheel

Fig. 3.54: Fabrication of leafy crop harvester

Table 3.6: Specification of developed leafy crop harvester

S.No.	Parameters	Value
1.	Dimension	
	a. Length, mm	1500
	b. Width, mm	800
	c. Height, mm	1100
2.	Engine	1 hp
3.	Fuel	Petrol

S.No.	Parameters	Value
4.	Engine rpm	7600
5.	Frame	Stainless steel
6.	Cutting unit	
	a. Blade	Reciprocation cutter bar
	b. Rake angle	12^0
	c. Blade material	Stainless steel
	d. Transmission (engine to blade)	Throttle cable
	e. Blower	Centrifugal
	f. Nozzle in blower	8
7.	Conveying unit	
	a. Conveyor belt	Canvas
	b. Roller	Mild steel, 25 mm Φ
	c. Power	Ground wheel
	d. Transmission for conveyor	Chain drive, gear drive
	e. Chain drive	1:1
	f. Gear drive	1.5:1
	g. Conveyor velocity, mm s^{-1}	10-20
8.	Storage	
	a. Capacity, m^3	0.06
	b. Material	Aluminum sheet
9.	Wheel	
	a. Front wheel, diameter in mm	200
	b. Rear wheel, diameter in mm	600
10.	Type of machine	Manual push type

3.4 Performance Evaluation

3.4.1 Experimental study

Traditionally grown and mostly taken four types of leafy crops *viz.* chickpea, amaranthus, fenugreek and spinach in Chhattisgarh were sown in main plot of 50×50 m to evaluate the performance of developed leafy crop harvester as presented in Fig. 3.57. This machine was designed for 600 mm of width so 0.6 m bed was selected to grow the crops. Harvesting parameters were determined by taking different machine variables. Three different machine variables were selected *viz.* forward speed of operation, air velocity and cutting height denoted by S, V and H, respectively with three levels of each factors. Details of dependent and independent parameters are given in Table 3.7. Observed data were analyzed by using factorial randomized block design. Each dependent parameter was designed based on independent parameter for every crop individually.

Table 3.7: Dependent and independent parameters of experimental study

S.No.	Factors	Levels
Independent parameters		
1.	Forward speed (S)	• 0.5 km h^{-1} • 1.0 km h^{-1} • 1.5 km h^{-1}
2.	Air velocity (V)	• 3 m s^{-1} • 4 m s^{-1} • 5 m s^{-1}
3.	Cutting height (H) from ground	• 100 mm • 150 mm • 200 mm
Dependent parameters		
1.	Header loss	
2.	Conveying loss	
3.	Harvesting efficiency	

3.4.1.1 Experimental layout for testing of developed leafy crop harvester

Statistical design	: Factorial Randomized Block Design
Number of treatment	: 27 (3×3×3)
Number of replications	: 3
Total field size for each crop	: 32 m×17.2 m = 550.4 m^2
Total no. of plot	: 81
Plot size	: 10 m × 0.6 m = 6 m^2
Distance between replications	: 0.5 m
Distance between plots	: 0.5 m

3.4.2 Properties of soil at harvesting

Measurement of soil parameters like moisture content, bulk density and soil cone index were measured. Various instruments like core cutter, weighing balance, cone penetrometer and hot air oven were used for the measurement of soil parameters. The process of measurement of soil parameters are described as follow:

3.4.2.1 Moisture content

The soil moisture analysis was done by oven drying method. Randomly soil samples were collected from various places of selected field. The weight of the wet soil sample was measured by weighing balance. The soil sample was put in hot air oven at 105°C for 24 hours and then the weight of dry sample was measured. Moisture content was measured by using following Equation 3.35:

$$\text{Moisture content (\%)} = \frac{w_1 - w_2}{w_2} \quad \text{... (3.35)}$$

Where,

w_1 = Initial weight of soil sample, g; and

w_2 = Dry weight of soil sample, g.

3.4.2.2 Bulk density

Bulk density of soil is the ratio of mass and volume of soil. The bulk density was determined after the operation using core cutter and hammer. The diameter and length of the core cutter was 10 cm and 13.5 cm, respectively. Soil samples were collected from each experimental plot and weighted. The samples for drying were placed in an oven at 105° C for 24 hours. The dried samples re-weighted in an electrical balance meter having maximum capacity to weight 5 kg and the difference was recorded. Measurement of bulk density with core cutter and hammer was shown in Fig 3.55 and 3.56. Bulk density was calculated by using following Equation 3.36.

$$\text{Bulk density} = \frac{\text{Mass of soil sample}}{\text{Volume of core cutter}} \quad \text{... (3.36)}$$

$$\rho_b = \frac{M}{\pi D^2 L} \quad \text{... (3.36a)}$$

Where,

ρ_b = Bulk density, g cm^{-3};

M = Mass contained in soil sample of oven dry soil, g;

V = Volume of cylinder sampler, cm^3;

D = Diameter of cylinder sampler, cm and

L = Height of cylinder sampler, cm.

3.4.2.3 Cone Index

To determine cone index, a cone penetrometer (model BL, 250 EC, Baker Mercer type C10, LC = 0.002 mm), having 2.618 cm diameter of cone base with cone angle of 20°. Cone penetrometer was calibrated with known weights and the relationship between applied load and dial gauge deflection was established (Bhadoria, 1995) shown in Equation 3.37. The cone penetrometer resistance (CPR) per unit area (cm^2) was determined by the following relationship:

$$\text{CPR} = 0.648 + 0.025X, \text{kg cm}^{-2} \quad \dots (3.37)$$

Where,

X = Dial gauge deflection, small divisions.

3.4.3 Comparison with other harvesting methods

Different existing harvesting methods were compared with the developed leafy crop harvester. Selected harvesting methods were manual hand picking, manual harvesting with sickle, harvested with battery operated leafy harvester and developed leafy crop harvester, which are presented in Fig. 3.59 to Fig. 3.62. Detail specification of battery operated leafy harvester is given in Table 3.8. Randomized block design was used to compare these four harvesting methods as given in Fig. 3.58 with 5 replications of each. Each treatment was determined for every selected crop individually.

Fig. 3.55: Using core cutter for bulk density of soil

Fig. 3.56: Removing core from the soil

Details of experiment are given below:

T1 = Manual hand picking;

T2 = Manual harvesting with sickle;

T3 = Battery operated leafy harvester; and

T4 = Developed leafy crop harvester.

3.4.3.1 Experiment layout for comparative evaluation of harvesting methods

Statistical design	: Randomized Block Design
Number of treatment	: 4
Number of replications	: 5
Net plot size	: 50 m × 50 m
Total number of plots	: 20
Distance between two replications	: 0.5 m
Distance between two plots	: 0.5 m

Data obtained at different stages were analyze by using OPSTAT package develoed by O.P. Sheoran Programmer, Computer Section, CCS HAU, Hisar.

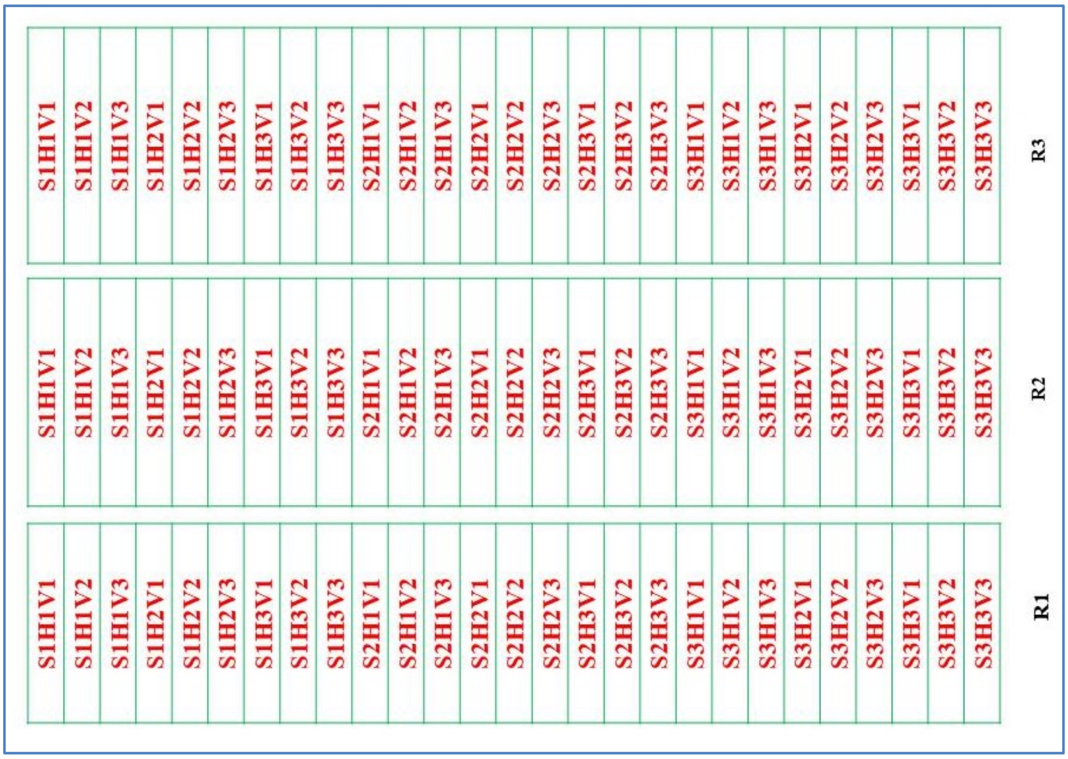


Fig. 3.57: Layout of plan for testing of developed leafy crop harvester

R1T1	**R1T2**	**R1T3**	**R1T4**	**R5T1**
R2T1	**R2T2**	**R2T3**	**R2T4**	**R5T2**
R3T1	**R3T2**	**R3T3**	**R3T4**	**R5T3**
R4T1	**R4T2**	**R4T3**	**R4T4**	**R5T4**

Fig. 3.58: Layout plan for comparative evaluation

Fig. 3.59: Manual plucking

Fig. 3.60: Sickle

Fig. 3.61: Battery operated tea leaf harvester

Fig. 3.62: Developed leafy crop harvester

Table 3.8: Specification of battery operated leaf harvester

S.No.	Parameters	Values
1.	Length of blade	300 mm
2.	Working efficiency	Greater than 30 kg h^{-1}
3.	Machine net weight	2.1 kg
4.	Motor rated power	60 W
5.	Battery	Lead acid battery 24V DC 8AH
6.	Running time	3-5 h after full charge

3.4.4 Field preparation and sowing

Experiment was conducted in the field of IGKV, Raipur (C.G.). Field was prepared to evaluate the performance of developed leafy crop harvester and also for comparative evaluation. Field preparation and sowing of seeds are represented in Fig. 3.63 to 3.68. Different harvesting methods performing in the field is shown in Fig. 3.69 to 3.71.

3.4.5 Harvesting parameters

3.4.5.1 Header loss

It was the remaining non harvested crop in field after passing of machine and determined by using Equation 3.38. Header loss was observed basis of weight of crop obtained from each plot and represented in t ha^{-1}.

$$\text{Header loss, \%} = \frac{\text{Weight of non harvested crop}}{\text{Totat weight of crop}} \times 100 \qquad \ldots (3.38)$$

3.4.5.2 Conveying loss

Conveying loss was the harvested crop left in the field after machine operation. It was determined by using Equation 3.39.

$$\text{Conveying loss, \%} = \frac{\text{Weight of harvested crop left in the field}}{\text{Totat weight of crop}} \times 100 \quad \ldots (3.39)$$

3.4.5.3 Harvesting efficiency

Total weight of crop obtained from the field was considered 100%, harvesting efficiency was determined by subtracting header loss (%) and conveying loss (%) from the 100% as presented in Equation 3.40.

$$\text{Harvesting efficiency, \%} = 100 - \text{header loss (\%)} - \text{Conveying loss (\%)} \qquad \ldots (3.40)$$

3.4.6 Machine parameters

3.4.6.1 Theoretical field capacity

Theoretical field capacity was determined by speed of the machine and effective width of the implement. The formula used is given below in Equation 3.41.

$$TFC = \frac{S \times W}{10} \qquad ... (3.41)$$

Where,

TFC = Theoretical field capacity, ha h^{-1};

W_e = Effective width of machine, m; and

S = Speed of operation, km h^{-1}.

3.4.6.2 Actual field capacity

The actual covered area during operation was called actual or effective field capacity and it was calculated by using Equation 3.42. In this term we consider the useful time and time loss for turning the machine.

$$EFC = \frac{A}{T} \qquad ... (3.42)$$

Where,

EFC. = Effective field capacity, ha h^{-1};

A = Area covered, ha; and

T = Productive time, h.

3.4.6.3 Field efficiency

Field efficiency is the ratio of effective field capacity to theoretical field capacity. The following Equation 3.43 was used to determine field efficiency.

$$FE = \frac{EFC}{TFC} \times 100 \qquad .... (3.43)$$

Where,

FE = Field efficiency, %;

EFC = Effective field capacity, ha h^{-1}; and

TFC = Theoretical field capacity, ha h^{-1}.

3.4.6.4 Forward speed

Two poles were placed at 10 m distance and harvester operates between them and the crossing time between these two poles was measured. The forward speed of operation calculated by observing the distance traveled and time taken for covering these two poles, by using following Equation 3.44 (Baineri *et al.*, 1956).

$$S = \frac{L}{t} \quad \text{... (3.44)}$$

Where,

S = Forward speed of machine, m s^{-1};

L = Distance travelled, m; and

t = Time taken, s.

Fig. 3.63: Seeds for sowing

Fig. 3.64: Prepared field

Fig. 3.65: Sowing in plot-1

Fig. 3.66: Sowing in plot-2

Fig. 3.67: Leafy crop plot-1

Fig. 3.68: Leafy crop plot-2

Fig. 3.69: Harvesting of leafy crop by developed leafy crop harvester

Fig. 3.70: Harvesting of leafy crop by tea leaf plucker

Fig. 3.71: Harvesting of leafy crop by manual method

3.4.6.5 Fuel consumption

Petrol was used to operate the engine of the developed leafy crop harvester. It was essential to calculate the fuel consumption. Top fill method was used to measure the fuel consumption of the machine and expressed in l h^{-1}. The Equation 3.45 was used for measuring the fuel consumption (FC).

$$\mathrm{FC} = \frac{\text{Amount of fuel required for operatoin (lit)}}{\text{Time of operation (h)}} \qquad \ldots (3.45)$$

3.4.7 Instruments

For measurement during the field operation many instruments are used. The instruments used for evaluation are measuring tape, stopwatch, tachometer, quadrat, weighing machine, weight balance, cone penetrometer, core cutter, friction measurement instruments, digital moisture meter for plant, soil survey instrument, vernier calipers, texture analyzer and anemometer. Details of all the instruments are given in Appendix-G.

3.5 Cost Analysis

Cost of operation depends on all the treatments basis of fabrication cost of implements, maintenance and labour cost. The operational cost of developed leafy crop harvester was divided into fixed and variable cost. Fixed cost was independent of operational use and cost of operation was increase/decreases with the variable cost (Kamboj *et al.* 2012). The depreciation, interest on the capital cost, shelter, insurance and taxes were taken under fixed cost and variable cost include fuel, lubricants, repair-maintenance cost and wages of labour. Details and calculation involved in cost analysis and energy is described in Appendix-F.

3.5.1 Fixed cost

a. Depreciation:

This cost reflects the reduction in value of a machine with use (wear) and time (obsolescence). It is the loss of value of a machine with the passing of time and calculated by the formula (IS 9164: 1979)

$$\mathrm{D} = \frac{\mathrm{C} - \mathrm{S}}{\mathrm{L} \times \mathrm{H}} \qquad \ldots (3.46)$$

Where,

D = Depreciation per hour;

C = Initial cost of implement, Rs;

S = Salvage value @ 10 % of C, Rs.

L = Working life of machine in years; and

H = Number of working hours per year;

b. **Interest:**

Interest was calculated on the average investment of the machine, taking into consideration the value of the machine in first and last year (IS 9164: 1979)

$$I = \frac{(C + S)}{2} \times \frac{i}{H} \qquad \ldots (3.47)$$

Where,

I = Interest per hour; and

i = 10% per year;

c. H**ousing cost**

Housing cost was calculated on the basis of the prevailing rate of the locality and generally taken as 1% of the initial cost of the machine per year. (IS 9164: 1979)

$$HC = \frac{C}{H} \times \frac{1}{100} \qquad \ldots (3.48)$$

Therefore,

$$\text{Total fixed cost} = \text{Depreciation} + \text{interest} + \text{housing} \qquad \ldots (3.49)$$

3.5.2 Variable cost

The variable costs are those cost which incurred due to operation of the machine

a. Repair maintenance cost

Cost of repairs and maintenance varies between 5 to 10% of the initial cost of the machine per year. (IS 9164: 1979)

b. Labour wages

Wages of labour was calculated on the basis of actual wages of the worker in present time. (IS 9164: 1979)

$$\text{Labour cost} = \text{Number of worker} \times \text{wage per hour} \qquad \ldots (3.50)$$

c. Fuel cont

Fuel cost was calculated by multiplied the market price of petrol to the fuel consumed during operation.

d. Lubrication cost

Lubrication cost was taken 20% of the fuel cost.

e. Total variable cost

Total variable cost is calculated by adding all variable cost occurred by above and it is calculated as follows:

$$\begin{aligned} \textit{Total variable cost} \\ &= \textit{Repair and maintenance cost} + \textit{labour wages} \\ &+ \textit{fuel cost} + \textit{lubrication cost} \qquad \ldots (3.51) \end{aligned}$$

3.5.3 Total cost of operation

The total cost of operation was calculated by adding both fixed cost as well as variable cost per hour.

$$\text{Total cost (TC)} = \text{Total fixed cost} + \text{total variable cost} \qquad \ldots (3.52)$$

3.5.4 Breakeven point

Breakeven point was the minimum operational time per year of machine to get profit and was determined by using Equation 3.53.

$$\text{BEP} = \frac{\text{FC}}{\text{CH} - \text{C}} \qquad \ldots (3.53)$$

Where,

BEP = Breakeven point, h y^{-1};

FC = Annual fixed cost, ₹ y^{-1};

C = Operating cost, ₹ h^{-1}; and

CH = Custom hiring charges, ₹ h^{-1}.

= (C + 25 per cent over head) + 25 per cent profit over new cost

3.5.5 Payback period

To know the time required to get back the investing, payback period was determined for developed leafy crop harvester by using Equation 3.54 to 3.56 (Reddy *et al.*, 2003).

$$\text{BP} = \frac{\text{IC}}{\text{ANP}} \qquad \dots (3.54)$$

Where,

PBP = Payback period, year;

IC = Initial cost of machine, ₹;

ANP = Average net annual profit, ₹ y^{-1}.

$$\text{ANP} = (\text{CH} - \text{C}) \text{x AU} \qquad \dots (3.55)$$

$$\text{AU} = \text{AA x EC} \qquad \dots (3.56)$$

Where,

CH = Custom hiring charges, ₹ h^{-1};

AA = Average annual use, h y^{-1}, and;

EC = Effective capacity of machine, ha h^{-1}.

CHAPTER-IV
RESULTS AND DISCUSSIONS

The present chapter deals with the results obtain in the proposed study on design, development and evaluation of leafy crop harvester. The biometric properties of leafy crop, its engineering properties were studied and presented in this chapter. It also includes various finding during design, development and performance evaluation of leafy crop harvester. The prototype of leafy crop harvester was fabricated in the workshop Department of Farm Machinery and Power Engineering, SV College of Agricultural Engineering and Technology & Research Station, IGKV, Raipur (C.G.) and tested in the central research farm, IGKV Raipur.

4.1 Biometric Properties of Leafy Crop

A field survey was conducted before designing of the machine to collect information about different leafy crops and their cultivation methods. Purposive survey was conducted at various farmers field to know the adopting practices for harvesting methods in different leafy crop cultivation. Some vegetables *viz.* chickpea, amaranthus, fenugreek and spinach have major contribution in leafy vegetables in Chhattisgarh, hence these four were considered in study. The biometrics properties of different leafy crop *viz.* chickpea, amaranthus, fenugreek and spinach were measured and are presented in subsequent sections.

4.1.1 Chickpea

Chickpea is one of the major leafy vegetable consumed in Chhattisgarh. Various types of biometric properties of chickpea are presented in Table 3.1. The row spacing and plant spacing between the plants were observed to be 30- 50 cm and 10-20 cm, respectively. Generally 2-3 harvesting was done for the chickpea leaves. In the purposive survey it was obtained that different crop parameter like row spacing, plant spacing, numbers of branches, plant population were measured about 29.80±0.73 cm, 11.20±0.73 cm, 15.80±1.69 and 42±1.39, respectively. Other parameters like number of stems per plant and diameter of stems were measured at five stages i.e. 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting. The height of plant was measured 12.50±0.55 cm, 16.96±0.88 cm, 25.12±1.25 cm, 25.38±0.59 cm and 25.60±1.09 cm at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting, respectively. The average stem diameter at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting were measured to be 2.43±0.23, 3.30±0.24, 4.18±0.29, 6.21±0.64 and 7.82±0.19, respectively.

4.1.2 Amaranthus

All biometric properties of red amaranthus are presented in Table 4.1. The row spacing between the plants was observed to be 15.38 cm. Generally 2-3 harvesting were required for the red amaranthus. Different crop parameters were row spacing, plant spacing, number of branches, plant population were measured to 15.38±0.606 cm, 5.24±0.45 cm, 11.20±1.14 and 78.20±13.56, respectively. Other parameters like number of stems per plant and diameter of stems were measured at five stages i.e. 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting. The height of plant was measured 11.38±0.66 cm, 22.33±0.70 cm, 32.57±0.79 cm, 25.39±1.41 cm and 26.48±1.54 cm at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting, respectively. The average stem diameter at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting were measured to be 2.31±0.61, 3.08±0.12, 2.47±0.51, 7.81±0.37 and 8.12±0.61, respectively.

4.1.3 Fenugreek

The biometric properties of fenugreek are presented in Table 4.1. The row spacing and plant spacing between the plants was observed to be 15 cm and 10 cm respectively. Generally 2-3 harvesting were required for the fenugreek leaves. Different crop parameters *viz.* row spacing, plant spacing, number of branches and plant population was measured to be 15.08±0.47 cm, 10.40±0.54 cm, 16.63±0.57 and 62.40±1.82, respectively.

Table 4.1: Biometric parameters of different leafy vegetable crops

S. No.	Parameters	Chickpea	Amaranthus	Fenugreek	Spinach
1.	Variety	JG 74	Arka Samraksha	Rajendra Kanti	Arka Anupama
2.	Sowing method	Line sowing	Broadcasting on check basin	Line sowing	Broadcasting on bed
3.	Spacing				
	Row spacing, cm	29.80±0.73	15.38±0.60	15.08±0.47	10.31±0.57
	Plant spacing, cm	11.20±0.73	5.24±0.45	10.40±054	5.44±0.50
4.	No. of stems per plant				
a)	10 DAS, cm	12.50±0.55	11.38±0.66	11.67±1.11	7.87±0.75
b)	20 DAS, cm	16.96±0.88	22.33±0.70	23.22±1.72	11.07±0.54
c)	30 DAS, cm	25.12±1.25	32.57±0.79	36.24±1.31	15.94±1.04
d)	10 days after 1st harvesting, cm	25.38±0.59	25.39±1.41	27.34±1.12	-
e)	10 days after 2nd harvesting, cm	25.60±1.09	26.48±1.54	27.07±1.50	-
5.	Diameter of stem				
a)	10 DAS, mm	2.43±0.23	2.31±0.16	2.91±0.69	2.69±0.26
b)	20 DAS, mm	3.30±0.24	3.08±0.12	4.25±0.78	3.67±0.35
c)	30 DAS, mm	4.18±0.29	2.47±0.51	5.51±0.83	5.35±0.62
d)	10 days after 1st harvesting, mm	6.21±0.64	7.81±0.37	6.46±0.45	-
e)	10 days after 2nd harvesting, mm	7.82±0.19	8.12±0.61	7.94±0.37	-
6.	Number of branches	15.80±1.69	11.20±1.14	16.63±0.57	17.40±1.00
7.	Plant population	42±1.39	78.20±13.56	62.40±1.82	185±10.15
8.	Time of harvesting	2-3	3-5	3-5	2-3
9.	Temperature of soil, °C	37±2.48	38.60±1.33	38.80±0.73	38.40±1.82
10.	pH of soil	6.82±0.21	6.68±0.31	6.88±0.23	6.72±0.38

Other parameters like number of stems per plant and diameter of stems were measured at five stages i.e. 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting. The number of stems per plant was measured 11.67±1.11 cm, 23.22±1.72 cm, 36.24±1.31 cm, 27.34±1.12 cm and 27.07±1.50 cm at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting, respectively. The average stem diameter at 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting were measured to be 2.91±0.69, 4.25±0.78, 5.51±0.83, 6.46±0.45 and 7.94±0.37, respectively.

4.1.4 Spinach

Spinach crop biometric properties are presented in Table 4.1. The row spacing and plant spacing between the plants was observed to be 300 mm and 100 mm respectively. Generally 2-3 harvesting were required for the spinach leaves. Different crop parameters like row spacing, plant spacing, number of branches and plant populations were measured to be 10.31±0.57 cm, 5.44±0.50 cm, 17.40±1.00 and 185±10.15, respectively.

Other parameters like number of stems per plant and diameter of stems were measured at five stages i.e. 10 DAS, 20 DAS and 30 DAS, 10 days after first harvesting and 10 days after second harvesting. The height of plant was measured 7.87±0.75 cm, 11.07±0.54 cm and 15.94±1.04 cm at 10 DAS, 20 DAS and 30 DAS, respectively. The average stem diameter at 10 DAS, 20 DAS and 30 DAS were measured to be 2.69±0.26, 3.67±0.35 and 5.35±0.62, respectively.

4.2 Properties of Leaves of Leafy Crop

Engineering properties of leaves of leafy crop were also measured to know the behavior of leaves. These include measurement of bulk density, terminal velocity, angle of repose, coefficient of friction and crushing resistance of the leaves, which are presented below.

4.2.1 Bulk density of leafy crop

Bulk density of the leaves was measured by weighing the known volume of leaves with the help of weighing balance. The average bulk density of the leaves of leafy crop chickpea, green amaranthus, red amaranthus, fenugreek and spinach were measured to be 74.48, 75.65, 73.73, 67.25 and 65.45 kg m^{-3}, respectively as given in Table 4.2. The parameter is used to decide the volume of storage tank.

4.2.2 Terminal velocity of leafy crop

Terminal velocity of the leafy crops was measured using suspension velocity method. The sample of leafy crop was taken to predetermined weight of 30 g used to measure the terminal velocity. Terminal velocity of leaves of different leafy crop was measured depicted in Table 4.2. The terminal velocity was observed to be 1.34±0.06 m s^{-1} for fenugreek. Terminal velocities of the leafy crops were mainly affected due to different size and moisture content. Similar results were also reported by Zewdu, 2007. Terminal velocity of crop is further used for designing of the blower of the machine.

4.2.3 Angle of repose of leafy crop

Angle of repose of the leafy crop was measured by using the free fall method. It would be used to decide the angle of conveyor of prototype of leafy crop harvester. The minimum angle of repose found for spinach leaves was to be 44.45±1.00° as presented in Table 4.2. Similar results were obtained by Kushwaha *et al.*, 2015.

4.2.4 Crushing resistance of leafy crop

A time-domain image was obtained by the semi-automatic texture analyzer and its supporting software. The mean maximum force required to deform the different leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach was measured to be 1.24, 1.25, 1.32, 1.34 and 1.20 N, respectively as presented in Table 4.2.

4.2.5 Coefficient of friction of leafy crop

Coefficient of friction of leaves of different leafy crop was observed by using the inclined plate method. This property of leave would be used for the selection of conveyor material for leafy crop harvester. Minimum coefficient of friction for different material was observed to be 0.65, 0.62, 0.61 and 0.51 for green amaranthus leafy crops for canvas, cotton, rubber and mild steel material, respectively as presented in Table 4.3. Coefficient of friction for canvas material was measured to be 0.79, 0.65, 0.77, 0.69 and 0.68 for chickpea, green amaranthus, red amaranthus, fenugreek and spinach leafy crops, respectively. It was observed that coefficient of the friction was maximum for canvas than any other materials for all the selected leafy crops. Hence, it was selected for the conveying system from cutting unit to the storage unit in developed machine.

Table 4.2: Engineering properties of leafy crops

Leafy crop	Bulk density, kg m^{-3}	Terminal velocity, m s^{-1}	Angle of repose, °	Rupture force, N
Chickpea	74.48±2.88	1.20±0.06	46.16±0.57	1.24±0.07
Green amaranthus	75.65±2.81	1.24±0.07	46.35±1.36	1.25±0.05
Red amaranthus	73.73±2.14	1.25±0.05	45.00±1.66	1.32±0.04
Fenugreek	67.15±2.06	1.34±0.06	45.46±2.05	1.34±0.06
Spinach	65.45±1.63	1.32±0.04	44.45±1.00	1.20±0.06

Table 4.3: Coefficient of friction of leafy vegetable crops

Leafy crop	Coefficient of friction			
	Canvas	Cotton	Rubber	Mild steel
Chickpea	0.73	0.68	0.64	0.56
Green amaranthus	0.65	0.62	0.61	0.51
Red amaranthus	0.77	0.71	0.68	0.57
Fenugreek	0.69	0.65	0.63	0.60
Spinach	0.68	0.65	0.63	0.51

4.3 Associated Problems in Leafy Crop Harvesting

A study was conducted to find out the problem associated with the harvesting of leafy crop. A purposive survey was conducted in various vegetable growers and the workers of nearby areas of Raipur and Mahasamund districts. A total number of 78 farmers were selected and a survey with a pre prepared questionnaires with Borg-10 scale body parts was carried out. Associated problems in harvesting were studied in terms of body part discomfort score of various harvesting methods. The study also includes the effect of various harvesting methods and tools on the growth parameter of the leafy crops.

4.3.1 Harvesting methods adopted in leafy crop harvesting

In the survey it was observed that about 62.82% farmers used manual hand plucking method for leafy crop harvesting in selected leafy crops where remaining 37.18% respondents used sickle for harvesting leafy crops. As given in Fig. 4.1 nipping of chickpea and harvesting of spinach was mostly done by manual harvesting method, that was observed 100% in Raipur for both crops. Mechanical harvesting was not reported by any farmers in the surveyed area.

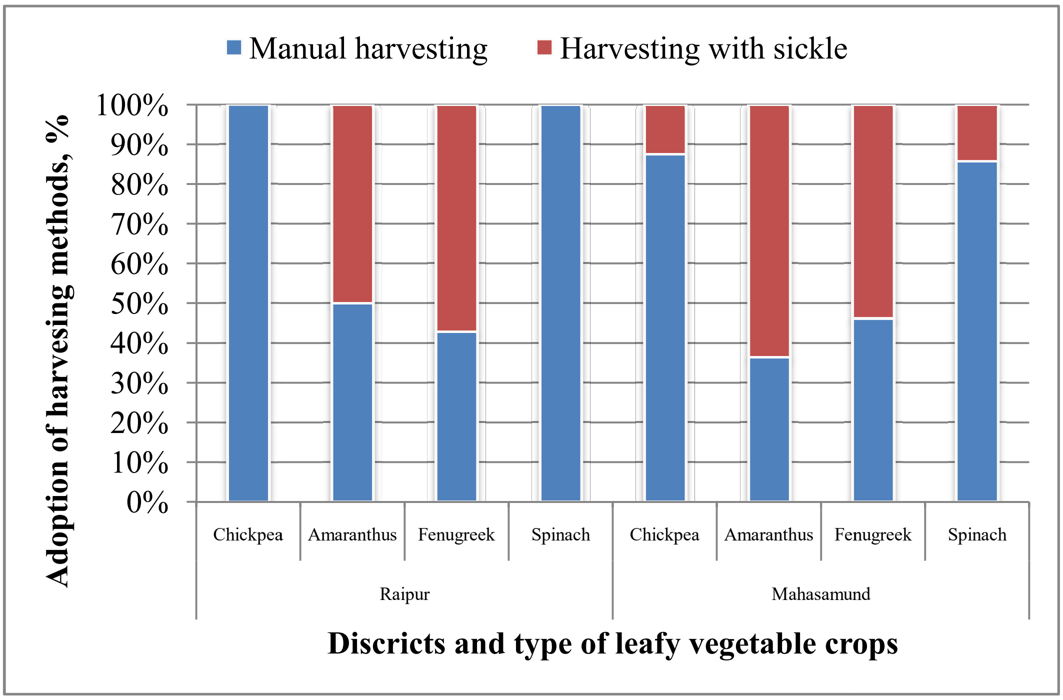


Fig. 4.1: Methods adopted for harvesting of leafy vegetables in Raipur and Mahasamund districts of Chhattisgarh

4.3.2 Body Parts Discomfort Score (BPDS)

A study conducted on the BPDS using Borg-10 scale. It was observed that out of the two different harvesting methods *viz.* manual hand plucking and manual harvesting with sickle as described in Section 3.3.2, BPDS were observed. The data obtained for BPDS of 27 different parts of the body during different harvesting method is presented in Table 4.85. The overall discomfort rate (ODR) was obtained maximum in manual harvesting (6.16) followed by harvesting with sickle of about 5.41. Similar result obtained by Premkumari *et al.*, 2018. The obtained data were compared with the developed machine latter on in Section 4.5.10.

4.3.3 Effect of different harvesting methods on growth parameters of leafy crop

Growth parameters of different leafy crop were taken as described in Section 3.3.3. Dependent parameters like number of branches and plant height were measured at an interval of 10 days after each harvesting, whereas, yield of the leafy crop was measured after each harvesting.

4.3.3.1 Number of branches

4.3.3.1.1 Number of branches of chickpea

The data obtained for number of branches of chickpea is given in Table 4.4 and Table 4.5. The mean value of number of branches (17.05) of chickpea was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

Table 4.4: ANOVA of number of branches of chickpea

S.V.	DF	SS	MSS	F-cal
Replication	3	5.309		
Factor D	2	277.418	138.709	64.305
Error (D)	6	12.942	2.157	
Factor M	3	25.047	8.349	1.563
Interaction D × M	6	2.119	0.353	0.066
Error (M)	27	144.199	5.341	
Total	47	467.034		

The number of branches were obtained maximum (15.29) by using stainless steel blade (M4), which was 5.09%, 15.48% and 14.88% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum number of branches was observed as 18.46 after 3rd harvesting (D3) with the use of stainless steel blade (M4) which is significantly higher (α=0.05) than other days after harvesting , it may be due to the increases in number of branches in multiple manner.

Table 4.5: Interactive effect of days after harvesting (D) and harvesting methods (M) on number of branches for chickpea

Factors	M1	M2	M3	M4	Mean D
D1	11.45	10.95	10.90	12.20	11.38
D2	14.30	12.57	13.40	15.22	13.87
D3	17.91	16.20	15.64	18.46	17.05
Mean M	14.55	13.24	13.31	15.29	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.62	0.22	0.15		
Factor(M)	0.27	0.13	0.09		
Factor M at same level of D	0.55	0.22	0.31		
Factor D at same level of M	0.73	0.29	0.20		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.1.2 Number of branches of green amaranthus

The data obtained for number of branches of green amaranthus is given in Table 4.6 and Table 4.7. The mean value of number of branches (9.85) of green amaranthus was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

The number of branches was obtained maximum (8.27) by using stainless steel blade (M4), which was 11.00%, 26.65% and 12.21% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum number of branches were observed as 10.95 after 3rd harvesting (D3) with the use of stainless steel blade (M4). It may be due to increase in number of branches after third harvesting of the crop.

Table 4.6: ANOVA of number of branches of green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	2	0.001		
Factor D	2	167.686	83.843	1039.77
Error (D)	4	0.323	0.081	
Factor M	3	13.552	4.517	129.048
Interaction D × M	6	0.719	0.12	3.423
Error (M)	18	0.63	0.035	
Total	35	182.91		

Table 4.7: Interactive effect of days after harvesting (D) and harvesting methods (M) on number of branches for green amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	4.55	4.00	4.55	5.30	4.60
D2	7.85	6.85	7.80	8.55	7.76
D3	9.95	8.75	9.75	10.95	9.85
Mean M	7.45	6.53	7.37	8.27	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.33	0.12	0.08		
Factor(M)	0.19	0.09	0.06		
Factor M at same level of D	0.37	0.15	0.16		
Factor D at same level of M	0.43	0.18	0.12		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.1.3 Number of branches in red amaranthus

The data obtained for number of branches for red amaranthus is given in Table 4.8 and Table 4.9. The mean value of number of branches (11.44) for red amaranthus was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

The number of branches were obtained maximum (9.42) by using stainless steel blade (M4), which was 6.08%, 21.55% and 9.28% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum number of branches were observed as 12.05 after 3rd harvesting (D3) with the use of stainless steel blade (M4). The increasing trends in the number of branch with the DAS may be due to increase in the number of branch per cut stem. Similar trends are also observed for other crops.

Table 4.8: ANOVA of number of branches of red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	2	0.004		
Factor D	2	194.527	97.264	918.087
Error (D)	4	0.424	0.106	
Factor M	3	13.073	4.358	114.317
Interaction D × M	6	0.351	0.058	1.534
Error (M)	18	0.686	0.038	
Total	35	209.065		

Table 4.9: Interactive effect of days after harvesting (D) and harvesting methods (M) on number of branches for red amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	5.80	4.95	5.70	6.55	5.75
D2	9.00	7.85	8.75	9.65	8.81
D3	11.85	10.45	11.40	12.05	11.44
Mean M	8.88	7.75	8.62	9.42	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.38	0.13	0.09		
Factor(M)	0.20	0.09	0.07		
Factor M at same level of D	NS	0.16	0.19		
Factor D at same level of M	NS	0.19	0.14		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.1.4 Number of branches of fenugreek

The data obtained for number of branches of fenugreek is given in Table 4.10 and Table 4.11. The mean value of number of branches (15.66) of fenugreek was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05). The number of branches was obtained maximum (12.05) by using stainless steel blade (M4), which was 4.06%, 13.15% and 7.30% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively.

Table 4.10: ANOVA of number of branches of fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	2	0.008		
Factor D	2	475.781	237.89	1271.5
Error (D)	4	0.748	0.187	
Factor M	3	9.403	3.134	58.97
Interaction D × M	6	0.33	0.055	1.033
Error (M)	18	0.957	0.053	
Total	35	487.227		

Table 4.11: Interactive effect of days after harvesting (D) and harvesting methods (M) on number of branches for fenugreek

Factors	M1	M2	M3	M4	Mean D
D1	6.90	6.20	6.70	7.30	6.78
D2	12.00	10.95	11.45	12.40	11.70
D3	15.85	14.80	15.55	16.45	15.66
Mean M	11.58	10.65	11.23	12.05	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.50	0.18	0.13		
Factor(M)	0.23	0.11	0.08		
Factor M at same level of D	NS	0.19	0.25		
Factor D at same level of M	NS	0.24	0.17		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

The maximum number of branches was observed as 16.45 after 3rd harvesting (D3) with the use of stainless steel blade (M4). The interaction table also inferred that with the increase in DAS may increases the number of branches in fenugreek.

4.3.3.1.5 Number of branches of spinach

The data obtained for number of branches of spinach is given in Table 4.12 and Table 4.13. The mean value of number of branches (17.01) of spinach was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

Table 4.12: ANOVA of number of branches of spinach

S.V.	DF	SS	MSS	F-cal
Replication	2	0.014		
Factor D	2	759.393	379.697	2332.84
Error (D)	4	0.651	0.163	
Factor M	3	9.047	3.016	50.663
Interaction D × M	6	2.039	0.34	5.71
Error (M)	18	1.071	0.06	
Total	35	772.217		

Table 4.13: Interactive effect of days after harvesting (D) and harvesting methods (M) on number of branches for spinach

Factors	M1	M2	M3	M4	Mean D
D1	6.21	5.64	5.31	6.33	5.87
D2	10.45	9.48	9.21	10.93	10.02
D3	17.55	16.20	16.95	17.31	17.01
Mean M	11.40	10.44	10.49	11.52	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.47	0.17	0.12		
Factor(M)	0.24	0.12	0.08		
Factor M at same level of D	0.49	0.20	0.23		
Factor D at same level of M	0.59	0.24	0.17		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

The number of branches was obtained maximum (11.52) by using stainless steel blade (M4), which was 1.05%, 10.34% and 9.82% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum number of branches was observed as 17.31 after 3rd harvesting (D3) with the use of stainless steel blade (M4).The maximum number of branches was observed as 17.31 after 3rd harvesting (D3) with the use of stainless steel blade (M4) which is significantly higher (α=0.05) then other days after harvesting, it may be due to the increases in number of branch in multiple manner.

4.3.3.2 Plant height of leafy crop

Three levels of harvesting days and four levels of different harvesting methods were evaluated in the field and obtained data was statistically analyzed using Split Plot Design with the help of OPSTAT statistical package developed by HAU, Hissar. Effect on plant height of different harvesting methods and tool is presented in this section for different leafy crops. Plant height was measured with the help of measuring scale from ground to top of the plant at different stages at specific interval of time of each crop.

4.3.3.2.1 Plant height of chickpea

The data obtained for plant height of chickpea is given in Table 4.14 and Table 4.15. The mean value of plant height (23.64 cm) of chickpea was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

Table 4.14: ANOVA of plant height (cm) of chickpea

S.V.	DF	SS	MSS	F-cal
Replication	2	0.011		
Factor D	2	176.6	88.3	229.939
Error (D)	4	1.536	0.384	
Factor M	3	75.215	25.072	33.818
Interaction D × M	6	79.139	13.19	17.791
Error (M)	18	13.345	0.741	
Total	35	345.846		

The plant height was obtained maximum (23.23 cm) by using stainless steel blade (M4), which was 13.37%, 15.98% and 19.37% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum height of plant was observed as 28.10 cm after 3rd harvesting (D3) with the use of stainless steel blade (M4) which is significantly higher (α=0.05) than treatment combinations. As it was the main stage of the plant growth, the height also increases with the days after sowing.

Table 4.15: Interactive effect of days after harvesting (D) and harvesting methods (M) on plant height (cm) for chickpea

Factors	M1	M2	M3	M4	Mean D
D1	16.65	19.75	17.88	18.65	18.23
D2	20.63	18.18	20.43	22.93	20.54
D3	24.20	22.18	20.08	28.10	23.64
Mean M	20.49	20.03	19.46	23.23	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.72	0.25	0.18		
Factor(M)	0.86	0.41	0.29		
Factor M at same level of D	1.56	0.70	0.36		
Factor D at same level of M	1.47	0.66	0.47		

4.3.3.2.2 Plant height of green amaranthus

The data obtained for plant height of spinach is given in Table 4.16 and Table 4.17. The mean value of plant height (23.64 cm) of green amaranthus was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05). The plant height was obtained maximum (25.66 cm) by using stainless steel blade (M4), which was 0.71%, 5.47% and 11.66% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum height of plant was observed as 28.10 cm after 3rd harvesting (D3) with the use of stainless steel blade (M4) which is significantly higher (α=0.05) than other DAS.

Table 4.16: ANOVA of plant height (cm) of green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	2	0.002		
Factor D	2	539.547	269.774	588.419
Error (D)	4	1.834	0.458	
Factor M	3	41.219	13.74	17.384
Interaction D × M	6	23.408	3.901	4.936
Error (M)	18	14.226	0.79	
Total	35	620.236		

Table 4.17: Interactive effect of days after harvesting (D) and harvesting methods (M) on plant height (cm) for green amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	20.25	21.12	18.95	19.54	19.97
D2	25.93	23.21	22.36	26.21	24.43
D3	30.25	28.65	27.64	31.23	29.44
Mean M	25.48	24.33	22.98	25.66	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.79	0.28	0.20		
Factor(M)	0.89	0.42	0.30		
Factor M at same level of A	1.62	0.73	0.39		
Factor A at same level of M	1.54	0.69	0.49		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.2.3 Plant height of red amaranthus

The data obtained for plant height of red amaranthus is given in Table 4.18 and Table 4.19. The mean value of plant height (23.64 cm) of red amaranthus was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05).

The plant height was obtained maximum (26.86 cm) by using stainless steel blade (M4), which was 1.05%, 5.37% and 12.01% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum height of plant was observed as 32.53 cm after 3rd harvesting (D3) with the use of stainless steel blade (M4) followed by M_1. Interactive effect was showing significant difference at 5% level of significance. It inferred that on height the mechanical harvesting methods not affected the yield.

Table 4.18: ANOVA of plant height (cm) of red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	2	0.010		
Factor D	2	539.669	269.834	558.103
Error (D)	4	1.934	0.483	
Factor M	3	45.910	15.303	18.719
Interaction D × M	6	19.639	3.273	4.004
Error (M)	18	14.715	0.818	
Total	35	621.877		

Table 4.19: Interactive effect of days after of harvesting (D) and harvesting methods (M) on plant height (cm) for red amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	21.45	22.22	19.85	20.84	21.09
D2	26.83	24.51	23.56	27.21	25.53
D3	31.45	29.75	28.54	32.53	30.57
Mean M	26.58	25.49	23.98	26.86	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.81	0.28	0.20		
Factor(M)	0.90	0.43	0.30		
Factor M at same level of A	1.65	0.74	0.40		
Factor A at same level of M	1.57	0.70	0.50		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.2.4 Plant height of fenugreek

The data obtained for plant height of fenugreek is given in Table 4.20 and Table 4.21. The mean value of plant height (33.56 cm) of fenugreek was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05). The plant height was obtained maximum (30.57 cm) by using stainless steel blade (M4), which was 0.96%, 4.66% and 9.94% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The significant height of plant was observed as 35.56 cm after 3rd harvesting (D3) with the use of stainless steel blade (M4).

Table 4.20: ANOVA of plant height (cm) of fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	2	0.029		
Factor D	2	348.065	174.032	302.55
Error (D)	4	2.301	0.575	
Factor M	3	50.343	16.781	18.229
Interaction D × M	6	23.592	3.932	4.271
Error (M)	18	16.571	0.921	
Total	35	440.901		

Table 4.21: Interactive effect of days after harvesting (D) and harvesting methods (M) on plant height (cm) for fenugreek

Factors	M1	M2	M3	M4	Mean D
D1	26.38	27.27	24.93	25.77	26.09
D2	30.03	27.41	26.31	30.39	28.54
D3	34.43	32.80	31.44	35.56	33.56
Mean M	30.28	29.16	27.56	30.57	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.88	0.31	0.22		
Factor(M)	0.96	0.45	0.32		
Factor M at same level of A	1.76	0.78	0.44		
Factor A at same level of M	1.67	0.75	0.53		

D1=10 days after 1st harvesting, D2= 10 days after 2nd harvesting, D3 = 10 days after 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.2.5 Plant height of spinach

The data obtained for plant height of spinach is given in Table 4.22 and Table 4.23. The mean value of plant height (17.72 cm) of spinach was obtained maximum after 3rd harvesting, which was significantly highest (α=0.05). The plant height was obtained maximum (15.15 cm) by using stainless steel blade (M4), which was 2.09%, 7.52% and 10.18% higher than the manual harvesting (M1), sickle (M2) and fiber blade (M3), respectively. The maximum height of plant was observed as 18.62 cm after 3rd harvesting (D3) with the use of stainless steel blade (M4).

Table 4.22: ANOVA of plant height (cm) of spinach

S.V.	DF	SS	MSS	F-cal
Replication	2	0.024		
Factor D	2	274.762	137.381	492.821
Error (D)	4	1.115	0.279	
Factor M	3	11.359	3.786	5.863
Interaction D × M	6	2.511	0.418	0.648
Error (M)	18	11.625	0.646	
Total	35	301.396		

Table 4.23: Interactive effect of days after harvesting (D) and harvesting methods (M) on plant height (cm) for spinach

Factors	M1	M2	M3	M4	Mean D
D1	11.27	10.84	10.65	11.09	10.96
D2	15.13	14.21	13.69	15.73	14.69
D3	18.13	17.21	16.91	18.62	17.72
Mean M	14.84	14.09	13.75	15.15	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.61	0.22	0.15		
Factor(M)	0.80	0.38	0.27		
Factor M at same level of A	NS	0.66	0.31		
Factor A at same level of M	NS	0.61	0.43		

4.3.3.3 Yield of leafy crop

Three levels of harvesting days and four levels of different harvesting methods were used to evaluate the yield of leafy crops and obtained data were analyzed with the use of OPSTAT statistical package in Split Plot Design. Yield was one of the major parameter to select the best harvesting technique.

4.3.3.3.1 Yield of chickpea

The ANOVA of yield data's obtained from field by using different method of harvesting and days after harvesting are depicted in Table 4.24 and Table 4.25**.** A significant difference was observed due to harvesting days on yield of chickpea leafy crop at 5% level of significance. Out of the different harvesting method maximum average yield of 2.40 t ha^{-1} was observed with the use of stainless steel blade (M4), which was 1.27%, 7.14% and 7.62% significantly higher than the M1, M2 and M3, respectively. The interactive effects of the harvesting days and harvesting method were found to be significant. The highest yield was found to be 2.96 t ha^{-1} after 3rd harvesting (D3) by using stainless steel blade (M4), it is significantly higher (α=0.05) than other treatment combination.

Table 4.24: ANOVA of yield of chickpea (t ha^{-1})

S.V.	DF	SS	MSS	F-cal
Replication	2	0		
Factor D	2	5.91	2.955	3589.61
Error (D)	4	0.003	0.001	
Factor M	3	0.188	0.063	20.956
Interaction D × M	6	0.227	0.038	12.661
Error (M)	18	0.054	0.003	
Total	35	6.382		

Table 4.25: Interactive effect of days after harvesting (D) and harvesting methods (M) on yield (t ha^{-1}) for chickpea

Factors	M1	M2	M3	M4	Mean D
D1	1.82	1.85	1.75	1.73	1.79
D2	2.45	2.32	2.26	2.51	2.39
D3	2.85	2.56	2.72	2.96	2.77
Mean M	2.37	2.24	2.23	2.40	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.03	0.01	0.01		
Factor(M)	0.06	0.03	0.02		
Factor M at same level of D	0.10	0.05	0.02		
Factor D at same level of M	0.09	0.04	0.03		

D1= 1st harvesting, D2 = 2nd harvesting, D3 = 3rd harvesting;

M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.3.2 Yield of green amaranthus

The ANOVA of yield data's obtained from field by using different method of harvesting and days after harvesting are depicted in Table 4.26 and Table 4.27**.** Highest average yield of green amaranthus was observed after 3rd harvesting (D3) of about 11.42 t ha^{-1}.

Out of the four harvesting methods maximum average yield of 11.21 t ha^{-1} was observed with the use of stainless steel blade (M4), which was 1.291%, 4.47%

and 7.62% higher than the M1, M2 and M3, respectively. The interactive effects of the harvesting days and harvesting method were found to be significant (α=0.05). The highest yield was found to be 11.96 t ha^{-1} after 3rd harvesting (D3) by using stainless steel blade (M4).

Table 4.26: ANOVA of yield of green amaranthus (t ha^{-1})

S.V.	DF	SS	MSS	F-cal
Replication	2	0.007		
Factor D	2	4.953	2.476	270.719
Error (D)	4	0.037	0.009	
Factor M	3	1.203	0.401	27.227
Interaction D × M	6	0.803	0.134	9.094
Error (M)	18	0.265	0.015	
Total	35	7.267		

Table 4.27: Interactive effect of days after harvesting (D) and harvesting methods (M) on yield (t ha^{-1}) for green amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	10.65	10.52	10.42	10.47	10.52
D2	10.92	10.62	10.84	11.21	10.90
D3	11.43	11.05	11.24	11.96	11.42
Mean M	11.00	10.73	10.83	11.21	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.11	0.04	0.03		
Factor(M)	0.12	0.06	0.04		
Factor M at same level of D	0.22	0.10	0.06		
Factor D at same level of M	0.21	0.09	0.07		

D1=1st harvesting, D2= 2nd harvesting, D3 = 3rd harvesting;

M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.3.3 Yield of red amaranthus

The ANOVA of yield data's obtained from field by using different method of harvesting and days after harvesting are depicted in Table 4.28 and Table 4.29**.** Highest average yield of red amaranthus was observed after 3rd harvesting (D3) of about 11.87 t ha^{-1}.

Out of the different harvesting method maximum average yield of 11.88 t ha^{-1} was observed with the use of stainless steel blade (M4), which was 1.36%, 5.60% and 7.61% higher than the M1, M2 and M3, respectively. The interactive effects of the harvesting days and harvesting method were found to be significant (α=0.05). The highest yield was found to be 12.10 t ha^{-1} after 3rd harvesting (D3) by using stainless steel blade (M4). The manual plucking have 11.94 t ha^{-1} after 3rd harvesting. This may be due to proper growth in the plant after 2nd harvesting of the crop.

Table 4.28: ANOVA of yield of red amaranthus (t ha^{-1})

S.V.	DF	SS	MSS	F-cal
Replication	2	0.011		
Factor D	2	2.781	1.391	139.137
Error (D)	4	0.040	0.010	
Factor M	3	4.161	1.387	86.411
Interaction D × M	6	3.703	0.617	38.443
Error (M)	18	0.289	0.016	
Total	35	10.985		

Table 4.29: Interactive effect of days after harvesting (D) and harvesting methods (M) on yield (t ha^{-1}) for red amaranthus

Factors	M1	M2	M3	M4	Mean D
D1	11.71	11.52	10.21	11.61	11.26
D2	11.51	10.56	11.17	11.94	11.30
D3	11.94	11.68	11.75	12.10	11.87
Mean M	11.72	11.25	11.04	11.88	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.12	0.04	0.03		
Factor(M)	0.13	0.06	0.04		
Factor M at same level of D	0.23	0.10	0.06		
Factor D at same level of M	0.22	0.10	0.07		

D1= 1st harvesting, D2= 2nd harvesting, D3 = 3rd harvesting;

M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

4.3.3.3.4 Yield of fenugreek

The ANOVA of yield data's obtained from field by using different method of harvesting and days after harvesting are depicted in Table 4.30 and Table 4.31.

Highest average yield of fenugreek was observed after 3rd harvesting (D3) of about 8.51 t ha^{-1}.

Table 4.30: ANOVA of yield of fenugreek (t ha^{-1})

S.V.	DF	SS	MSS	F-cal
Replication	2	0.003		
Factor D	2	8.997	4.499	1036.26
Error (D)	4	0.017	0.004	
Factor M	3	1.077	0.359	46.684
Interaction D × M	6	0.54	0.09	11.716
Error (M)	18	0.138	0.008	
Total	35	10.773		

Table 4.31: Interactive effect of days after harvesting (D) and harvesting methods (M) on yield (t ha^{-1}) for fenugreek

Factors	M1	M2	M3	M4	Mean D
D1	7.42	7.32	7.25	7.30	7.32
D2	7.86	7.32	7.45	7.96	7.65
D3	8.54	8.20	8.42	8.87	8.51
Mean M	7.94	7.61	7.71	8.04	
Factors	C.D.	SE(d)	SE(m)		
Factor(D)	0.08	0.03	0.02		
Factor(M)	0.09	0.04	0.03		
Factor M at same level of D	0.16	0.07	0.04		
Factor D at same level of M	0.15	0.07	0.05		

D1= 1st harvesting, D2= 2nd harvesting, D3 = 3rd harvesting;

M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

A significant difference was observed due to harvesting days on yield of chickpea leafy crop at 5% level of significance. Out of the different harvesting method maximum average yield of 8.04 t ha^{-1} was observed with the use of stainless steel blade (M4), which was 1.26%, 5.65% and 4.28% significantly higher than the M1, M2 and M3, respectively. The interactive effects of the harvesting days and harvesting method were found to be significant (α=0.05). The highest yield was found to be 8.87 t ha^{-1} after 3rd harvesting (D3) by using stainless steel blade (M4) followed by 8.54 t ha^{-1} by manual hand plucking.

4.3.3.3.5 Yield of spinach

The ANOVA of yield data's obtained from field by using different method of harvesting and days after harvesting are depicted in Table 4.32 and Table 4.33. Highest average yield of spinach was observed after 3rd harvesting (D3) of about 3.49 t ha^{-1}.

Table 4.32: ANOVA of yield of spinach (t ha^{-1})

S.V.	DF	SS	MSS	F-cal
Replication	2	0		
Factor D	2	0.626	0.313	338.049
Error (D)	4	0.004	0.001	
Factor M	3	0.845	0.282	87.138
Interaction D × M	6	0.256	0.043	13.213
Error (M)	18	0.058	0.003	
Total	35	1.789		

Table 4.33: Interactive effect of days after harvesting (D) and harvesting methods (M) on yield (t ha^{-1}) for spinach

Factors	M1	M2	M3	M4	Mean D
D1	3.21	3.12	3.15	3.21	3.17
D2	3.52	3.21	3.12	3.63	3.37
D3	3.69	3.31	3.25	3.72	3.49
Mean M	3.47	3.21	3.17	3.52	
Factors	C.D.	SE(d)	SE(m)		
Factor (D)	0.04	0.01	0.01		
Factor (M)	0.06	0.03	0.02		
Factor M at same level of D	0.10	0.05	0.02		
Factor D at same level of M	0.09	0.04	0.03		

D1= 1st harvesting, D2= 2nd harvesting, D3 = 3rd harvesting;
M1= Manual hand plucking, M2= harvesting with sickle, M3= harvesting with fiber blade, M4= harvesting with stainless steel blade

Out of the different harvesting methods maximum average yield of 3.52 t ha^{-1} was observed with the use of stainless steel blade (M4), which was 1.44%, 9.66% and 11.04% significantly higher than the M1, M2 and M3, respectively. The interactive effects of the harvesting days and harvesting method were found to be significant (α=0.05). The highest yield was found to be 3.72 t ha^{-1} after 3rd harvesting (D3) by using stainless steel blade (M4). Similar trends are also observed for other crops.

4.4 Design and Selection of Machine Components

The design of the machine is already covered in Chapter-III (Section 3.3). The machine is fabricated and developed in the workshop of Department of Farm Machinery and Power Engineering, SVCAET, IGKV Raipur. The brief description of the machine is as follows:

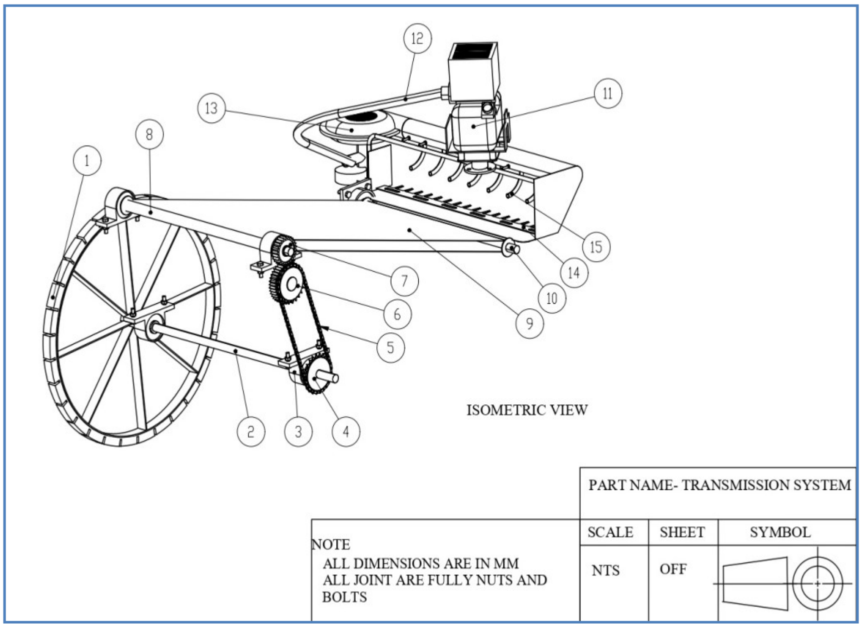
The cutter bar assembly of the machine is operated by one hp 2 stroke petrol engine. It is a "Kisan kraft" make engine. The cutter bar assembly consists of cutting unit as well as blower unit. The rated rpm of the engine is 7600. The leafy harvester is push type equipment. The whole equipment is supported by four wheels, out of which two are rubber make (diameter 200 mm) and in back it is iron wheel with rubber lugged (600 mm). Cutting resistance of the leafy crop was found very less. Stainless steel material was selected to for cutter bar. Working width of the leafy crop was considered 600 mm, so market available cutter bar of stainless steel material was selected for leafy crop harvester. There were two stainless steel blades used to give scissor action for cutting of leafy crop, first was fixed (600 mm length) and second (630 mm) was for performing reciprocating motion over fixed blade. The blower unit is one of the important part to push the cut leaves to the conveyor after cutting the leaves by cutter bar and the required volume of the air stream was calculated about 2.50×10^{-3} m^3 s^{-1}.So based on required volume of air the diameter of casing was selected 180 mm with impeller diameter 140 mm which had capacity of 3.54×10^{-3} m^3s^{-1} at full throttle speed of engine.

Material of the conveyor belt was selected based on the coefficient of static friction and angle of repose between belt material and harvested leaves of leafy crop. The diameter of the roller shaft was selected as 25 mm and length of belt was calculated 1778.54 mm based on center distance between roller shaft which was 850 mm.

In the leafy crop harvester two transmission systems are used, first was used to transmit power from engine to cutter bar and second was used to transmit rotary motion to conveyor from the ground wheel. Market available throttle cable

(8mm) was selected to transmit the power from engine to cutter bar of 1 m length. The conveyer belt was rotated by power obtained from the ground wheel with the help of chain and gear drive as shown in Fig. 4.2.

Collection unit was made by using aluminum sheet with 0.06 mm^3. Dimension of the collection unit was 520×250×450 mm. Collection unit was mounted on back side and it was just behind the conveyor unit to collect the harvested leafy crop.



1. Wheel	6. Sprocket-2 and gear-1	11. Engine
2. Wheel shaft	7. Gear-2	12. Throttle cable
3. Bearing	8. Conveyor shaft-1	13. Blower
4. Sprocket-1	9. Conveyor	14. Cutter bar
5. Chain	10. Conveyor shaft-2	15. Blower outlet

Fig. 4.2: Transmission system of leafy crop harvester

After designing all components of machine a frame was designed to mount it in specific position. Based on the working load required strength of the frame was calculated and also analyzed by ANSYS 2021 computer software. Frame was made by using stainless steel material with overall dimension about 1600×600×600 mm.

A Finite Element Analysis (FEA) was done by using ANSYS software for conceptual frame and is presented in Fig. 4.3 to 4.5. Total number of nodes and elements were used 39050 and 8576, respectively for the statistical analysis of the frame in ANSYS 2021 software. The maximum stresses were obtained 0.57 MPa, with maximum deformation 0.08 mm on the frame due to various working load on frame. These obtained stresses were very smaller than the allowable stress of the selected stainless steel material and it was found desirable for design of frame. Final dimensions of frame and components of the developed leafy crop harvester are given in Fig. 4.6 and 4.7.

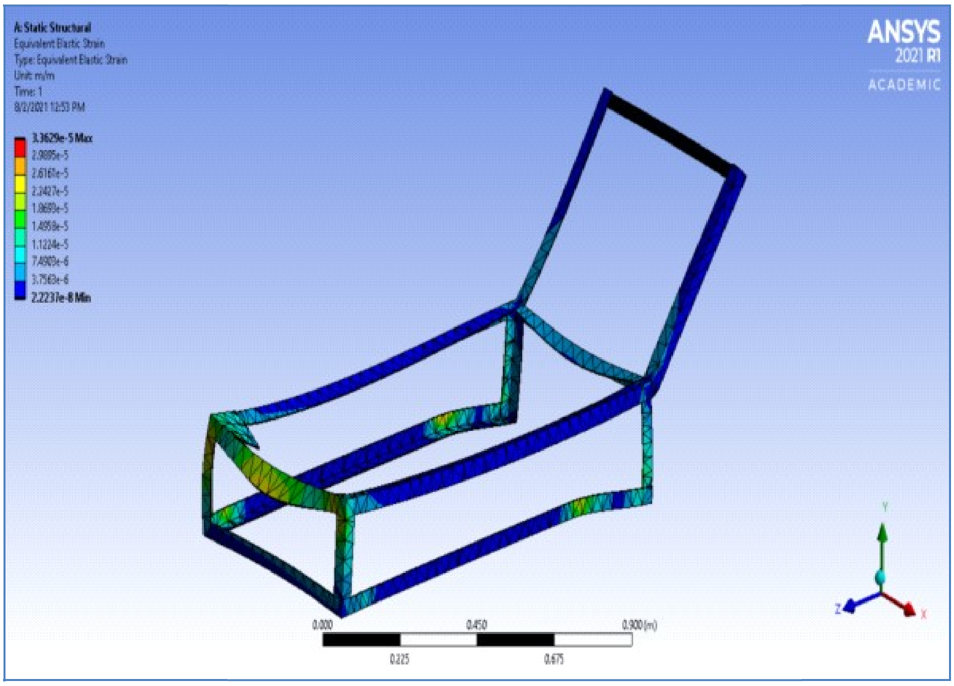


Fig. 4.3: Equivalent elastic strain of frame

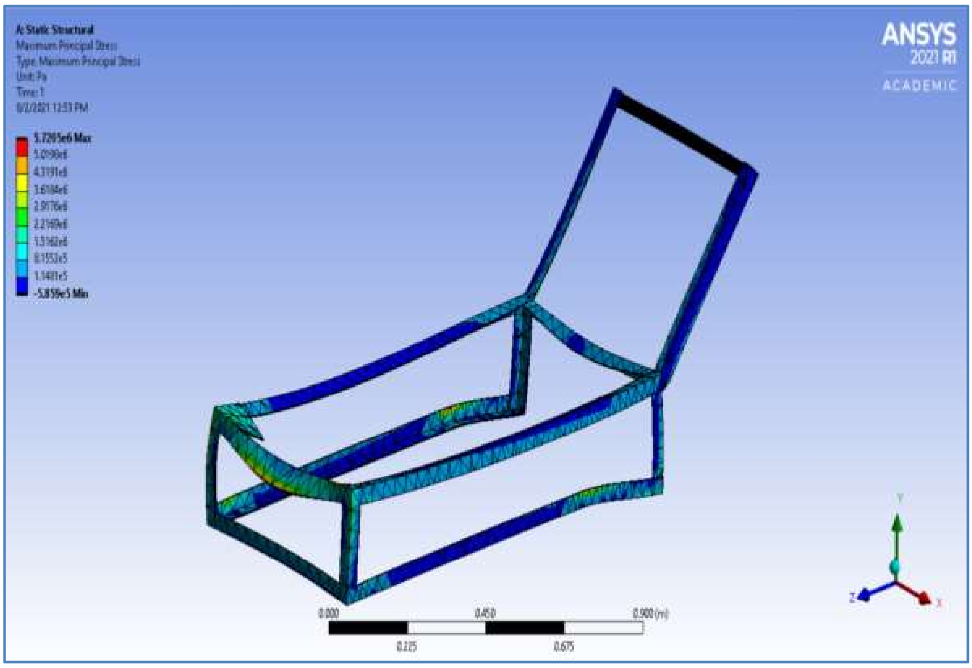


Fig. 4.4: Maximum principal stress of frame

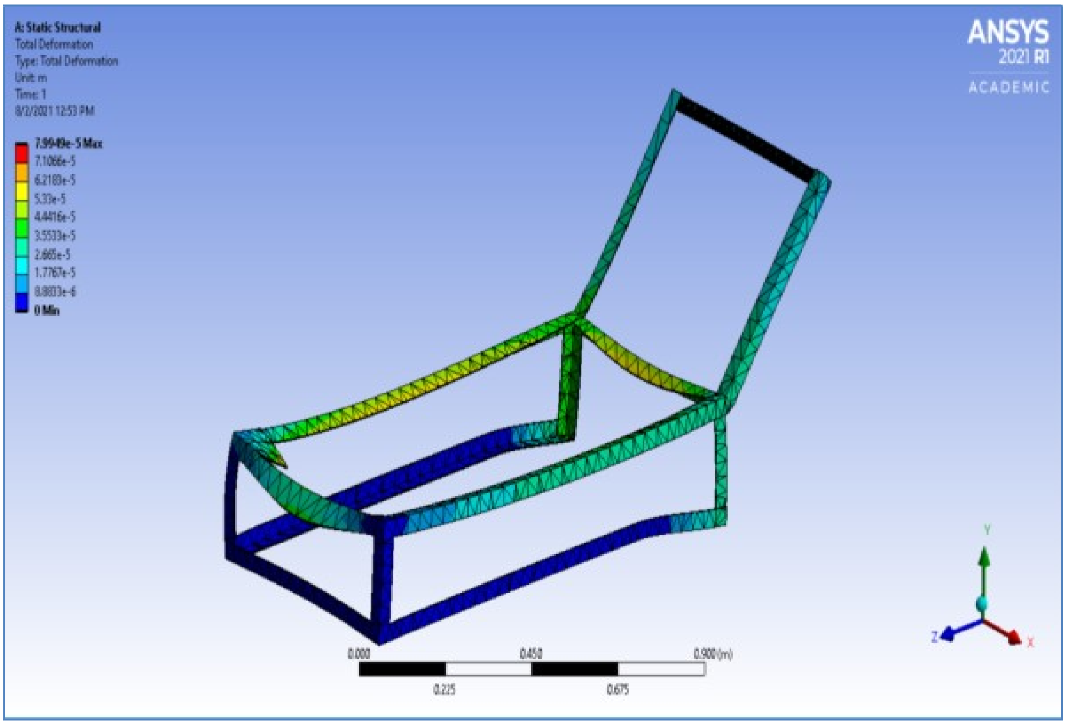
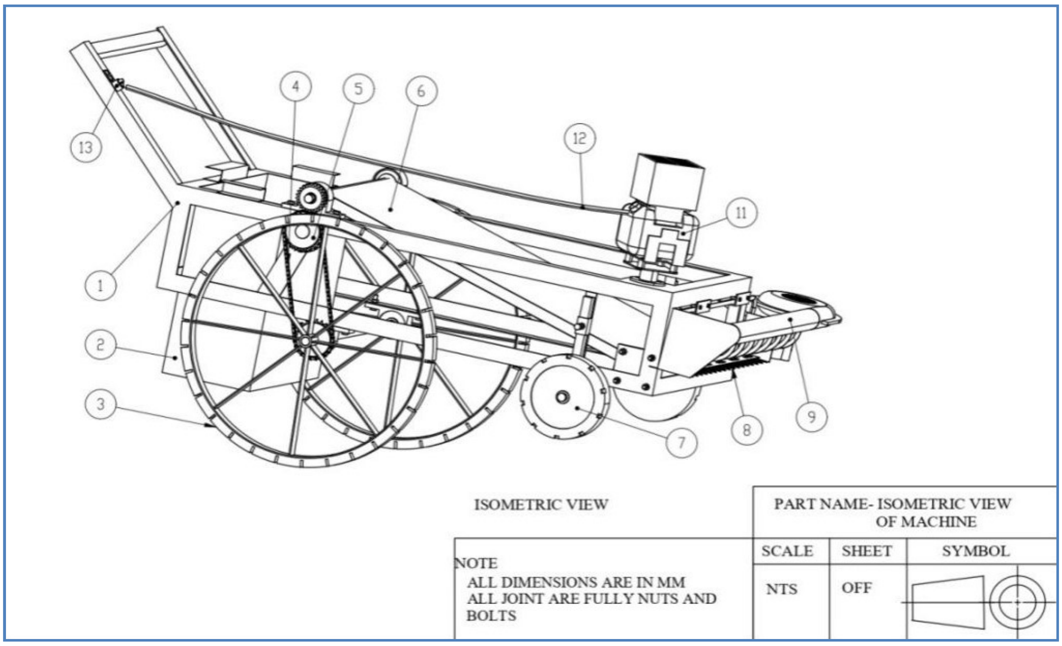


Fig. 4.5: Total deformation of frame

Fig. 4.6: Developed leafy crop harvester



1. Frame	5. Gear drive	9. Blower
2. Storage tank	6. Conveyor	11. Engine
3. Rear wheel	7. Front wheel	12. Wire
4. Chain drive	8. Cutter bar	13. Accelerator/switch

Fig. 4.7: Components of the leafy crop harvester

4.5 Performance Evaluation

The performance evaluation of the machine was conducted in the field of IGKV, Raipur (C.G.). Factorial Randomized Block Design was designed to evaluate three factors with three level of each factors *viz.* forward speed (S1= 0.5 km h^{-1}, S2= 1.0 km h^{-1} and S3= 1.5 km h^{-1}), air velocity (V1 = 3 m s^{-1}, V2 = 4 m s^{-1} and V3 = 5 m s^{-1}) and cutting height (H1 = 100 mm, H2 = 150 mm and H3 = 200 mm) with three replications for each treatment. The output parameters involved are header loss, conveying loss and harvesting efficiency of the developed harvester.

4.5.1 Performance evaluation for chickpea by developed machine

4.5.1.1 Header loss of chickpea

Header loss is one of the major factors that affect the performance of the harvester. Header loss was calculated by using formula as described in Chapter –III in section 3.4.5.1. The data related to the calculation of header loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The minimum average header loss was observed to be 0.80% at forward speed of 1.5 km h^{-1} (S3), 1.50% at cutting height of 100 mm (H1) and 1.71% at air velocity of 5 m s^{-1} (Table 4.34).

Table 4.34: Effect of forward speed, cutting height and air velocity on header loss (%) by leafy harvester in harvesting of chickpea

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	4.06±.65	100 mm (H1)	1.50±0.43	3 m s^{-1} (V1)	3.20±0.78
1 km h^{-1} (S2)	2.39±.41	150 mm (H2)	2.47±0.60	4 m s^{-1} (V2)	2.35±0.60
1.5 km h^{-1} (S3)	0.80±.23	200 mm (H3)	3.28±0.80	5 m s^{-1} (V3)	1.71±0.53
SE(m)	0.025	SE(m)	0.025	SE(m)	0.025
CD (P=0.05)	0.072	CD (P=0.05)	0.072	CD (P=0.05)	0.072

It was observed that the header loss decreased with increase in forward speed due to more inclination of crop at back side of cutter bar at higher speed as compared to lower speed. Similarly as the air velocity increase the header loss decrease, because air stream at air velocity 5 m s^{-1} help to move the leaves to conveyor more effectively than the air stream at air velocity 3 m s^{-1}. The detail ANOVA is presented in Table 4.35.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.8. The lowest header loss (0.56%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm, whereas it was observed to be highest (5.60%) at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm. It was also observed that with the increase in the forward speed the header loss was also decreases significantly at 5% level with CD value of 0.125 (Table 4.36). Similar result was observed by Gharkhani *et al.* (2017) due to different forward speed on header loss.

It was also observed that at higher cutting height the header loss was also high as compared to lower height. It may be due to at lower speed the opportunity time for falling on the conveyer belt was less as compared to higher speed and as a result the leaves fall on the ground. It was also observed that at higher height due to its forward bending over the cutting height of the stem it may be losses on the ground. Similar result was observed by Bawatharani *et al.* (2015) due to different cutting height on header loss.

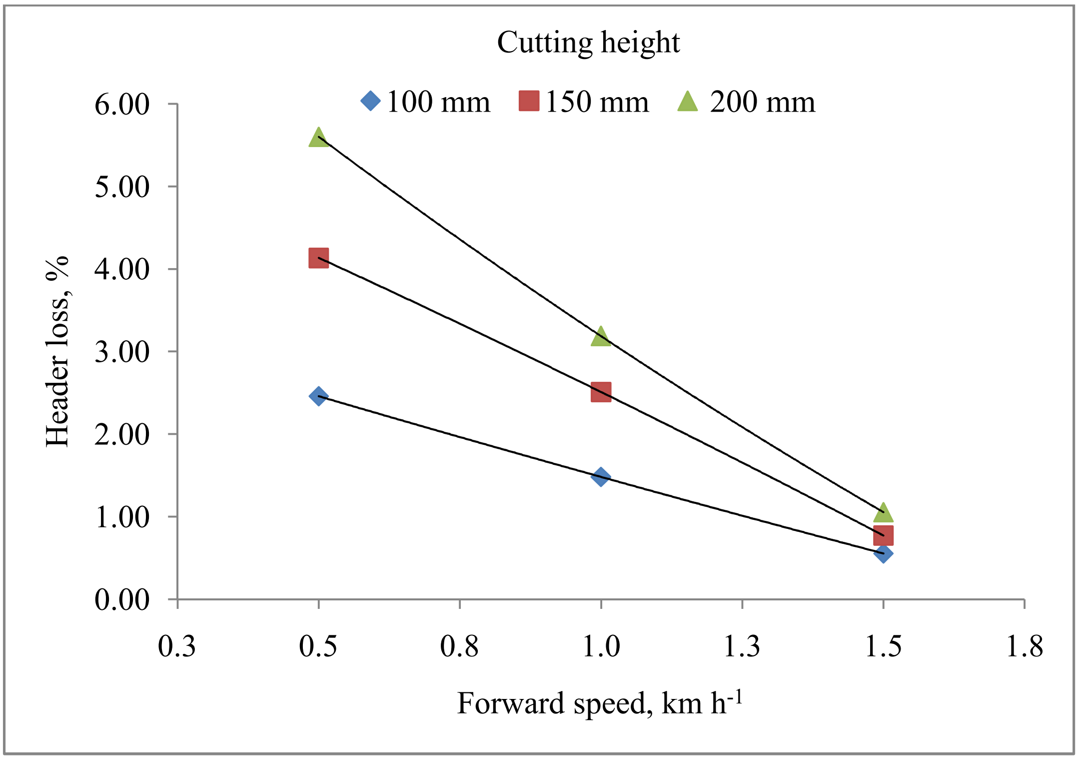


Fig. 4.8: Effect of cutting height and forward speed on header loss in chickpea

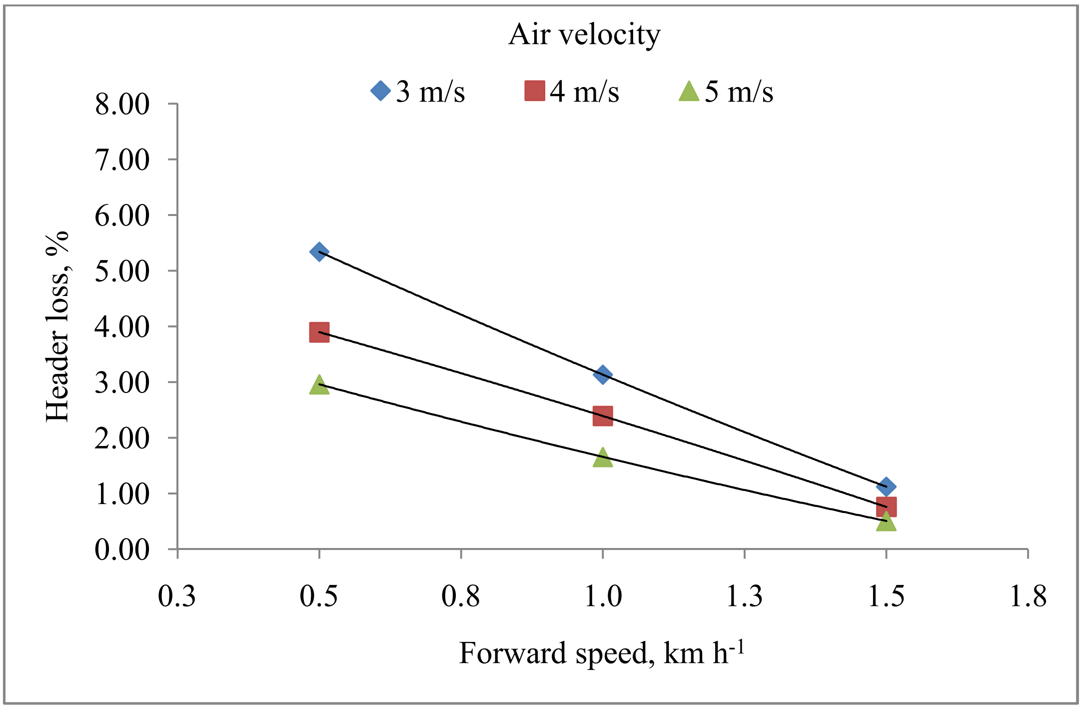


Fig. 4.9: Effect of air velocity and forward speed on header loss in chickpea

The interactive effect of forward speed VS air velocity is depicted in Fig. 4.9. The lowest header loss (0.51%) was obtained at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}, whereas, it was observed to be highest (5.34%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}. It was observed that with the increase in the forward speed the header loss was also decreases significantly (CD=0125 at 5% level) Table 3.35. It was also observed that at higher air velocity the header loss was significantly lower as compared to lower air velocity. It may be due to the air thrust at higher air velocity reduces the chances of falling down.

The interactive effect of cutting height and air velocity is presented in Fig 4.10. It was observed that with the increase in the cutting height and air velocity the header loss was increases significantly at 5% level with CD value of 0.125 (Table 4.35). There was significant difference (CD= 0.216 at 5% level) was observed due to interactive effect between machine speed, cutting height and air velocity by developed harvester on header loss in chickpea (Table 4.36).

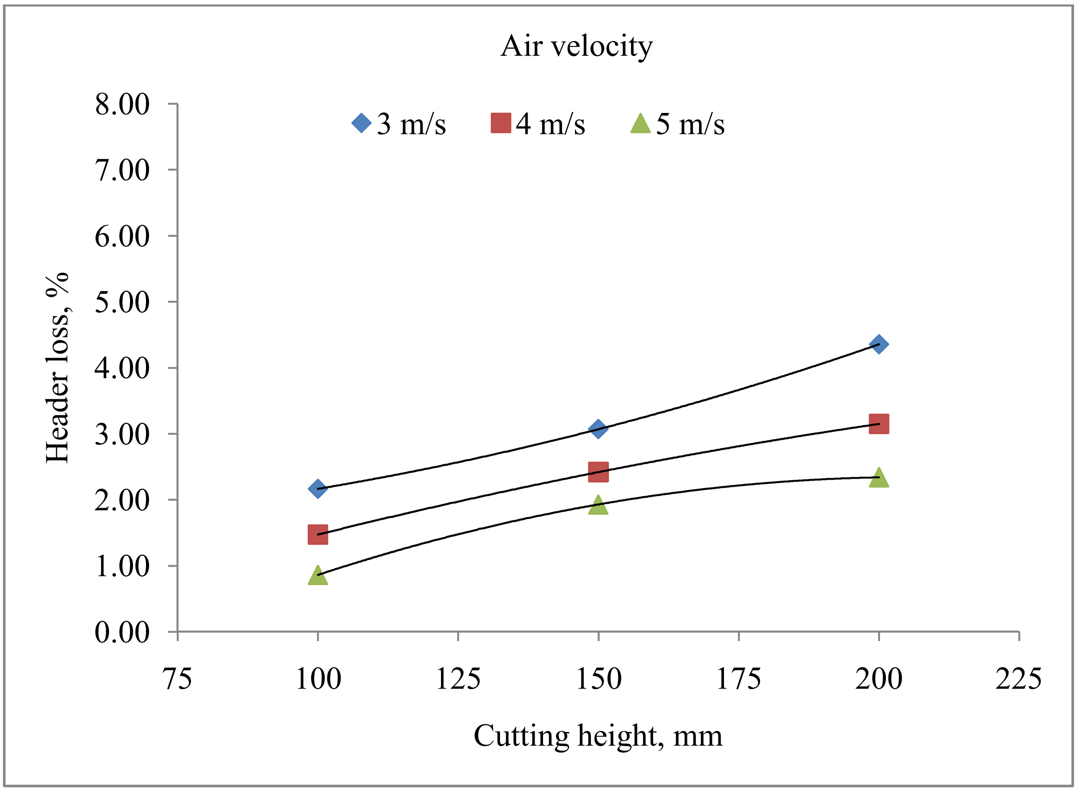


Fig. 4.10: Effect of cutting height and air velocity on header loss in chickpea

Table 4.35: ANOVA of header loss (%) of leafy crop harvester at chickpea

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.025	0.013	0.719		
Treatment	26	242.899	9.342	536.301		
Forward speed	2	144.280	72.140	4141.268	0.025	0.072
Cutting height	2	42.947	21.473	1232.701	0.025	0.072
Air velocity	2	30.170	15.085	865.962	0.025	0.072
S×H	4	15.857	3.964	227.569	0.044	0.125
S×V	4	7.238	1.809	103.872	0.044	0.125
H×V	4	2.036	0.509	29.222	0.044	0.125
S×H×V	8	0.371	0.046	2.663	0.076	0.216
Error	52	0.906	0.017			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.36: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.76	5.13	7.13	2.05	3.13	4.22	0.69	0.95	1.72	1.12
V2	2.36	4.01	5.31	1.52	2.52	3.13	0.54	0.73	1.01	0.76
V3	1.26	3.26	4.36	0.88	1.88	2.21	0.44	0.64	0.45	0.51
Mean S	2.46	4.13	5.60	1.48	2.51	3.19	0.56	0.77	1.06	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.1.2 Conveying loss of chickpea

Conveying loss is one of the major factors that affect the performance of the harvester. It was occurred during conveying the harvested leaves from cutter bar to storage tank. Conveying loss was calculated by using formula as described in Chapter –III in section 3.4.5.2. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. Minimum average conveying loss was observed at forward speed 0.5 km h^{-1} (S1) of about 1.72%, followed by 2.57% and 4.31% at forward speed 1.0 km h^{-1}and 1.5 km h^{-1}, respectively. Due to cutting heights minimum average conveying loss observed at cutting height 200 mm of about 2.17%, followed by 2.68% at cutting height 150 mm and 3.74% at cutting height 100 mm. Due to air velocity minimum conveying loss was observed at 4 m s^{-1} air velocity of about 1.79%, followed by 2.84% and 3.97% at air velocity 3 m s^{-1} and 5 m s^{-1}, respectively as presented in Table 4.37. The detail ANOVA table is presented in Table 4.38.

Table 4.37: Effect of forward speed, cutting height and air velocity on conveying loss (%) by leafy harvester in harvesting of chickpea

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	1.72±.32	100 mm (H1)	3.74±0.68	3 m s^{-1} (V1)	2.84±0.50
1 km h^{-1} (S2)	2.57±.56	150 mm (H2)	2.68±0.60	4 m s^{-1} (V2)	1.79±0.41
1.5 km h^{-1} (S3)	4.31±.54	200 mm (H3)	2.17±0.47	5 m s^{-1} (V3)	3.97±0.68
SE(m)	0.054	SE(m)	0.054	SE(m)	0.054
CD (P=0.05)	0.154	CD (P=0.05)	0.154	CD (P=0.05)	0.154

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.11 and no significant difference was bowered at 5% level of significance. The lowest conveying loss (1.29%) was obtained at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm, whereas it was observed to be highest (5.15%) at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.12. The lowest conveying (1.06%) was obtained at forward speed of 0.5 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be highest (5.65%) at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}. It was observed that with the increase in the forward speed the conveying loss decreases significantly (CD 0.267 at 5% level) Table 4.38. It was also observed that as the air velocity increased from 3 m s^{-1} to 4 m s^{-1} the conveying loss decreased to be 58.66%, but when it was increased from 4 m s^{-1} to 5 m s^{-1} the conveying losses increased to be 121.79%. It may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

The interactive effect of cutting height and air velocity is presented in Fig 4.13. It was observed that with increase in cutting height the conveying loss increases significantly (CD = 0.267 at 5% level of significance) with all three air velocities, but the minimum conveying loss observed at air velocity 4 m s^{-1}, it may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

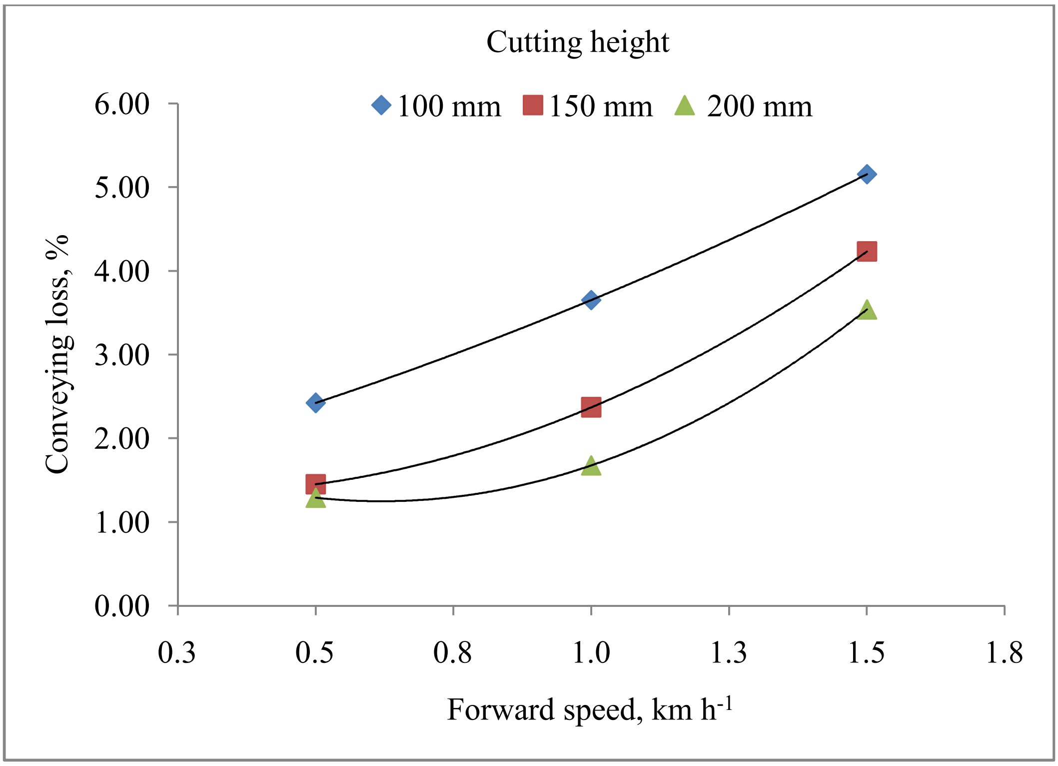


Fig. 4.11: Effect of cutting height and forward speed on conveying loss in chickpea

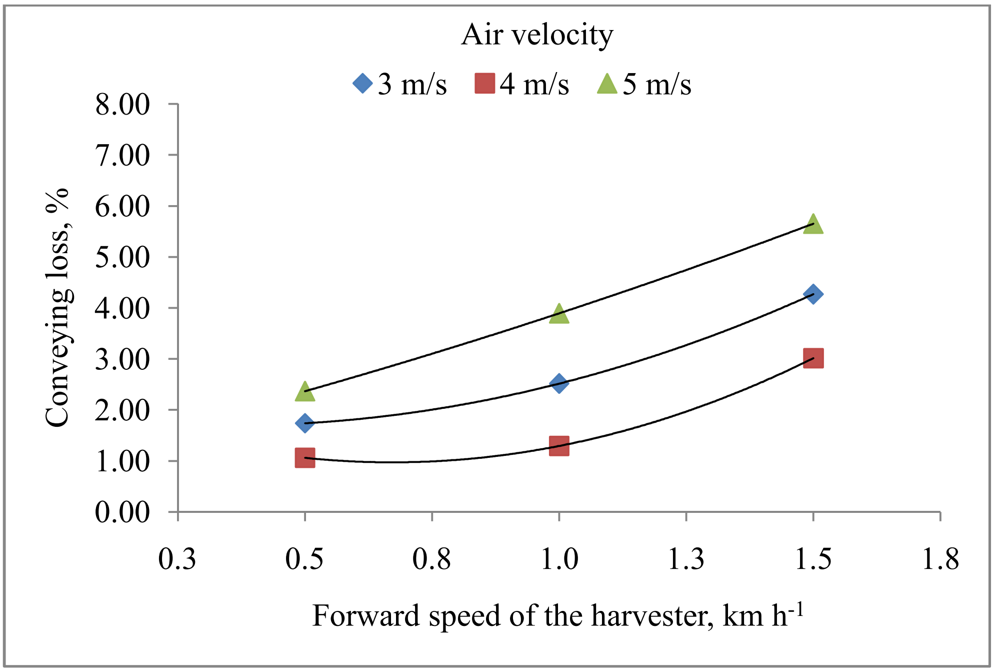


Fig. 4.12: Effect of air velocity and forward speed on conveying loss in chickpea

The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.39 and significant difference was observed (CD= 0.462) at 5% level of significance.

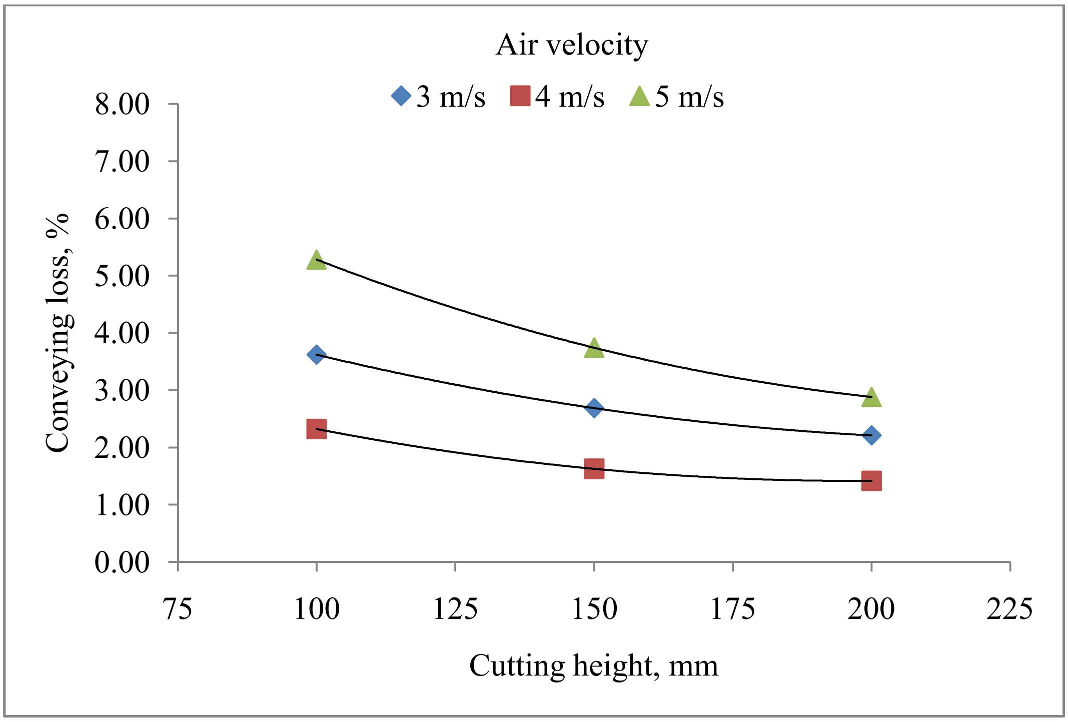


Fig. 4.13: Effect of cutting height and air velocity on conveying loss in chickpea

Table 4.38: ANOVA of conveying loss (%) of leafy crop harvester at chickpea

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.112	0.056	0.703		
Treatment	26	207.469	7.980	100.467		
Forward speed	2	94.109	47.054	592.441	0.054	0.154
Cutting height	2	34.688	17.344	218.371	0.054	0.154
Air velocity	2	64.054	32.027	403.238	0.054	0.154
S×H	4	1.872	0.468	5.891	0.094	0.267
S×V	4	5.202	1.300	16.374	0.094	0.267
H×V	4	5.239	1.310	16.491	0.094	0.267
S×H×V	8	2.306	0.288	3.629	0.163	0.462
Error	52	4.130	0.079			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.39: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	2.29	1.51	1.41	3.43	2.42	1.69	5.14	4.13	3.53	4.27
V2	1.75	0.82	0.61	2.01	1.11	0.76	3.21	2.95	2.88	3.01
V3	3.22	2.02	1.85	5.51	3.58	2.58	7.11	5.62	4.21	5.65
Mean S	2.42	1.45	1.29	3.65	2.37	1.68	5.15	4.23	3.54	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

It was also observed that at lower cutting height the conveying loss was high as compared to higher cutting height. It may be due to at lower cutting height angle of conveyor was more with the horizontal than the cutting at higher height, so the lower angle of conveyor was work effectively for conveying the harvested leaves from cutter bar to the storage tank.

4.5.1.3 Harvesting efficiency of chickpea

Harvesting efficiency is one of the most important that describe the performance of the harvester. Harvesting efficiency of developed leafy crop harvester was calculated by considering harvesting loss and conveying loss of chickpea. Harvesting efficiency was calculated by using formula as described in Chapter –III in section 3.4.5. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The maximum average header loss was observed to be 95.04% at forward speed of 1.0 km h^{-1} (S3), 94.84% at cutting height of 100 mm (H1) and 95.86% at air velocity of 4 m s^{-1} (Table 4.40). The detail of the ANOVA is given in Table 4.41. It was observed that forward speed and air velocity significantly affect the harvesting efficiency at 5% level of significance.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.14. There was significant difference observed due forward speed and cutting height (CD=0.328 at 5% level) by developed harvester on harvesting efficiency. The highest harvesting efficiency (95.40%) was obtained at forward speed of 1.0 km h^{-1} and at cutting height of 200 mm, whereas, it was observed to be lowest (93.11%) at forward speed of 0.5 km h^{-1} and at cutting height 200 mm.

Table 4.40: Effect of forward speed, cutting height and air velocity on harvesting efficiency (%) by leafy harvester in harvesting of chickpea

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	94.22±0.58	100 mm (H1)	94.76±0.59	3 m s^{-1} (V1)	93.96±0.51
1 km h^{-1} (S2)	95.04±0.54	150 mm (H2)	94.84±0.53	4 m s^{-1} (V2)	95.86±0.42
1.5 km h^{-1} (S3)	94.90±0.57	200 mm (H3)	94.55±0.61	5 m s^{-1} (V3)	94.33±0.53
SE(m)	0.067	SE(m)	0.067	SE(m)	0.067
CD (P=0.05)	0.189	CD (P=0.05)	0.189	CD (P=0.05)	0.189

The interactive effect of cutting height and air velocity is presented in Fig 4.17. There was significant difference observed due cutting height and air velocity (CD=0.328 at 5% level) by developed harvester on harvesting efficiency. The highest harvesting efficiency (96.20%) was obtained at cutting height of 100 mm and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (93.43%) at cutting height of 200 mm and at air velocity of 3 m s^{-1}. The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.42 and significant difference was observed (CD=0.568) at 5% level of significance. Operation of developed leafy crop harvester is shown in Fig 4.15 and Fig. 4.16.

Table 4.41: ANOVA of harvesting efficiency (%) of leafy crop harvester at chickpea

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.122	0.061	0.505		
Treatment	26	119.922	4.612	38.359		
Forward speed	2	10.486	5.243	43.604	0.067	0.189
Cutting height	2	1.231	0.616	5.120	0.067	0.189
Air velocity	2	54.954	27.477	228.512	0.067	0.189
S×H	4	23.614	5.904	49.097	0.116	0.328
S×V	4	16.780	4.195	34.888	0.116	0.328
H×V	4	9.180	2.295	19.086	0.116	0.328
S×H×V	8	3.677	0.460	3.822	0.200	0.568
Error	52	6.253	0.120			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

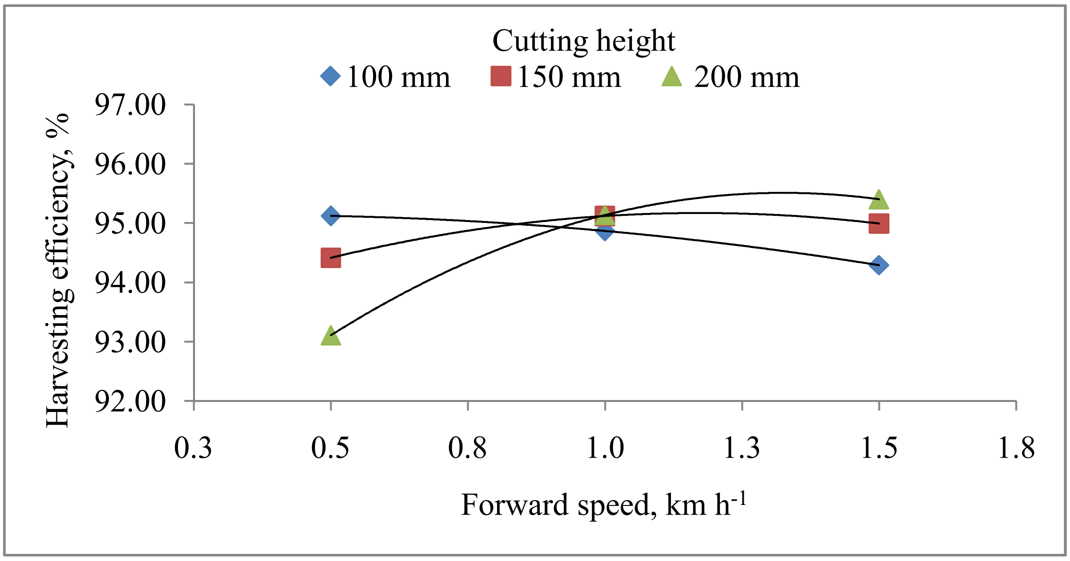


Fig. 4.14: Effect of cutting height and forward speed on harvesting efficiency in chickpea

Fig. 4.15: Operating developed leafy crop harvester in the field

Fig. 4.16: Operating developed leafy crop harvester in the field

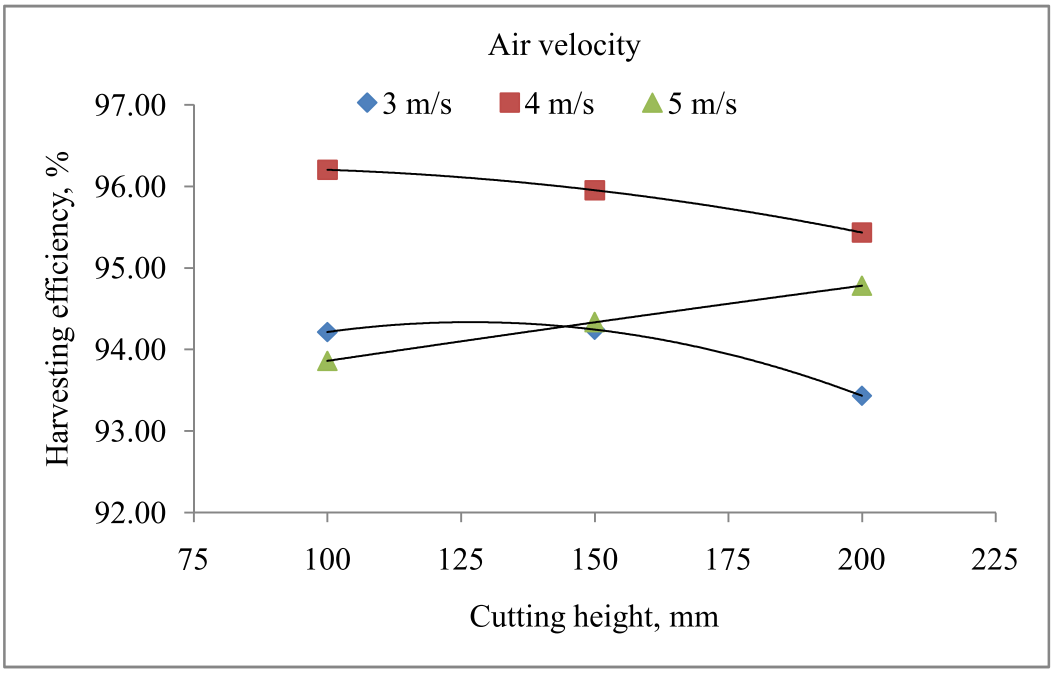


Fig. 4.17: Effect of air velocity and forward speed on harvesting efficiency in chickpea

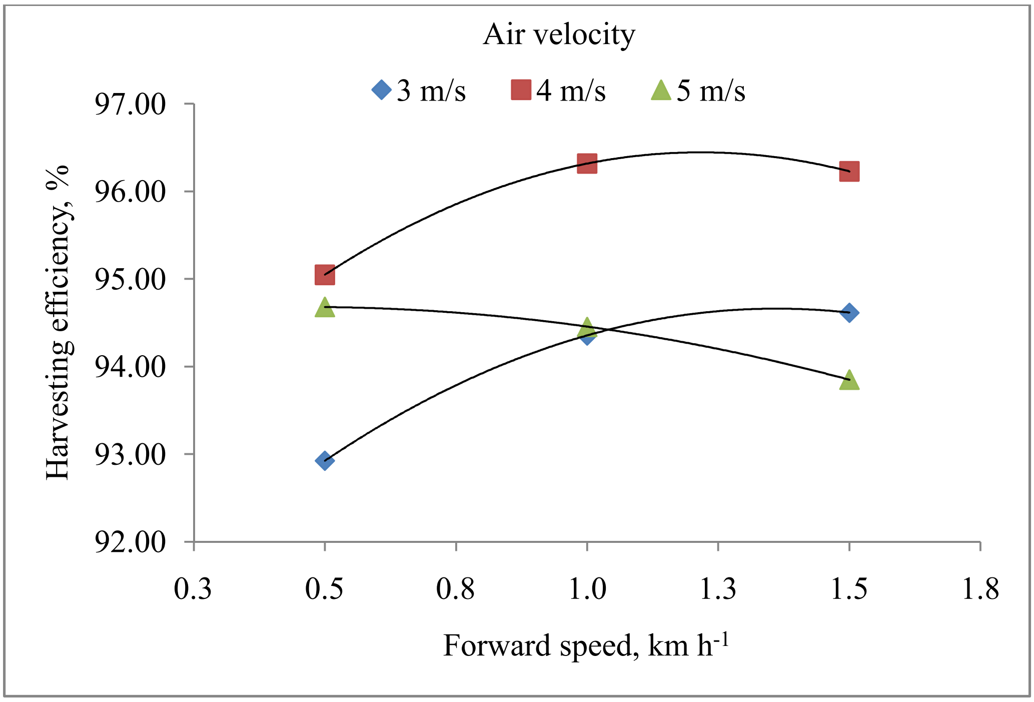


Fig. 4.18: Effect of cutting height and air velocity on harvesting efficiency in chickpea

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.18. There was significant difference observed due forward speed and air velocity

(CD=0.328 at 5% level) by developed harvester on harvesting efficiency. The highest harvesting efficiency (96.32%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (92.92%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}.

Table 4.42: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	93.95	93.36	91.46	94.52	94.45	94.09	94.17	94.92	94.75	94.61
V2	95.89	95.17	94.08	96.47	96.37	96.11	96.25	96.32	96.11	96.23
V3	95.52	94.72	93.79	93.61	94.54	95.21	92.45	93.74	95.35	93.85
Mean S	95.12	94.42	93.11	94.87	95.12	95.14	94.29	94.99	95.40	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.2 Performance evaluation for green amaranthus by developed machine

4.5.2.1 Header loss of green amaranthus

Header loss is one of the major factors that affect the performance of the harvester. Header loss was calculated by using formula as described in Chapter –III in section 3.4.5.1. The data related to the calculation of header loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The minimum average header loss was observed to be 1.90% at forward speed of 1.5 km h^{-1} (S3), 2.60% at cutting height of 100 mm (H1) and 2.81% at air velocity of 5 m s^{-1} (Table 4.43).

It was observed that the header loss decreased with increase in forward speed due to more inclination of crop at back side of cutter bar at higher speed as compared to lower speed. Similarly as the air velocity increase the header loss decrease, because air stream at air velocity 5 m s^{-1} help to move the leaves to conveyor more effectively than the air stream at air velocity 3 m s^{-1}. The detail ANOVA table is presented in Table 4.44.

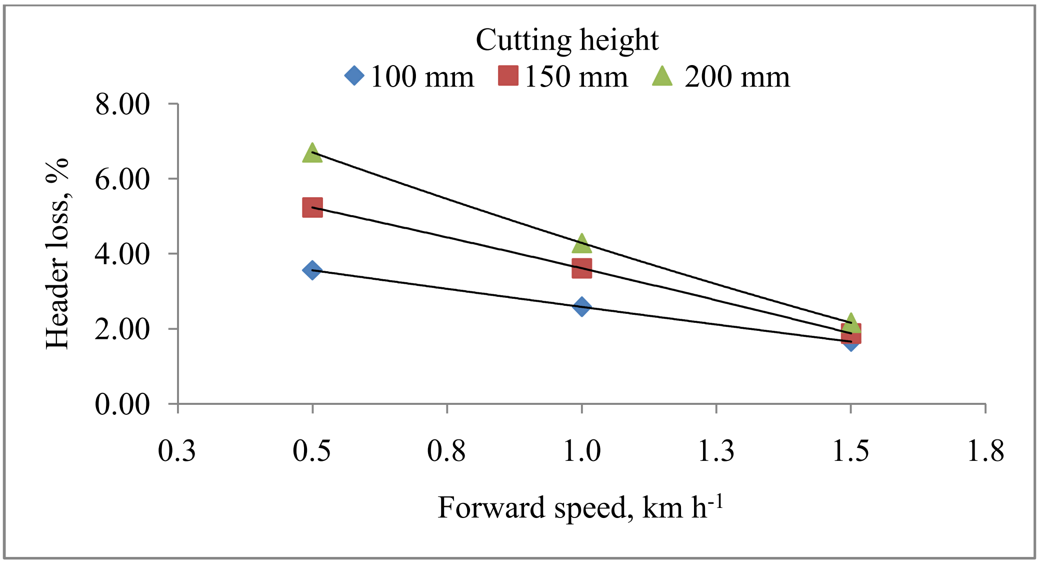
Table 4.43: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in green amarnathus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	5.16±.65	100 mm (H1)	2.60±0.42	3 m s^{-1} (V1)	4.30±0.78
1 km h^{-1} (S2)	3.49±.39	150 mm (H2)	3.57±0.60	4 m s^{-1} (V2)	3.45±0.60
1.5 km h^{-1} (S3)	1.90±.20	200 mm (H3)	4.38±0.80	5 m s^{-1} (V3)	2.81±0.52
SE(m)	0.028	SE(m)	0.028	SE(m)	0.028
CD (P=0.05)	0.078	CD (P=0.05)	0.078	CD (P=0.05)	0.078

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.19. The lowest header loss (1.66%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm, whereas it was observed to be highest (6.70%) at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm. It was also observed that with the increase in the forward speed the header loss was also decreases significantly at 5% level with CD value of 0.135 (Table 4.44). Similar result was observed by Gharkhani *et al.* (2017) due to different forward speed on header loss. It was also observed that at higher cutting height the header loss was also high as compared to lower height. It may be due to at lower speed the opportunity time for falling on the conveyer belt was less as compared to higher speed and as a result the leaves fall on the ground. It was also observed that at higher height due to its forward bending over the cutting height of the stem it may be losses on the ground. Similar result was observed by Bawatharani *et al.* (2015) due to different cutting height on header loss.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.20. The lowest header loss (1.61%) was obtained at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}, whereas, it was observed to be highest (6.44%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}. It was observed that with the increase in the forward speed the header loss was also decreases significantly (CD=0.135 at 5% level) Table 3.44. It was also observed that at higher air velocity the header loss was significantly lower as compared to lower air velocity. It may be due to the air thrust at higher air velocity reduces the chances of falling down.

The interactive effect of cutting height and air velocity is presented in Fig 4.21. It was observed that with the increase in the cutting height and air velocity the header loss was increases significantly at 5% level with CD value of 0.135 (Table 4.44). There was significant difference (CD= 0.235 at 5% level) was observed due to interactive effect between machine speed, cutting height and air velocity by developed harvester on header loss in chickpea (Table 4.45).



4.19: Effect of cutting height and forward speed on header loss in green amaranthus

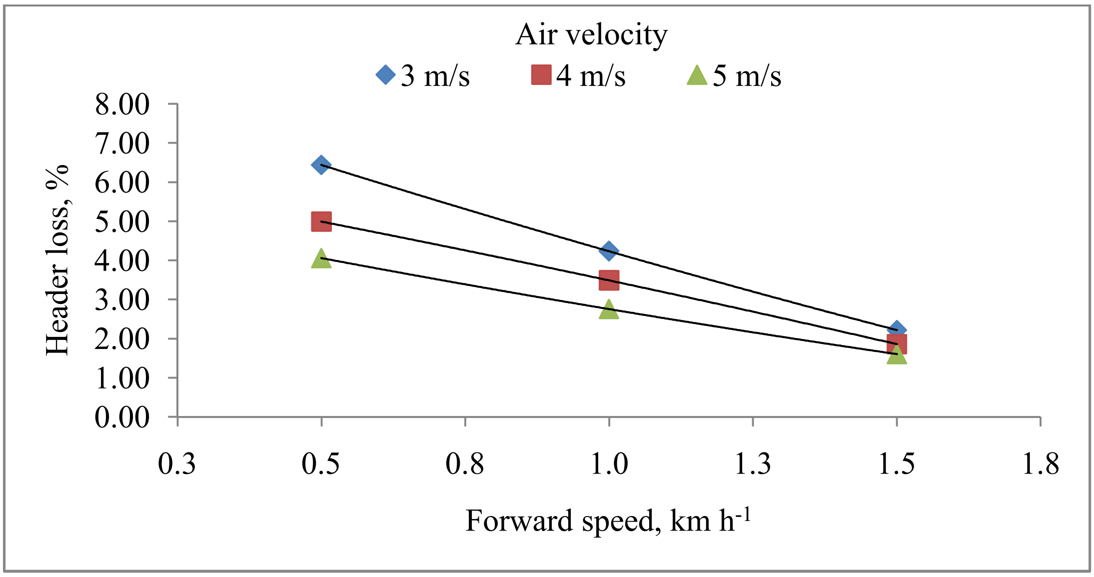


Fig. 4.20: Effect of air velocity and forward speed on header loss in green amaranthus

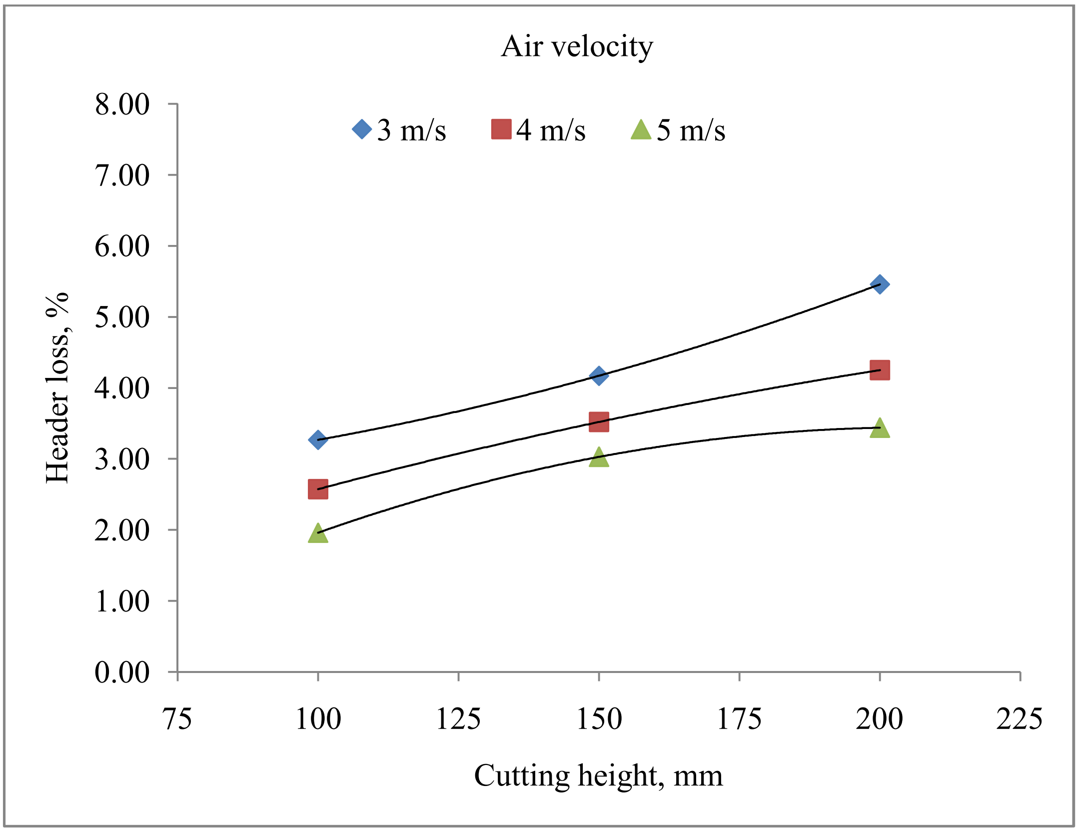


Fig. 4.21: Effect of cutting height and air velocity on header loss in green amaranthus

Table 4.44: ANOVA of header loss (%) of leafy crop harvester at green amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.017	0.008	0.408		
Treatment	26	242.663	9.333	455.302		
Forward speed	2	144.086	72.043	3514.480	0.028	0.078
Cutting height	2	43.051	21.525	1050.072	0.028	0.078
Air velocity	2	30.085	15.042	733.814	0.028	0.078
S×H	4	15.785	3.946	192.508	0.048	0.135
S×V	4	7.288	1.822	88.888	0.048	0.135
H×V	4	2.008	0.502	24.491	0.048	0.135
S×H×V	8	0.360	0.045	2.197	0.083	0.235
Error	52	1.066	0.020			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.45: Interaction S×H×V of header loss (%) on green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	4.86	6.23	8.23	3.15	4.23	5.32	1.79	2.05	2.82	2.22
V2	3.46	5.11	6.41	2.62	3.62	4.23	1.64	1.83	2.11	1.86
V3	2.36	4.36	5.46	1.98	2.98	3.31	1.54	1.74	1.55	1.61
Mean S	3.56	5.23	6.70	2.58	3.61	4.29	1.66	1.87	2.16	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.2.2 Conveying loss of green amaranthus

Conveying loss is one of the major factors that affect the performance of the harvester. It was occurred during conveying the harvested leaves from cutter bar to storage tank. Conveying loss was calculated by using formula as described in Chapter –III in section 3.4.5.2. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. Minimum average conveying loss was observed at forward speed 0.5 km h^{-1} (S1) of about 2.82%, followed by 3.67% and 5.41% at forward speed 1.0 km $h^{-1}$and 1.5 km h^{-1}, respectively. Due to cutting heights minimum average conveying loss observed at cutting height 200 mm of about 3.27%, followed by 3.78% at cutting height 150 mm and 4.84% at cutting height 100 mm. Due to air velocity minimum conveying loss was observed at 4 m s^{-1} air velocity of about 2.89%, followed by 3.94% and 5.07% at air velocity 3 m s^{-1} and 5 m s^{-1}, respectively as presented in Table 4.46. The detail ANOVA table is presented in Table 4.47.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.22 and significant difference was observed (CD=0.201) at 5% level of significance. The lowest conveying loss (2.39%) was obtained at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm, whereas it was observed to be highest (6.25%) at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm.

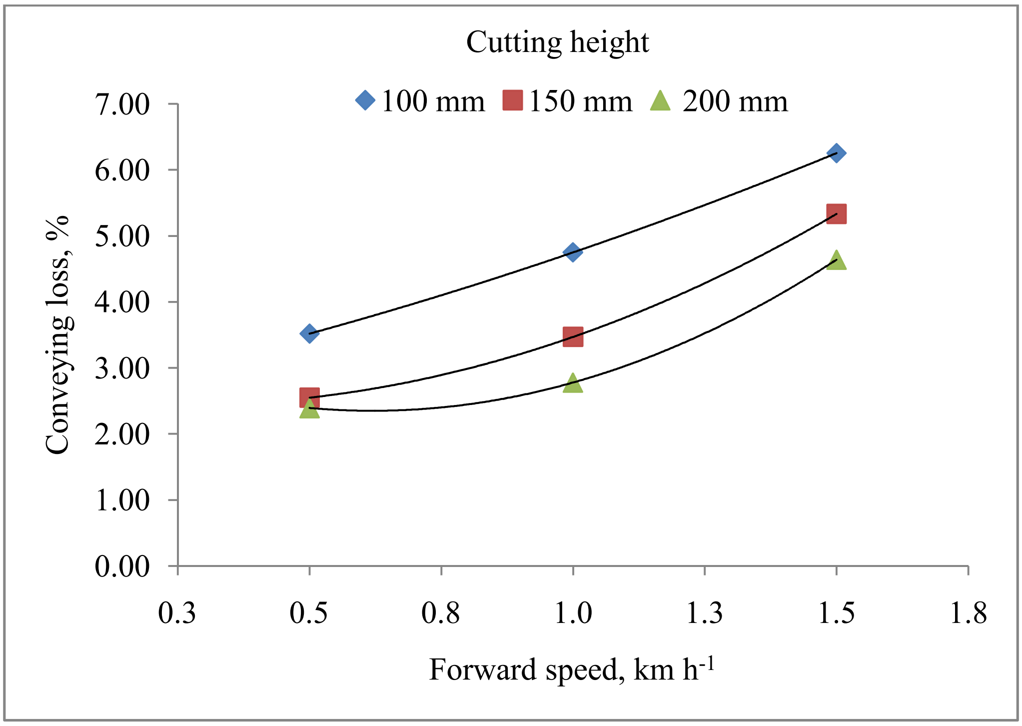


Fig. 4.22: Effect of cutting height and forward speed on conveying loss in green amaranthus

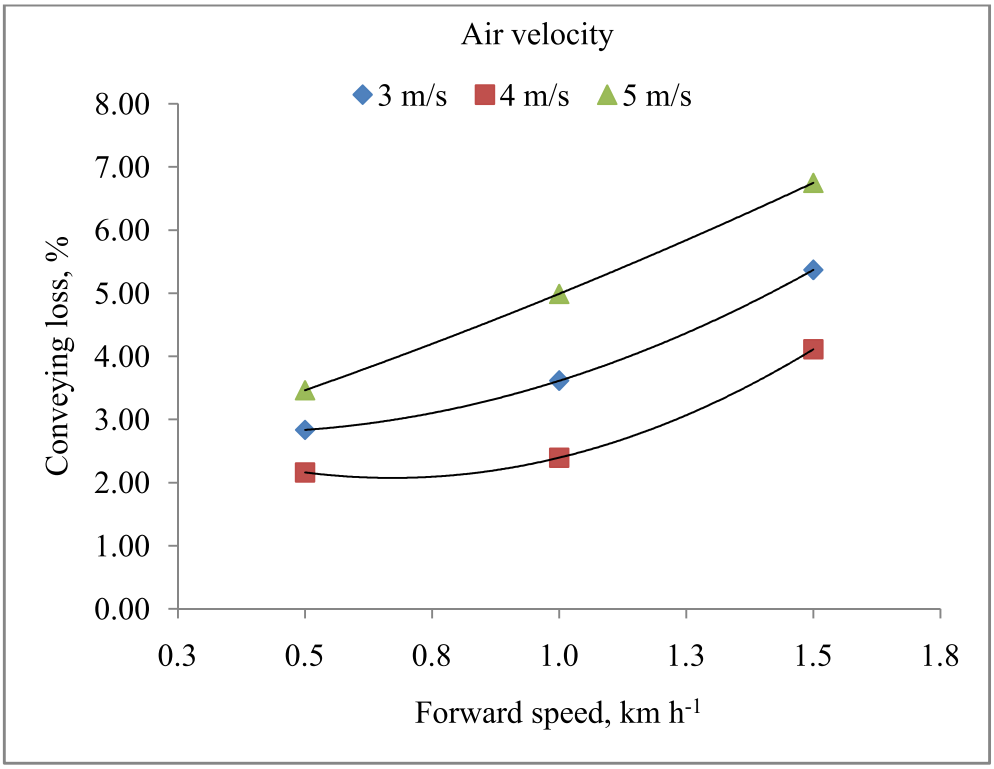


Fig. 4.23: Effect of air velocity and forward speed on conveying loss in green amaranthus

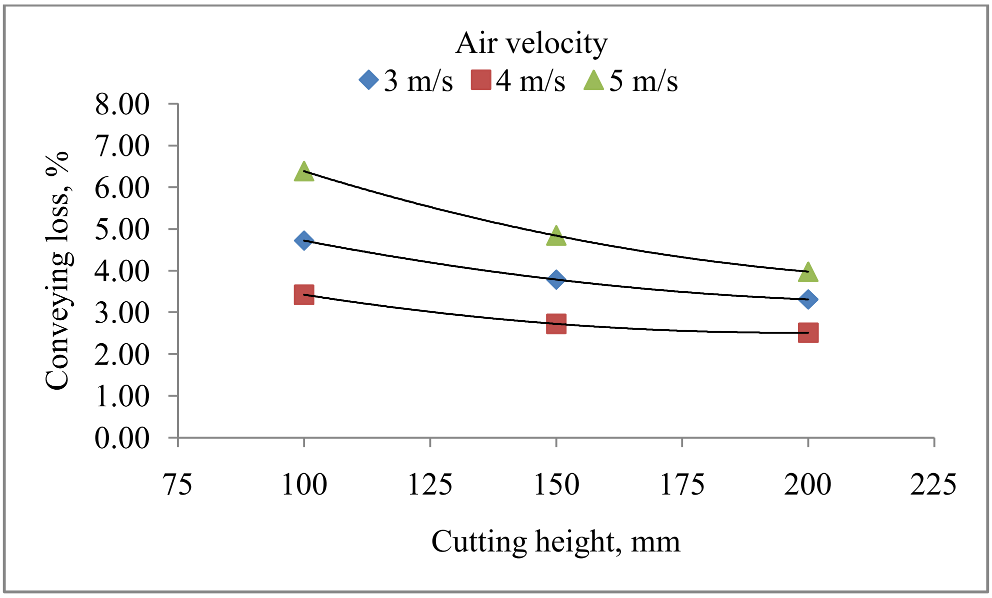


Fig. 4.24: Effect of cutting height and air velocity on conveying loss in green amaranthus

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.23. The lowest conveying (2.16%) was obtained at forward speed of 0.5 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be highest (6.75%) at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}.

It was observed that with the increase in the forward speed the conveying loss decreases significantly (CD=0.348 at 5% level) Table 4.47. It was also observed that as the air velocity increased from 3 m s^{-1} to 4 m s^{-1} the conveying loss decreased to be 36.33%, but when it was increased from 4 m s^{-1} to 5 m s^{-1} the conveying losses increased to be 75.43%. It may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

The interactive effect of cutting height and air velocity is presented in Fig 4.24. It was observed that with increase in cutting height the conveying loss increases significantly (CD = 0.348 at 5% level of significance) with all three air velocities, but the minimum conveying loss observed at air velocity 4 m s^{-1}, it may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

Table 4.46: Effect of forward speed, cutting height and air velocity on conveying loss (%) by leafy harvester in harvesting of green amaranthus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h-1 (S1)	2.82±0.32	100 mm (H1)	4.84±0.67	3 m s-1 (V1)	3.94±0.49
1 km h-1 (S2)	3.67±0.55	150 mm (H2)	3.78±0.59	4 m s-1 (V2)	2.89±0.40
1.5 km h-1 (S3)	5.41±0.54	200 mm (H3)	3.27±0.46	5 m s-1 (V3)	5.07±0.68
SE(m)	0.071	SE(m)	0.071	SE(m)	0.071
CD (P=0.05)	0.201	CD (P=0.05)	0.201	CD (P=0.05)	0.201

Table 4.47: ANOVA of conveying loss (%) of leafy crop harvester at green amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.128	0.064	0.475		
Treatment	26	207.469	7.980	59.103		
Forward speed	2	94.109	47.054	348.524	0.071	0.201
Cutting height	2	34.688	17.344	128.464	0.071	0.201
Air velocity	2	64.054	32.027	237.219	0.071	0.201
S×H	4	1.872	0.468	3.465	0.122	0.348
S×V	4	5.202	1.300	9.632	0.122	0.348
H×V	4	5.239	1.310	9.702	0.122	0.348
S×H×V	8	2.306	0.288	2.135	0.212	0.602
Error	52	7.021	0.135			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.48: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.39	2.61	2.51	4.53	3.52	2.79	6.24	5.23	4.63	5.37
V2	2.85	1.92	1.71	3.11	2.21	1.86	4.31	4.05	3.98	4.11
V3	4.32	3.12	2.95	6.61	4.68	3.68	8.21	6.72	5.31	6.75
Mean S	3.52	2.55	2.39	4.75	3.47	2.78	6.25	5.33	4.64	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

It was also observed that at lower cutting height the conveying loss was high as compared to higher cutting height. It may be due to at lower cutting height angle of conveyor was more with the horizontal than the cutting at higher height, so the lower angle of conveyor was work effectively for conveying the harvested leaves from cutter bar to the storage tank. There was significant difference (CD= 0.602 at 5% level) was observed due to interactive effect between machine speed, cutting height and air velocity by developed harvester on header loss in chickpea (Table 4.48).

4.5.2.3 Harvesting efficiency of green amaranthus

Harvesting efficiency is one of the most important that describe the performance of the harvester. Harvesting efficiency of developed leafy crop harvester was estimated by considering harvesting loss and conveying loss of green amaranthus. Harvesting efficiency was calculated by using formula as described in Chapter –III in section 3.4.5.3. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The maximum average header loss was observed to be 92.84% at forward speed of 1.0 km h^{-1} (S3), 92.64% at cutting height of 100 mm (H1) and 93.66% at air velocity of 4 m s^{-1} (Table 4.49). The detail of the ANOVA is given in Table 4.50. It was observed that forward speed and air velocity significantly affect the harvesting efficiency at 5% level of significance.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.25. There was significant difference observed (CD=0.445 at 5% level) due forward speed and cutting height by developed harvester on harvesting efficiency. The highest harvesting efficiency (93.20%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 200 mm, whereas, it was observed to be lowest (90.91%) at forward speed of 0.5 km h^{-1} and at cutting height 200 mm.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.26. There was significant difference observed (CD=0.445 at 5% level) due forward speed and air velocity by developed harvester on harvesting efficiency. The highest harvesting efficiency (94.12%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (90.72%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}.

The interactive effect of cutting height and air velocity is presented in Fig 4.27. It was observed that there is no significant effect of the two factors at 5% level. There was significant difference observed (CD=0.445 at 5% level) due cutting height and air velocity by developed harvester on harvesting efficiency.

Table 4.49: Effect of forward speed, cutting height and air velocity on harvesting efficiency (%) by leafy harvester in harvesting of green amaranthus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h-1 (S1)	92.02±0.57	100 mm (H1)	92.56±0.57	3 m s-1 (V1)	91.76±0.49
1 km h-1 (S2)	92.84±0.49	150 mm (H2)	92.64±0.51	4 m s-1 (V2)	93.66±0.39
1.5 km h-1 (S3)	92.70±0.55	200 mm (H3)	92.35±0.59	5 m s-1 (V3)	92.13±0.49
SE(m)	0.091	SE(m)	0.091	SE(m)	0.091
CD (P=0.05)	0.257	CD (P=0.05)	NS	CD (P=0.05)	0.257

The highest harvesting efficiency (94.00%) was obtained at cutting height of 100 mm and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (91.23%) at cutting height of 200 mm and at air velocity of 3 m s^{-1}. The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.51 and significant difference was observed at 5% level of significance.

Table 4.50: ANOVA of harvesting efficiency (%) of leafy crop harvester at green amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.167	0.084	0.378		
Treatment	26	119.847	4.610	20.810		
Forward speed	2	10.465	5.232	23.623	0.091	0.257
Cutting height	2	1.251	0.626	2.825	0.091	NS
Air velocity	2	55.001	27.500	124.156	0.091	0.257
S×H	4	23.533	5.883	26.561	0.157	0.445
S×V	4	16.859	4.215	19.029	0.157	0.445
H×V	4	9.105	2.276	10.276	0.157	0.445
S×H×V	8	3.633	0.454	2.050	0.272	NS
Error	52	11.518	0.221			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.51: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	91.75	91.16	89.26	92.32	92.25	91.89	91.97	92.72	92.55	92.41
V2	93.69	92.97	91.88	94.27	94.17	93.91	94.05	94.12	93.91	94.03
V3	93.32	92.52	91.59	91.41	92.34	93.01	90.25	91.54	93.15	91.65
Mean S	92.92	92.22	90.91	92.67	92.92	92.94	92.09	92.79	93.20	

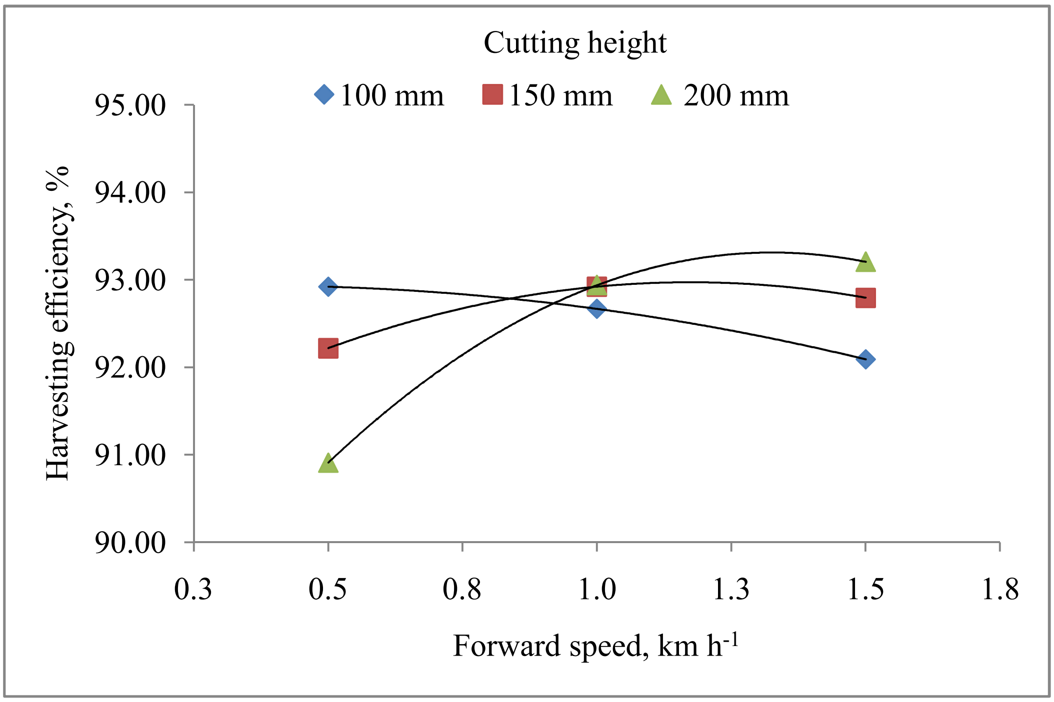


Fig. 4.25: Effect of cutting height and forward speed on harvesting efficiency in green amaranthus

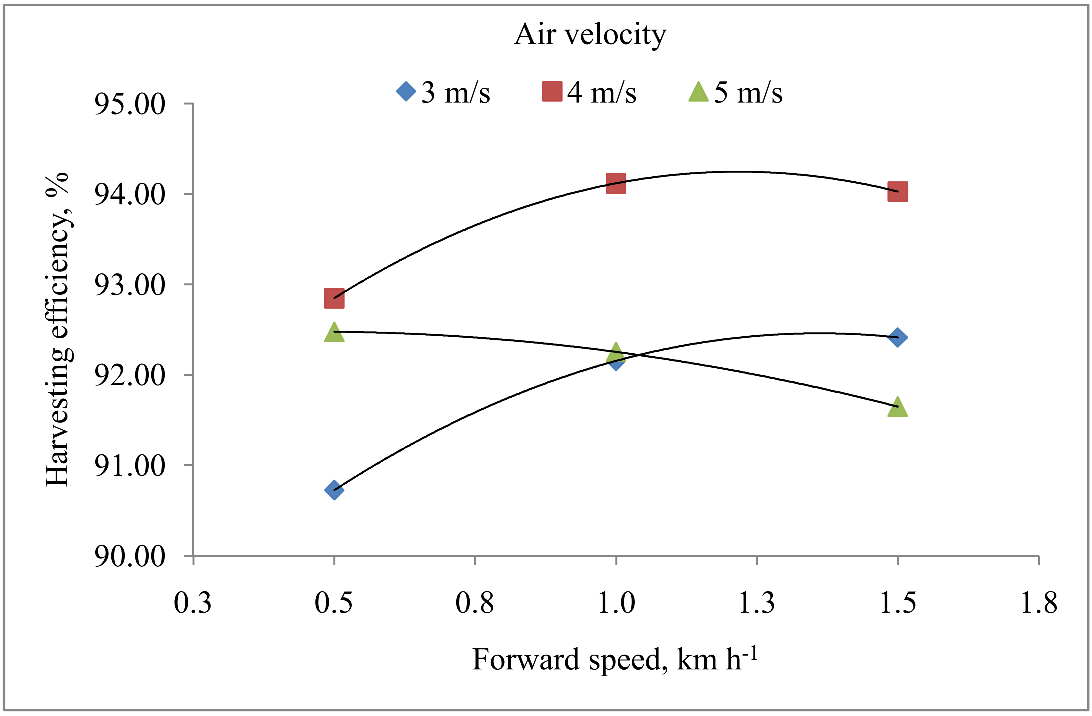


Fig. 4.26: Effect of air velocity and forward speed on harvesting efficiency in green amaranthus

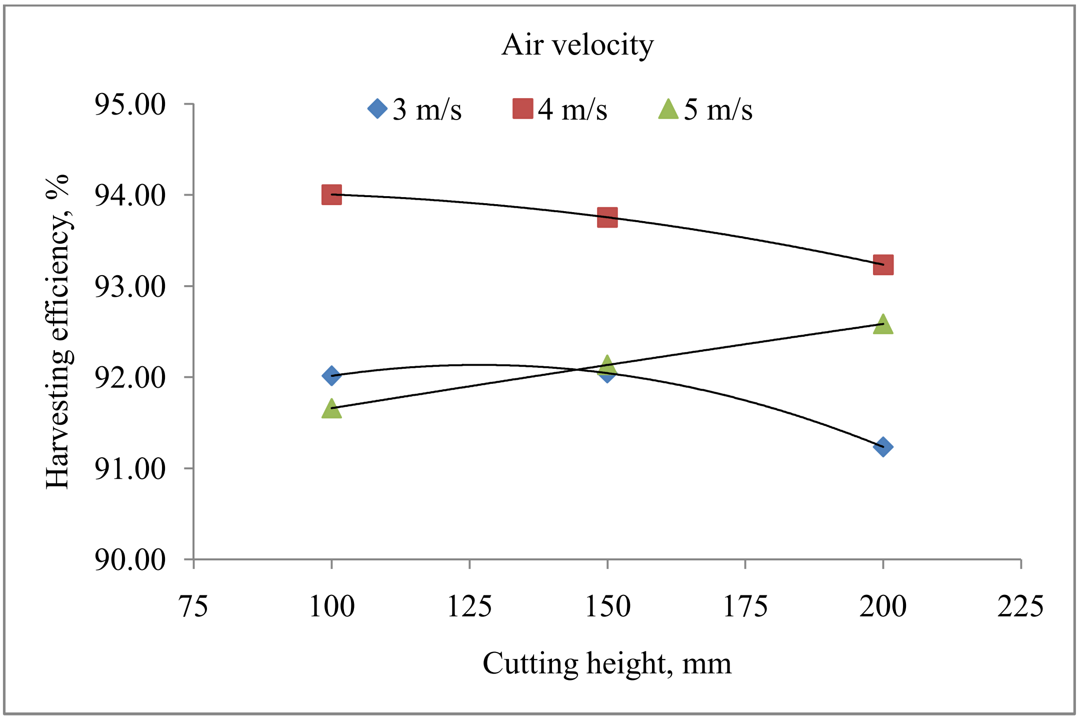


Fig. 4.27: Effect of cutting height and air velocity on harvesting efficiency in green amaranthus

4.5.3 Performance evaluation for red amaranthus by developed machine

4.5.3.1 Header loss of red amaranthus

Header loss is one of the major factors that affect the performance of the harvester. Header loss was calculated by using formula as described in Chapter –III in section 3.4.5.1. The data related to the calculation of header loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The minimum average header loss was observed to be 2.23% at forward speed of 1.5 km h^{-1} (S3), 2.89% at cutting height of 100 mm (H1) and 3.03% at air velocity of 5 m s^{-1} (Table 4.52). It was observed that the header loss decreased with increase in forward speed due to more inclination of crop at back side of cutter bar at higher speed as compared to lower speed. Similarly as the air velocity increase the header loss decrease, because air stream at air velocity 5 m s^{-1} help to move the leaves to conveyor more effectively than the air stream at air velocity 3 m s^{-1}. The detail ANOVA table is presented in Table 4.53.

Table 4.52: Effect of forward speed, cutting height and air velocity on header loss (%) by leafy harvester in harvesting of red amaranthus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	5.33±.66	100 mm (H1)	2.89±0.46	3 m s^{-1} (V1)	4.54±0.77
1 km h^{-1} (S2)	3.72±.44	150 mm (H2)	3.81±0.62	4 m s^{-1} (V2)	3.70±0.61
1.5 km h^{-1} (S3)	2.23±.28	200 mm (H3)	4.57±0.79	5 m s^{-1} (V3)	3.03±0.54
SE(m)	0.041	SE(m)	0.041	SE(m)	0.041
CD (P=0.05)	0.116	CD (P=0.05)	0.116	CD (P=0.05)	0.116

Table 4.53: ANOVA of header loss (%) of leafy crop harvester at red amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.035	0.018	0.391		
Treatment	26	222.324	8.551	190.777		
Forward speed	2	129.710	64.855	1446.969	0.041	0.116
Cutting height	2	38.007	19.003	423.981	0.041	0.116
Air velocity	2	30.630	15.315	341.691	0.041	0.116
S×H	4	14.400	3.600	80.320	0.071	0.200
S×V	4	7.265	1.816	40.519	0.071	0.200
H×V	4	1.543	0.386	8.605	0.071	0.200
S×H×V	8	0.769	0.096	2.143	0.122	0.347
Error	52	2.331	0.045			
Total	80					

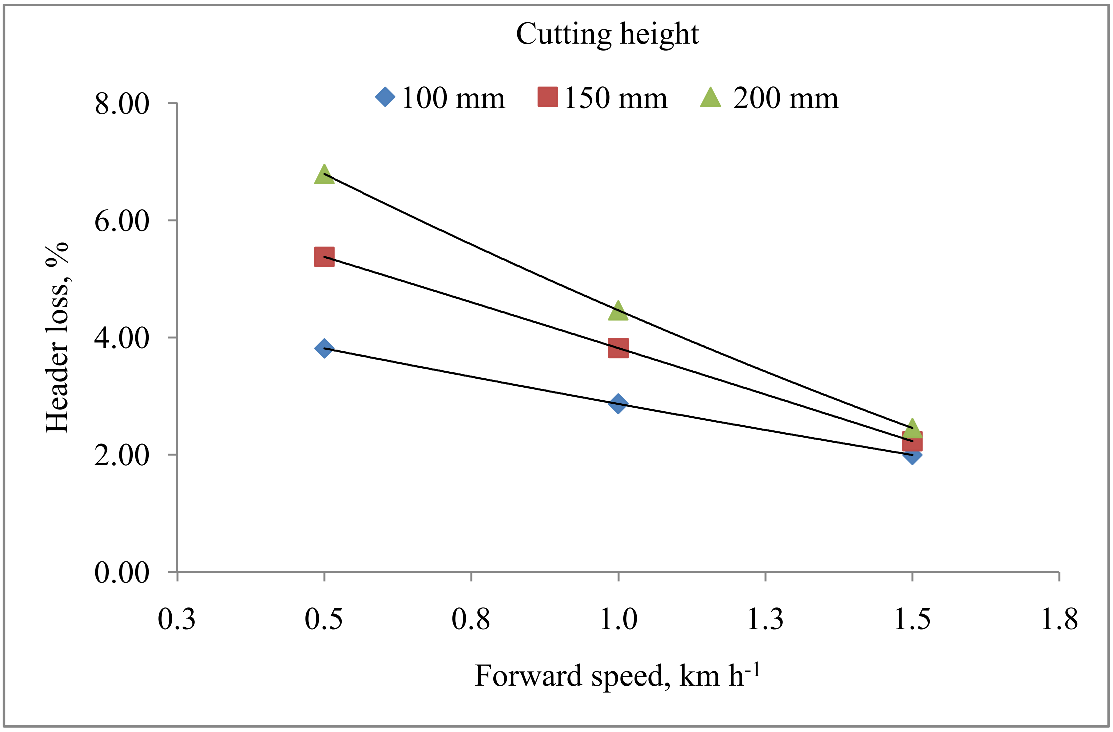
S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.28. The lowest header loss (2.00%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm, whereas it was observed to be highest (6.97%) at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm. It was also observed that with the increase in the forward speed the header loss was also decreases significantly at 5% level with CD value of 0.20 (Table 4.53). Similar result was observed by Gharkhani *et al.* (2017) due to different forward speed on header loss. It was also observed that at higher cutting height the header loss was also high as compared to lower height. It may be due to at lower speed the opportunity time for falling on the conveyer belt was less as compared to higher speed and as a result the leaves fall on the ground. It was also observed that at higher height due to its forward bending over the cutting height of the stem it may be losses on the ground. Similar result was observed by Bawatharani *et al.* (2015) due to different cutting height on header loss.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.29. The lowest header loss (1.90%) was obtained at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}, whereas, it was observed to be highest (6.63%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}. It was observed that with the increase in the forward speed the header loss was also decreases significantly (CD=0.20 at 5% level) Table 3.53. It was also observed that at higher air velocity the header loss was significantly lower as compared to lower air velocity. It may be due to the air thrust at higher air velocity reduces the chances of falling down.



4.28: Effect of cutting height and forward speed on header loss in red amaranthus

The interactive effect of cutting height and air velocity is presented in Fig 4.30. There was significant difference observed (CD=0.20 at 5% level) due cutting height and air velocity by developed harvester on header loss. It was also observed that there is significant effect (CD=0.347 at 5% level) of combination of the three factor viz. machine speed, cutting height and air velocity. The interactive effect is presented in Table 4.54.

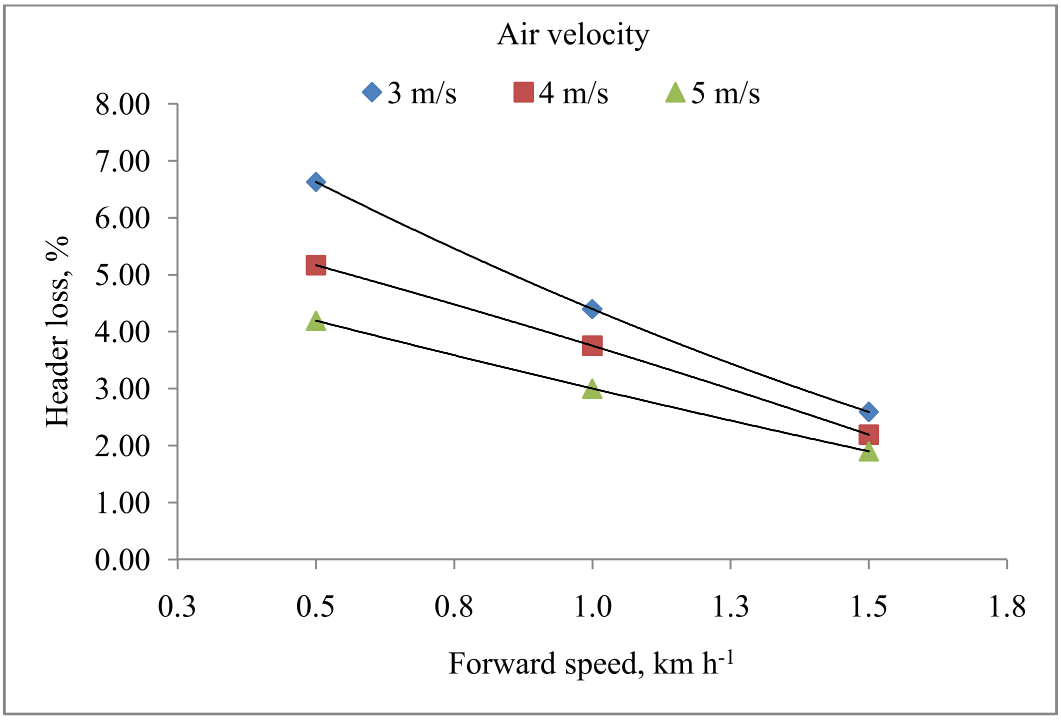


Fig. 4.29: Effect of air velocity and forward speed on header loss in red amaranthus

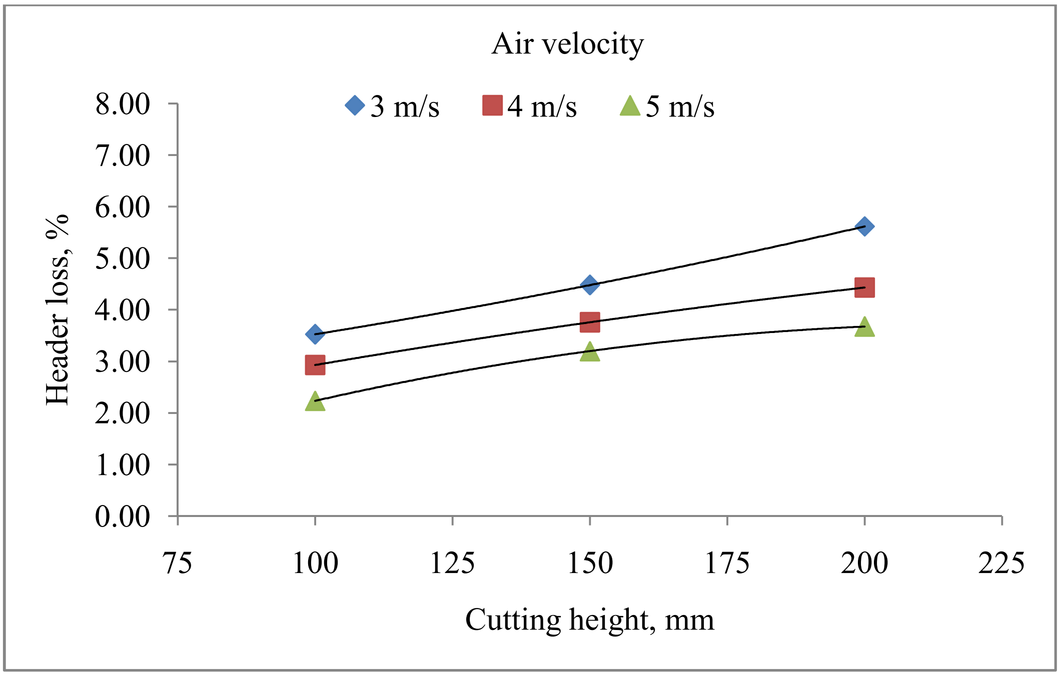


Fig. 4.30: Effect of cutting height and air velocity on header loss in red amaranthus

Table 4.54: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in red amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	5.16	6.40	8.33	3.32	4.46	5.40	2.08	2.57	3.12	2.59
V2	3.76	5.24	6.49	2.96	3.92	4.38	2.07	2.11	2.41	2.19
V3	2.53	4.49	5.56	2.33	3.08	3.61	1.85	2.02	1.84	1.90
Mean S	3.82	5.38	6.79	2.87	3.82	4.47	2.00	2.23	2.46	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.3.2 Conveying loss of red amaranthus

Conveying loss is one of the major factors that affect the performance of the harvester. It was occurred during conveying the harvested leaves from cutter bar to storage tank. Conveying loss was calculated by using formula as described in Chapter –III in section 3.4.5.2. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. Minimum average conveying loss was observed at forward speed 0.5 km h^{-1} (S1) of about 2.97%, followed by 3.90% and 5.70% at forward speed 1.0 km $h^{-1}$and 1.5 km h^{-1}, respectively. Due to cutting heights minimum average conveying loss observed at cutting height 200 mm of about 3.47%, followed by 4.00% at cutting height 150 mm and 5.10% at cutting height 100 mm. Due to air velocity minimum conveying loss was observed at 4 m s^{-1} air velocity of about 3.10%, followed by 4.18% and 5.30% at air velocity 3 m s^{-1} and 5 m s^{-1}, respectively as presented in Table 4.55. The detail ANOVA table is presented in Table 4.56.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.31 and significant difference was observed (CD=0.316) at 5% level of significance. The lowest conveying loss (2.53%) was obtained at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm, whereas it was observed to be highest (6.53%) at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm.

Table 4.55: Effect of forward speed, cutting height and air velocity on conveying loss (%) by leafy harvester in harvesting of red amaranthus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	2.97±0.40	100 mm (H1)	5.10±0.70	3 m s^{-1} (V1)	4.18±0.53
1 km h^{-1} (S2)	3.90±0.58	150 mm (H2)	4.00±0.65	4 m s^{-1} (V2)	3.10±0.49
1.5 km h^{-1} (S3)	5.70±0.57	200 mm (H3)	3.47±0.52	5 m s^{-1} (V3)	5.30±0.72
SE(m)	0.064	SE(m)	0.064	SE(m)	0.064
CD (P=0.05)	0.183	CD (P=0.05)	0.183	CD (P=0.05)	0.183

Table 4.56: ANOVA of conveying loss (%) of leafy crop harvester at green amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.146	0.073	0.650		
Treatment	26	221.385	8.515	76.063		
Forward speed	2	103.964	51.982	464.356	0.064	0.183
Cutting height	2	37.365	18.682	166.889	0.064	0.183
Air velocity	2	65.544	32.772	292.753	0.064	0.183
S×H	4	2.118	0.529	4.730	0.112	0.316
S×V	4	4.587	1.147	10.243	0.112	0.316
H×V	4	5.467	1.367	12.210	0.112	0.316
S×H×V	8	2.340	0.292	2.613	0.193	0.548
Error	52	5.821	0.112			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.32. The lowest conveying (2.22%) was obtained at forward speed of 0.5 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be highest (7.06%) at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}. It was observed that with the increase in the forward speed the conveying loss decreased. It was also observed that as the air velocity increased from 3 m s^{-1} to 4 m s^{-1} the conveying loss decreased to be 34.84%, but when it was increased from 4 m s^{-1} to 5 m s^{-1} the conveying losses increased to be 90.97%. It may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

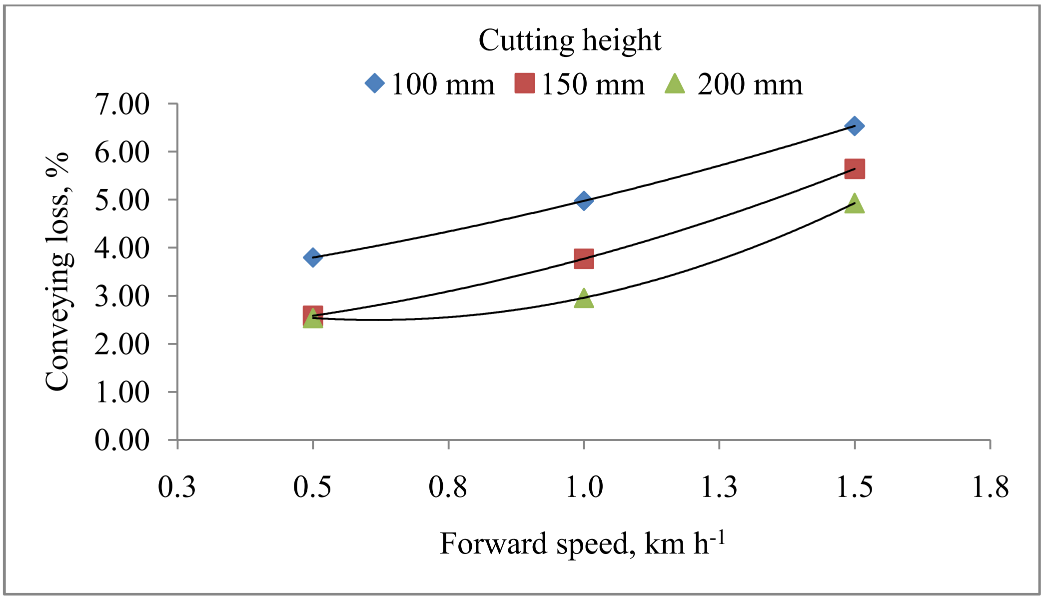


Fig. 4.31: Effect of cutting height and forward speed on conveying loss in red amaranthus

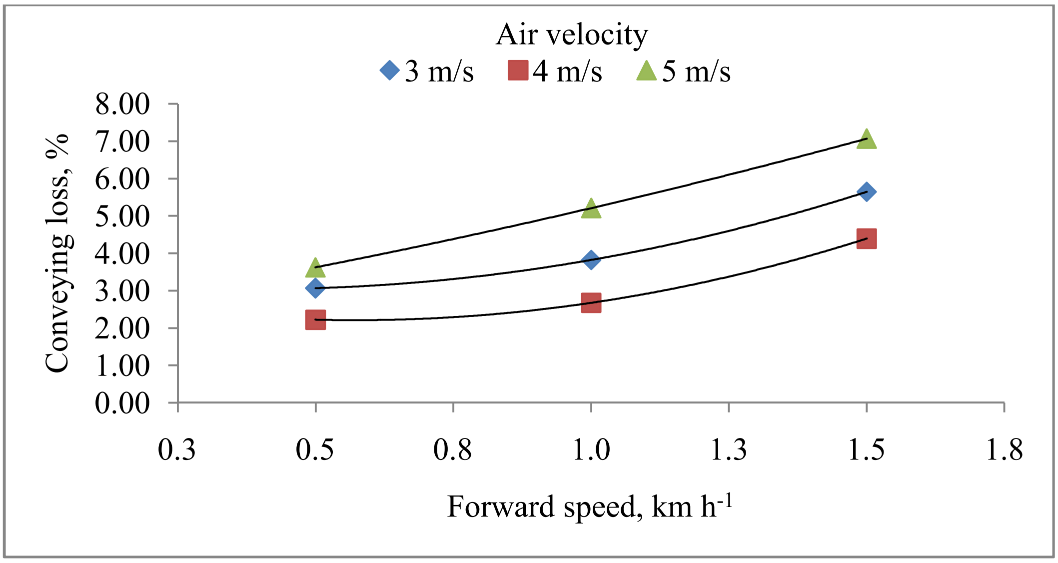


Fig. 4.32: Effect of air velocity and forward speed on conveying loss in red amaranthus

The interactive effect of cutting height and air velocity is presented in Fig 4.33. There was significant difference observed (CD=0.316 at 5% level) due cutting height and air velocity by developed harvester on conveying loss. It was observed that with increase in cutting height the conveying loss increases with all three air velocities, but the minimum conveying loss observed at air velocity 4 m s^{-1}, it may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer. It was also observed that at lower cutting height the conveying loss was high as compared to higher cutting height. It may be due to at lower cutting height angle of conveyor was more with the horizontal than the cutting at higher height, so the lower angle of conveyor was work effectively for conveying the harvested leaves from cutter bar to the storage tank. The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.57 and significant difference was observed (CD=0.548) at 5% level of significance.

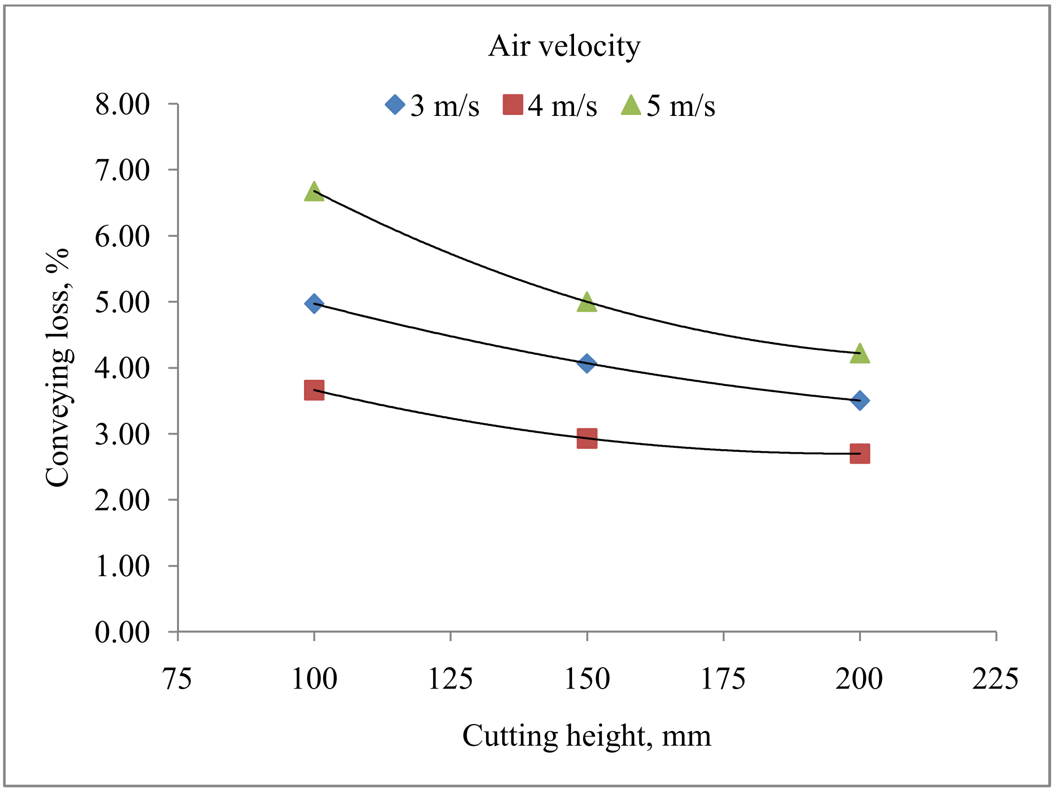


Fig. 4.33: Effect of cutting height and air velocity on conveying loss in red amaranthus

Table 4.57: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in red amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.79	2.69	2.71	4.70	3.89	2.87	6.41	5.62	4.92	5.65
V2	3.02	1.82	1.83	3.36	2.64	2.01	4.60	4.32	4.25	4.39
V3	4.59	3.23	3.06	6.86	4.78	3.98	8.58	6.99	5.61	7.06
Mean S	3.80	2.58	2.53	4.98	3.77	2.96	6.53	5.64	4.92	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.3.3 Harvesting efficiency of amaranths red

Harvesting efficiency is one of the most important that describe the performance of the harvester. Harvesting efficiency of developed leafy crop harvester was estimated by considering harvesting loss and conveying loss of red amaranthus. Harvesting efficiency was calculated by using formula as described in Chapter –III in section 3.4.5.3. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The maximum average header loss was observed to be 92.84% at forward speed of 1.0 km h^{-1} (S3), 92.64% at cutting height of 100 mm (H1) and 93.66% at air velocity of 4 m s^{-1} (Table 4.58). The detail of the ANOVA is given in Table 4.59. It was observed that forward speed and air velocity significantly affect (CD=0.275 at 5% level) the harvesting efficiency.

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.34. There was significant difference observed (CD=0.477 at 5% level) due forward speed and cutting height by developed harvester on harvesting efficiency. The highest harvesting efficiency (92.62%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 200 mm, whereas, it was observed to be lowest (90.67%) at forward speed of 0.5 km h^{-1} and at cutting height 200 mm.

Table 4.58: Effect of forward speed, cutting height and air velocity on harvesting efficiency (%) by leafy harvester in harvesting of red amaranthus

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	91.70±0.56	100 mm (H1)	92.00±0.56	3 m s^{-1} (V1)	91.28±0.39
1 km h^{-1} (S2)	92.38±0.44	150 mm (H2)	92.19±0.45	4 m s^{-1} (V2)	93.20±0.34
1.5 km h^{-1} (S3)	92.07±0.52	200 mm (H3)	91.96±0.54	5 m s^{-1} (V3)	91.67±0.49
SE(m)	0.097	SE(m)	0.097	SE(m)	0.097
CD (P=0.05)	0.275	CD (P=0.05)	NS	CD (P=0.05)	0.275

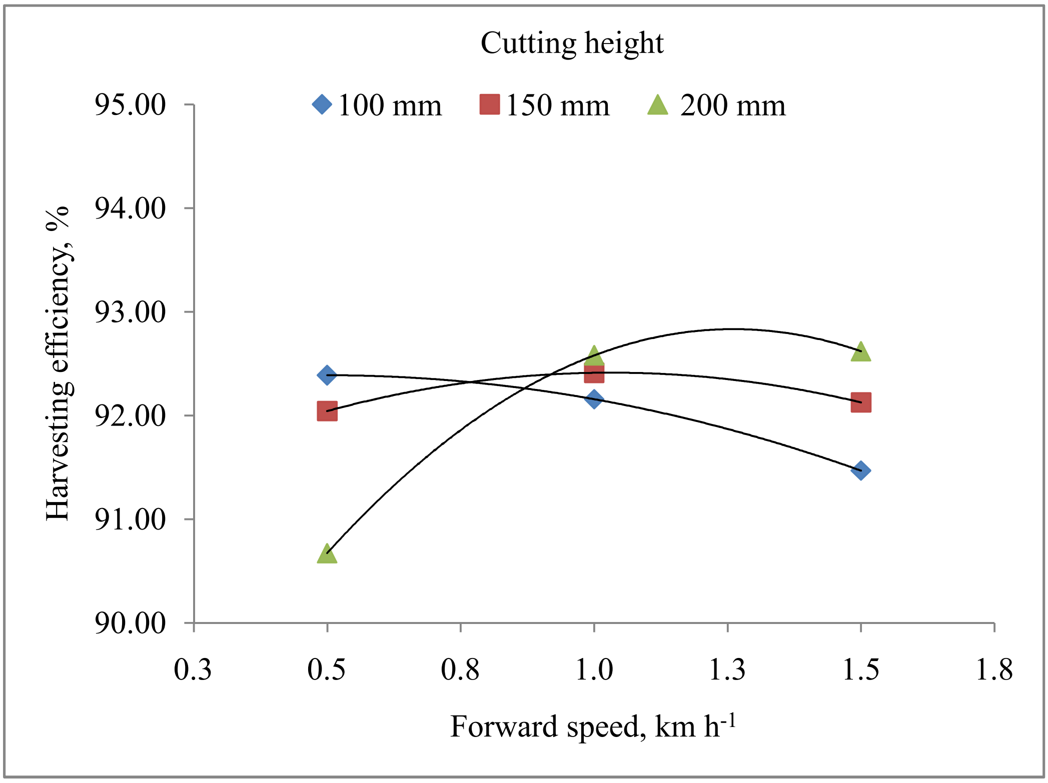


Fig. 4.34: Effect of cutting height and forward speed on harvesting efficiency in red amaranthus

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.35. There was significant difference observed (CD=0.477 at 5% level) due forward speed and air velocity by developed harvester on harvesting efficiency. The highest harvesting efficiency (93.57%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (90.31%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}.

Table 4.59: ANOVA of harvesting efficiency (%) of leafy crop harvester on red amaranthus

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.217	0.109	0.427		
Treatment	26	113.387	4.361	17.168		
Forward speed	2	6.318	3.159	12.436	0.097	0.275
Cutting height	2	0.834	0.417	1.643	0.097	NS
Air velocity	2	55.545	27.773	109.331	0.097	0.275
S×H	4	20.699	5.175	20.372	0.168	0.477
S×V	4	17.449	4.362	17.173	0.168	0.477
H×V	4	7.804	1.951	7.680	0.168	0.477
S×H×V	8	4.737	0.592	2.331	0.291	0.826
Error	52	13.209	0.254			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.60: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in red amaranthus

Factors	S1			S2			S3			Mean D
	H1	H2	H3	H1	H2	H3	H1	H2	H3	
V1	91.05	90.91	88.96	91.97	91.65	91.72	91.51	91.82	91.96	91.76
V2	93.22	92.94	91.68	93.68	93.44	93.60	93.33	93.57	93.34	93.41
V3	92.89	92.28	91.37	90.81	92.15	92.41	89.57	90.99	92.55	91.04
Mean S	92.39	92.04	90.67	92.16	92.41	92.58	91.47	92.13	92.62	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

The interactive effect of cutting height and air velocity is presented in Fig 4.36. There was significant difference observed (CD=0.477 at 5% level) due cutting height and air velocity by developed harvester on harvesting efficiency. The highest harvesting efficiency (93.41%) was obtained at cutting height of 100 mm and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (90.88%) at cutting height of 200 mm and at air velocity of 3 m s^{-1}. The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was also presented in Table 4.60 and significant difference was observed (CD=0.826) at 5% level of significance.

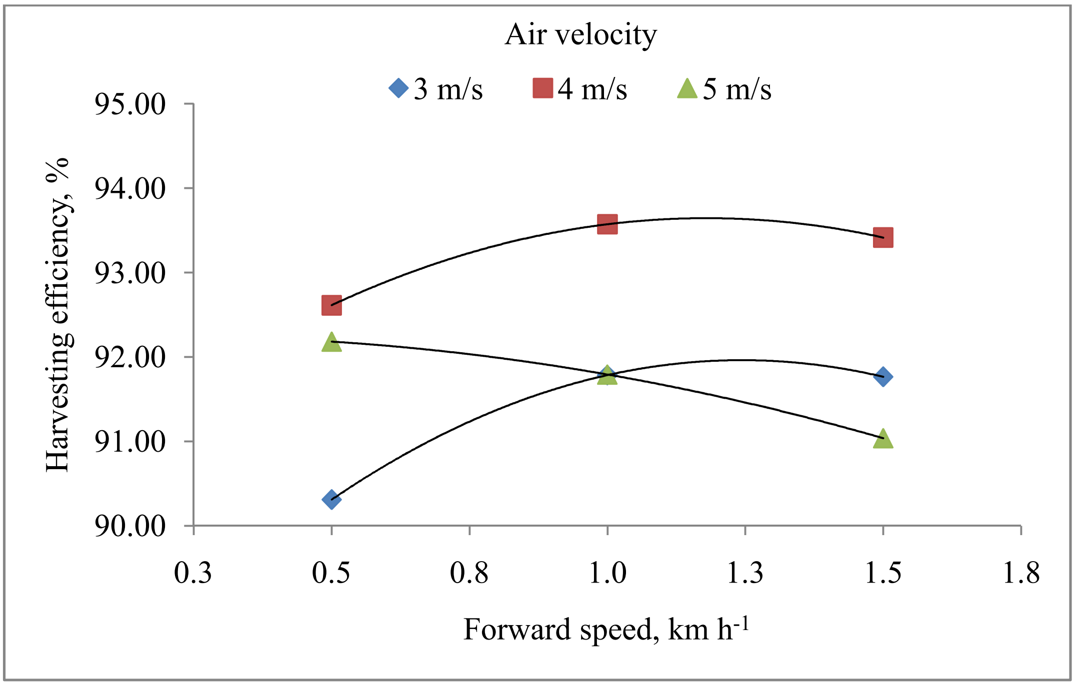


Fig. 4.35: Effect of air velocity and forward speed on harvesting efficiency in red amaranthus

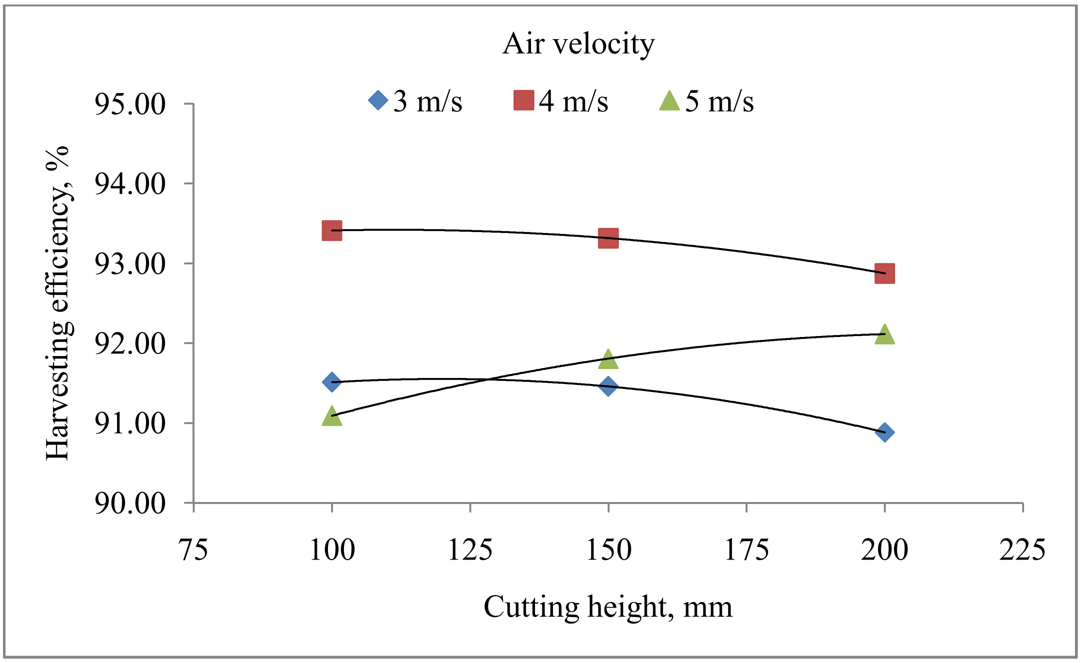


Fig. 4.36: Effect of cutting height and air velocity on harvesting efficiency in red amaranthus

4.5.4 Performance evaluation for fenugreek by developed machine

4.5.4.1 Header loss of fenugreek

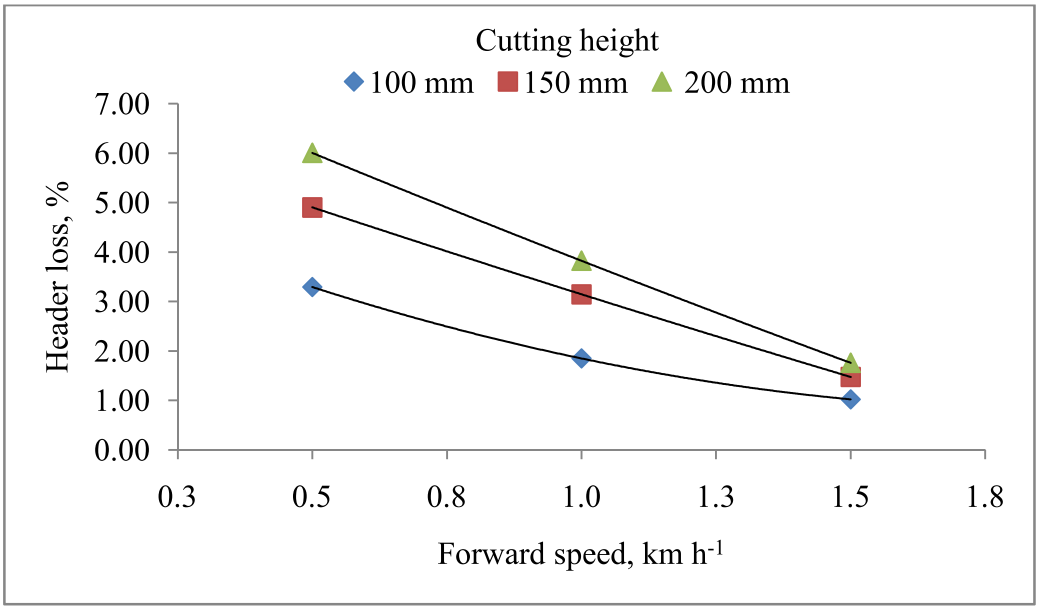
Header loss is one of the major factors that affects the performance of the harvester. Header loss was calculated by using formula as described in Chapter –III in section 4.5.3.1. The data related to the calculation of header loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The minimum average header loss was observed 1.42% at forward speed of 1.5 km h^{-1} (S3), 2.06 at cutting height of 100 mm (H1) and 2.32 at air velocity of 5 m s^{-1} (Table 4.61). It was observed that the header loss decreased with increase in forward speed due to more inclination of crop at back side of cutter bar at higher speed as compared to lower speed. Similarly as the air velocity increase the header loss decrease, because air stream at air velocity 5 m s^{-1} help to move the leaves to conveyor more effectively than the air stream at air velocity 3 m s^{-1}. The detail ANOVA table is presented in Table 4.62.

Table 4.61: Effect of forward speed, cutting height and air velocity on header loss (%) by leafy harvester in harvesting of fenugreek

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	4.73±.60	100 mm (H1)	2.06±0.44	3 m s^{-1} (V1)	3.80±0.80
1 km h^{-1} (S2)	2.94±.42	150 mm (H2)	3.17±0.62	4 m s^{-1} (V2)	2.97±0.59
1.5 km h^{-1} (S3)	1.42±.23	200 mm (H3)	3.86±0.76	5 m s^{-1} (V3)	2.32±0.51
SE(m)	0.047	SE(m)	0.047	SE(m)	0.047
CD (P=0.05)	0.132	CD (P=0.05)	0.132	CD (P=0.05)	0.132

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.37. The lowest header loss (1.02%) was obtained at forward speed of 1.5 km h^{-1} and at cutting height of 100 mm, whereas it was observed to be highest (6.0%) at forward speed of 0.5 km h^{-1} and at cutting height of 200 mm. It was also observed that with the increase in the forward speed the header loss was also decreases significantly at 5% level with CD value of 0.229 (Table 4.62). Similar result was observed by Gharkhani *et al.* (2017) due to different forward speed on header loss.

It was also observed that at higher cutting height the header loss was also high as compared to lower height. It may be due to at lower speed the opportunity time for falling on the conveyer belt was less as compared to higher speed and as a result the leaves fall on the ground. It was also observed that at higher height due to its forward bending over the cutting height of the stem it may be losses on the ground. Similar result was observed by Bawatharani *et al.* (2015) due to different cutting height on header loss.



4.37: Effect of cutting height and forward speed on header loss of fenugreek

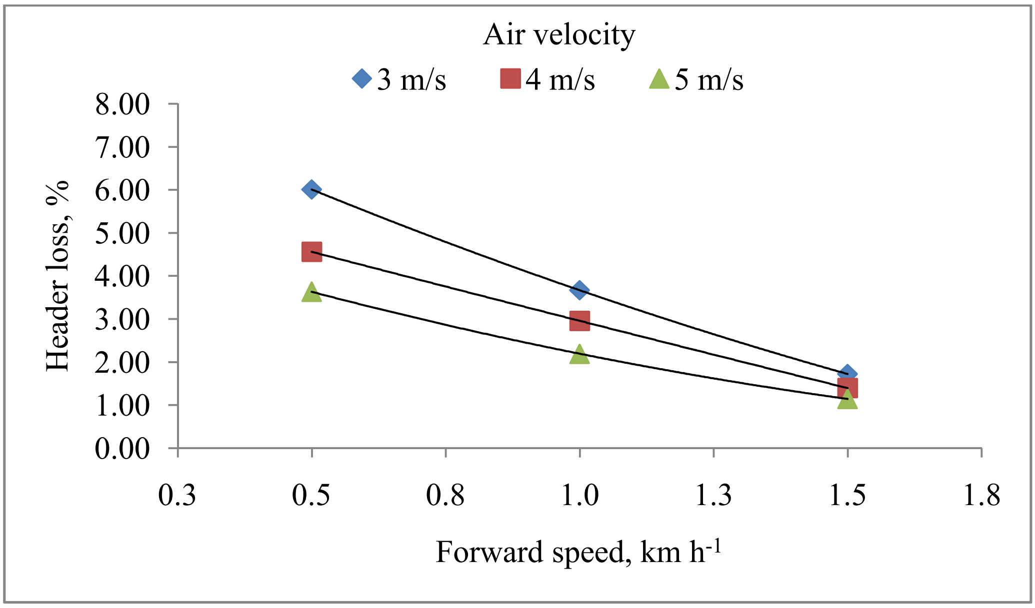


Fig. 4.38: Effect of air velocity and forward speed on header loss of fenugreek

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.38. The lowest header loss (1.14%) was obtained at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}, whereas, it was observed to be highest (6.01%) at forward speed of 0.5 km h^{-1} and at air velocity of 3m s^{-1}. It was observed that with the increase in the forward speed the header loss was also decreases significantly (CD 0.229 at 5% level) Table 4.62. It was also observed that at higher air velocity the header loss was significantly lower as compared to lower air velocity. It may be due to the air thrust at higher air velocity reduces the chances of falling down.

The interactive effect of cutting height and air velocity is presented in Fig 4.39. There was also significant difference observed (CD=0.229 at 5% level) due forward speed and cutting height and air velocity by developed harvester on harvesting efficiency. Interactive effect is presented in Table 4.63. It was also observed that there is significant effect of combination of the three factor viz. machine speed, cutting height and air velocity with CD=0.397 at 5% level of significance.

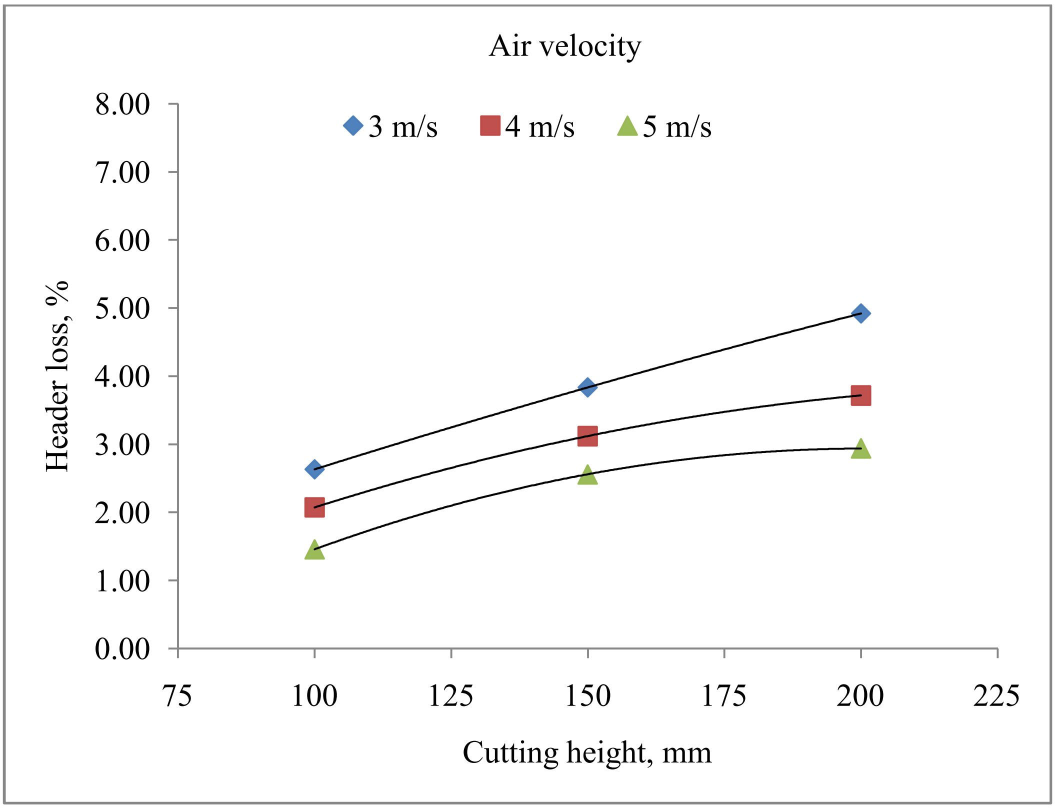


Fig. 4.39: Effect of cutting height and air velocity on header loss in red amaranthus

Table 4.62: ANOVA of header loss (%) of leafy crop harvester on fenugreek

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)±	CD (P=0.05)
Replication	2	0.068	0.034	0.582		
Treatment	26	242.569	9.330	159.200		
Forward speed	2	148.542	74.271	1267.355	0.047	0.132
Cutting height	2	44.734	22.367	381.672	0.047	0.132
Air velocity	2	29.666	14.833	253.114	0.047	0.132
S×H	4	9.114	2.279	38.881	0.081	0.229
S×V	4	7.558	1.889	32.241	0.081	0.229
H×V	4	1.938	0.485	8.268	0.081	0.229
S×H×V	8	1.016	0.127	2.168	0.140	0.397
Error	52	3.047	0.059			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

Table 4.63: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in fenugreek

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	4.36	6.03	7.63	2.35	3.93	4.72	1.19	1.55	2.42	1.72
V2	3.26	4.81	5.61	1.92	3.22	3.73	1.04	1.33	1.81	1.39
V3	2.26	3.86	4.76	1.28	2.28	3.01	0.84	1.54	1.04	1.14
Mean S	3.29	4.90	6.00	1.85	3.14	3.82	1.02	1.47	1.76	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.4.2 Conveying loss of fenugreek

Conveying loss is one of the major factors that affects the performance of the harvester. It was occurred during conveying the harvested leaves from cutter bar to storage tank. Conveying loss was calculated by using formula as described in Chapter –III in section 3.4.5.2. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. Minimum average conveying loss was observed at forward speed 0.5 km h^{-1} (S1) about 2.34%, followed by 3.23% and 4.85% at forward speed 1.0 km $h^{-1}$and 1.5 km h^{-1}, respectively. Due to cutting heights minimum average conveying loss observed at cutting height 200 mm of about 2.75%, followed by 3.31% at cutting height 150 mm and 2.75% at cutting height 100 mm. Due to air velocity minimum conveying loss was observed at 4 m s^{-1} air velocity about 2.41%, followed by 3.44% and 4.58% at air velocity 3 m s^{-1} and 5 m s^{-1}, respectively as presented in Table 4.64. The detail ANOVA table is presented in Table 4.65.

Table 4.64: Effect of forward speed, cutting height and air velocity on conveying loss (%) by leafy harvester in harvesting of fenugreek

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	2.34±.33	100 mm (H1)	4.37±0.64	3 m s^{-1} (V1)	3.44±0.48
1 km h^{-1} (S2)	3.23±.60	150 mm (H2)	3.31±0.59	4 m s^{-1} (V2)	2.41±0.41
1.5 km h^{-1} (S3)	4.85±.51	200 mm (H3)	2.75±0.49	5 m s^{-1} (V3)	4.58±0.67
SE(m)	0.08	SE(m)	0.08	SE(m)	0.08
CD (P=0.05)	0.139	CD (P=0.05)	0.139	CD (P=0.05)	0.139

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.40. The lowest conveying loss (1.92%) was obtained at forward speed of 0.5 km h^{-1} and at cutting height of 100 mm, whereas it was observed to be highest (5.52%) at forward speed of 1.5 km h^{-1} and at cutting height of 200 mm. It was also observed that with the increase in the forward speed the conveying loss was increases significantly at 5% level with CD value of 0.395 (Table 4.64). It was also observed that at lower cutting height the conveying loss was high as compared to higher cutting height. It may be due to at higher speed creates problem to flow cut material over conveyor because vibration was more at higher speed than the lower forward speed. It was also observed that at lower cutting height angle of conveyor was more with the horizontal than the cutting at higher height, so the lower angle of conveyor was work effectively for conveying the harvested leaves from cutter bar to the storage tank.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.41. The lowest conveying (1.69%) was obtained at forward speed of 0.5 km h^{-1} and at air velocity of 4 m/s, whereas, it was observed to be highest (6.18%) at forward speed of 1.5 km/h and at air velocity of 5 m/s. It was observed that with the increase in the forward speed the conveying loss decreases significantly (CD 0.395 at 5% level) Table 4.64. It was also observed that as the air velocity increased from 3 m s^{-1} to 4 m s^{-1} the conveying loss decreased to be 42.74%, but when it was increased from 4 m s^{-1} to 5 m s^{-1} the conveying losses increased to be 90.04%. It may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

The interactive effect of cutting height and air velocity is presented in Fig 4.42. It was observed that with increases in cutting height the conveying loss increases significantly (CD = 0.395 at 5% level) with all three air velocities and minimum conveying loss observed at air velocity 4 m s^{-1}.

The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.66 and significant difference was observed with CD=0.684 at 5% level of significance.

Table 4.65: ANOVA of conveying loss (%) of leafy crop harvester on fenugreek

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.072	0.036	0.205		
Treatment	26	206.706	7.950	45.621		
Forward speed	2	87.532	43.766	251.141	0.080	0.228
Cutting height	2	36.931	18.465	105.959	0.080	0.228
Air velocity	2	63.431	31.715	181.991	0.080	0.228
S×H	4	5.611	1.403	8.049	0.139	0.395
S×V	4	5.051	1.263	7.246	0.139	0.395
H×V	4	4.783	1.196	6.862	0.139	0.395
S×H×V	8	3.368	0.421	2.415	0.241	0.684
Error	52	9.062	0.174			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

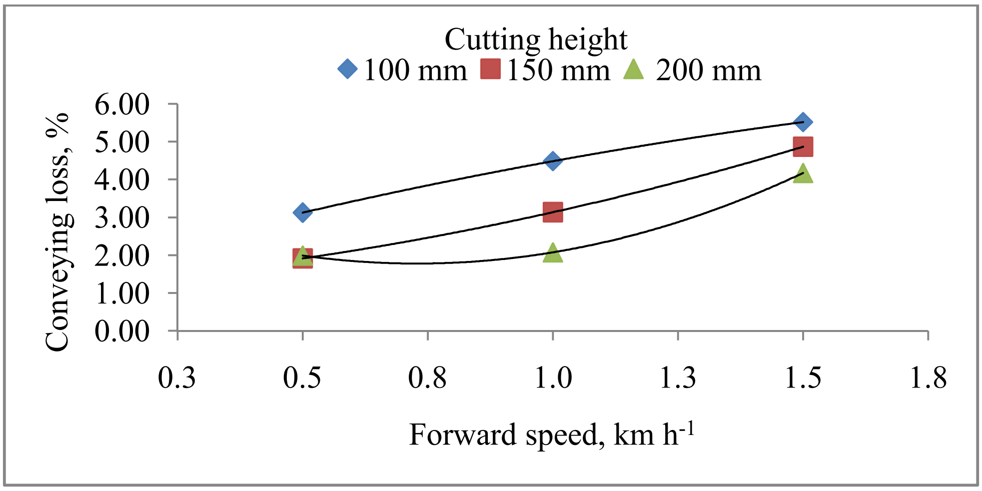


Fig. 4.40: Effect of cutting height and forward speed on conveying loss in fenugreek

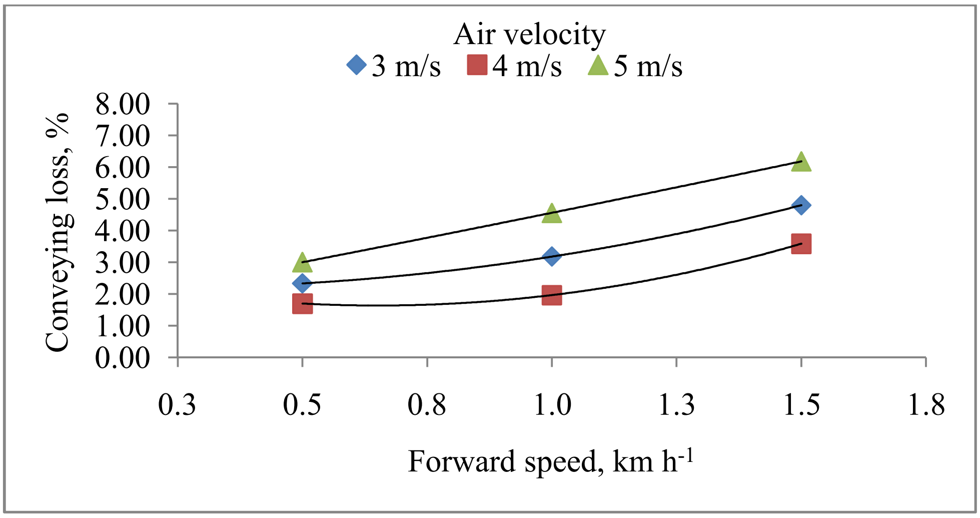


Fig. 4.41: Effect of air velocity and forward speed on conveying loss in fenugreek

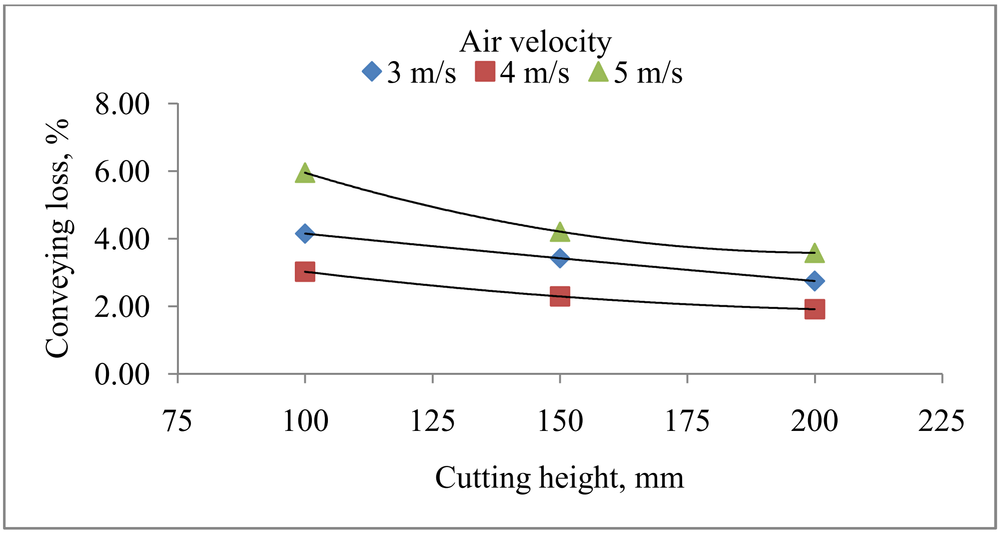


Fig. 4.42: Effect of cutting height and air velocity on conveying loss in fenugreek

Table 4.66: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in fenugreek

Factors	S1			S2			S3			Mean D
	H1	H2	H3	H1	H2	H3	H1	H2	H3	
V1	2.99	2.01	2.01	4.03	3.32	2.19	5.44	4.93	4.03	4.80
V2	2.55	1.32	1.21	2.91	1.91	1.06	3.61	3.65	3.48	3.58
V3	3.82	2.42	2.75	6.51	4.18	2.98	7.51	6.02	5.01	6.18
Mean S	3.12	1.92	1.99	4.48	3.14	2.08	5.52	4.87	4.17	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})
H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)
V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

4.5.4.3 Harvesting efficiency of fenugreek

Harvesting efficiency is one of the most important that describe the performance of the harvester. Harvesting efficiency of developed leafy crop harvester was estimated by considering harvesting loss and conveying loss of fenugreek. Harvesting efficiency was calculated by using formula as described in Chapter –III in section 3.4.5.1. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The maximum average header loss was observed to be 93.83% at forward speed of 1.0 km h^{-1} (S3), 93.57% at cutting height of 100 mm (H1) and 94.26% at air velocity of 4 m s^{-1} (Table 4.67). The detail of the ANOVA is given in Table 4.68. It was observed that forward speed and air velocity significantly affect the harvesting efficiency at 5% level of significance.

Table 4.67: Effect of forward speed, cutting height and air velocity on harvesting efficiency (%) by leafy harvester in harvesting of fenugreek

Factors	Mean	Factors	Mean	Factors	Mean
Forward speed		Cutting height		Air velocity	
0.5 km h^{-1} (S1)	92.93±0.53	100 mm (H1)	93.57±0.53	3 m s^{-1} (V1)	92.76±0.48
1 km h^{-1} (S2)	93.83±0.50	150 mm (H2)	93.52±0.50	4 m s^{-1} (V2)	94.62±0.37
1.5 km h^{-1} (S3)	93.73±0.51	200 mm (H3)	93.39±0.57	5 m s^{-1} (V3)	93.10±0.46
SE(m)	0.118	SE(m)	0.118	SE(m)	0.118
CD (P=0.05)	0.335	CD (P=0.05)	NS	CD (P=0.05)	0.335

The interactive effect of forward speed vs cutting height is depicted in Fig. 4.43. There was significant difference observed (CD=0.58 at 5% level) due forward speed and cutting height by developed harvester on harvesting efficiency. The highest harvesting efficiency (94.10%) was obtained at forward speed of 1.0 km h^{-1} and at cutting height of 200 mm, whereas, it was observed to be lowest (92.01%) at forward speed of 0.5 km h^{-1} and at cutting height 200 mm.

The interactive effect of forward speed vs air velocity is depicted in Fig. 4.44. There was significant difference observed (CD=0.58 at 5% level) due forward speed and air velocity by developed harvester on harvesting efficiency. The highest harvesting efficiency (95.08%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (91.66%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}.

Table 4.68: ANOVA of harvesting efficiency (%) of leafy crop harvester on fenugreek

S.V.	D.F.	S.S.	M.S.S.	F-cal	SE(m)	CD (P=0.05)
Replication	2	0.159	0.079	0.211		
Treatment	26	111.418	4.285	11.390		
Forward speed	2	13.228	6.614	17.580	0.118	0.335
Cutting height	2	0.443	0.222	0.589	0.118	NS
Air velocity	2	52.700	26.350	70.036	0.118	0.335
S×H	4	14.411	3.603	9.576	0.204	0.580
S×V	4	16.558	4.140	11.003	0.204	0.580
H×V	4	8.150	2.037	5.415	0.204	0.580
S×H×V	8	5.928	0.741	1.969	0.354	NS
Error	52	19.564	0.376			
Total	80					

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

The interactive effect of cutting height and air velocity is presented in Fig 4.45. There was significant difference was observed (CD=0.58 at 5% level) due forward speed and cutting height by developed harvester on harvesting efficiency. The highest harvesting efficiency (94.90%) was obtained at cutting height of 100 mm and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (92.33%) at cutting height of 200 mm and at air velocity of 3 m s^{-1}.

The interactive effect of combination of the three factor *viz.* machine speed, cutting height and air velocity was presented in Table 4.69 and no significant difference was observed at 5% level of significance.

Table 4.69: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in fenugreek

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	92.65	91.96	90.36	93.62	92.75	93.09	93.37	93.52	93.55	93.48
V2	94.19	93.87	93.18	95.17	94.87	95.21	95.35	95.02	94.71	95.03
V3	93.92	93.72	92.49	92.21	93.54	94.01	91.65	92.44	93.95	92.68
Mean S	93.59	93.18	92.01	93.67	93.72	94.10	93.46	93.66	94.07	

S = Forward speed (S1= 0.5 km h^{-1}, S2 = 1 km h^{-1}, S3 = 1.5 km h^{-1})

H = Cutting height (H1= 100 mm, H2 = 150 mm, H3 = 200 mm)

V = Air velocity (V1 = 3 m s^{-1},V2 = 4 m s^{-1},V3 = 5 m s^{-1})

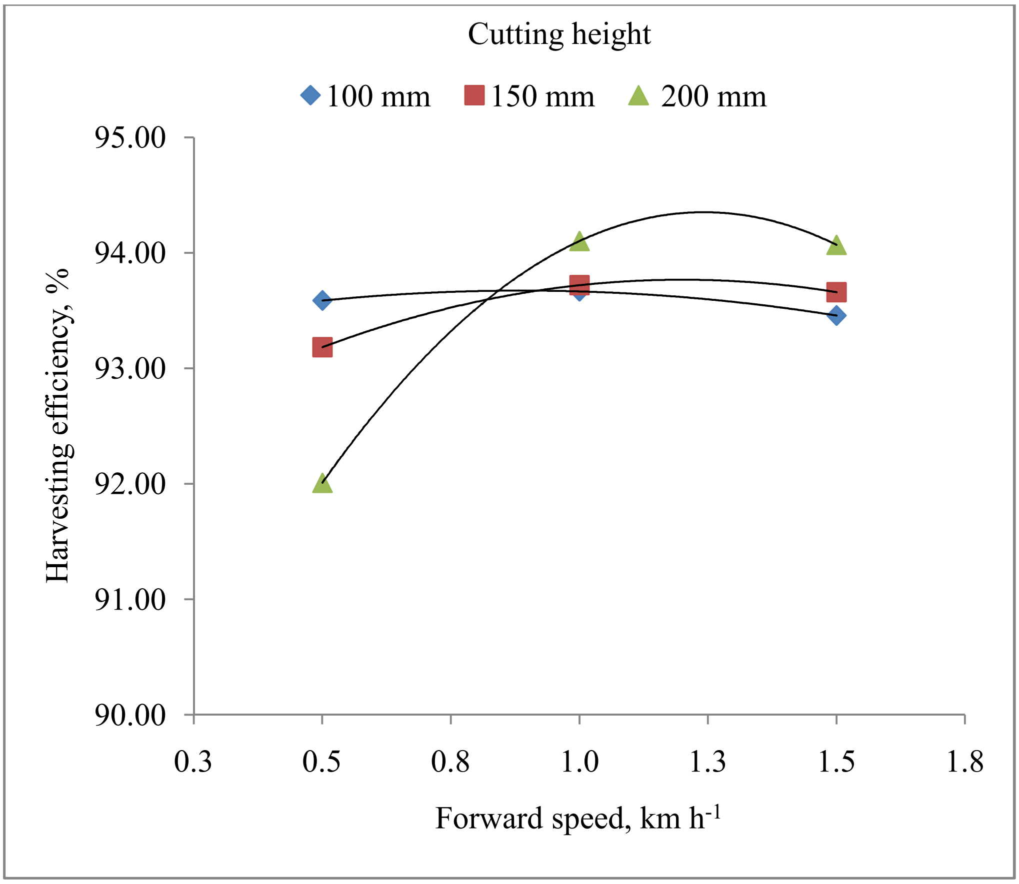


Fig. 4.43: Effect of cutting height and forward speed on harvesting efficiency in fenugreek

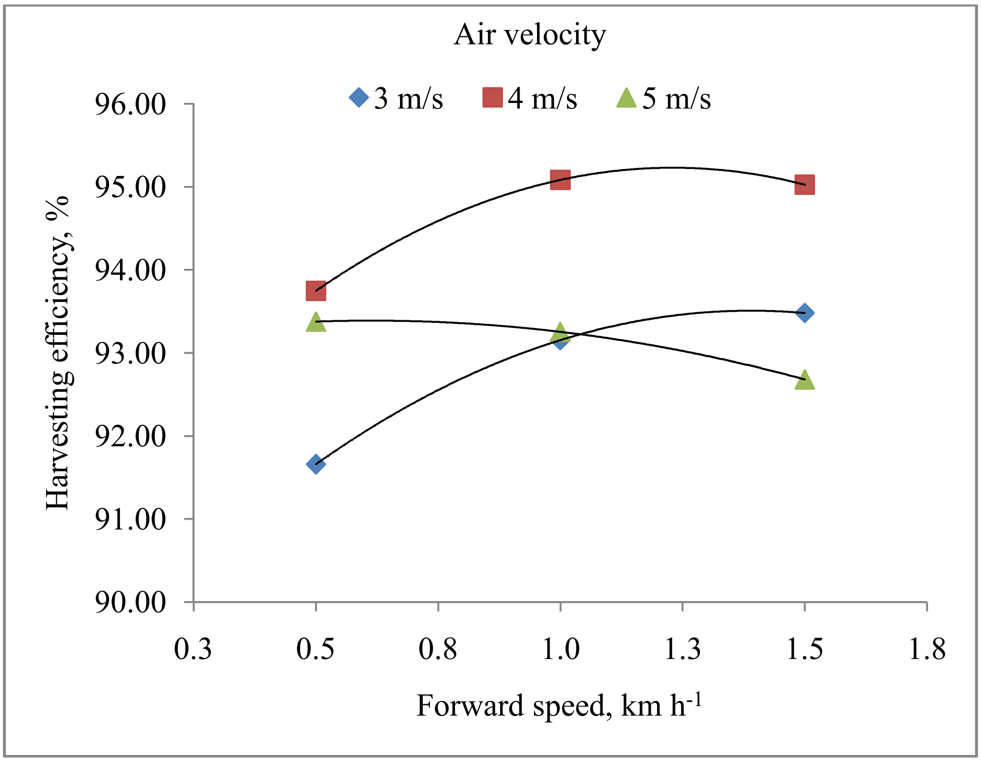


Fig. 4.44: Effect of air velocity and forward speed on harvesting efficiency in fenugreek

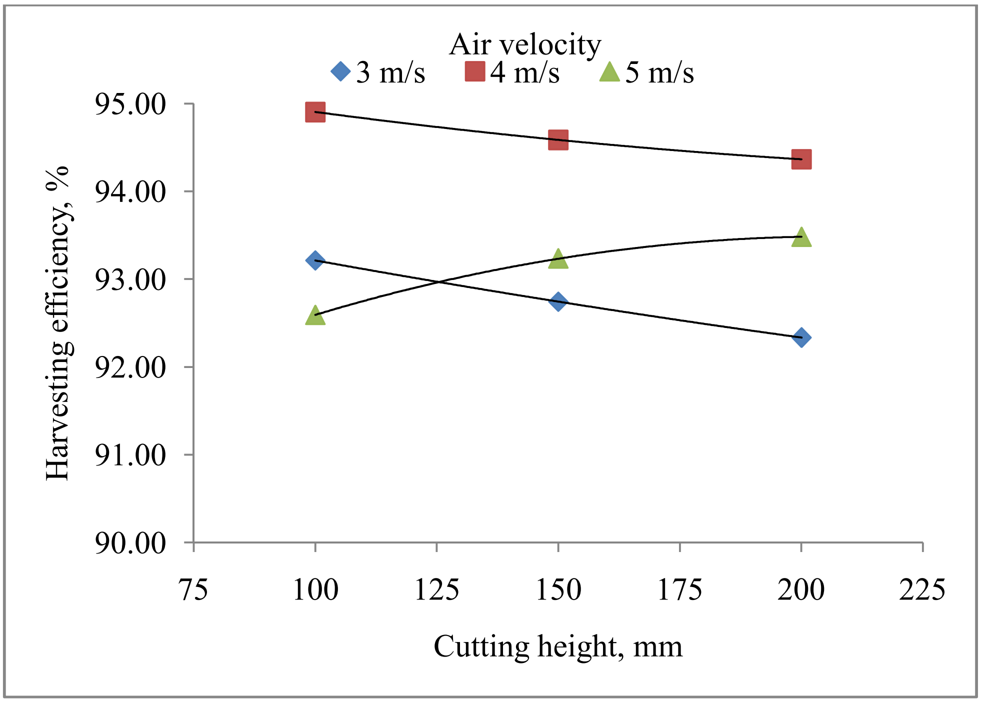


Fig. 4.45: Effect of cutting height and air velocity on harvesting efficiency in fenugreek

4.5.5 Performance evaluation for spinach by developed machine

4.5.5.1 Header loss of spinach

Header loss is one of the major factors that affects the performance of the harvester. Header loss was calculated by using formula as described in Chapter –III in section 3.4.5.1. The data related to the calculation of header loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The minimum average header loss was observed to be 2.96% at forward speed of 1.5 km h^{-1} (S3) and 4.23% at air velocity of 5 m s^{-1} (Table 4.70). The detail ANOVA is presented in Table 4.71. It was observed that the header loss decreased with increase in forward speed due to more inclination of crop at back side of cutter bar at higher speed as compared to lower speed. Similarly as the air velocity increase the header loss decrease, because air stream at air velocity 5 m s^{-1} help to move the leaves to conveyor more effectively than the air stream at air velocity 3 m s^{-1}.

Table 4.70: Effect of forward speed and air velocity on header loss (%) by leafy harvester in harvesting of spinach

Forward speed, km h^{-1}		Air velocity, m s^{-1}	
Level	Header loss, %	Level	Header loss, %
0.5 km h^{-1} (S1)	7.26	3 m s^{-1} (V1)	5.74
1.0 km h^{-1} (S2)	4.47	4 m s^{-1} (V2)	4.72
1.5 km h^{-1} (S3)	2.96	5 m s^{-1} (V3)	4.23
CD (P=0.05)	0.68	CD (P=0.05)	0.68
SE(m)	0.22	SE(m)	0.22
SE(d)	0.32	SE(d)	0.32

The interactive effect of forward speed vs air velocity is given in Table 4.72. The lowest header loss (2.83%) was obtained at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}, whereas, it was observed to be highest (8.37%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}. It was observed that with the increase in the forward speed the header loss was also decreases. It was also observed that at higher air velocity the header loss was significantly lower as compared to lower air velocity. It may be due to the air thrust at higher air velocity reduces the chances of falling down.

Table 4.71: ANOVA of header loss (%) of leafy crop harvester at spinach

S.V.	D.F.	S.S.	M.S.S.	F-cal
Replication	2	0.051		
Forward speed (S)	2	85.637	42.819	95.029
Air velocity (V)	2	10.642	5.321	11.809
S×V	4	3.594	0.898	1.994
Error	16	7.209	0.451	
Total	26	107.133		

Table 4.72: Interactive effect of forward speed (S) and air velocity (V) on header loss (%) by developed harvester in spinach

Factors	3 m s^{-1} (V1)	4 m s^{-1} (V2)	5 m s^{-1} (V3)	Mean S
0.5 km h^{-1} (S1)	8.37	7.12	6.29	7.26
1.0 km h^{-1} (S2)	5.73	4.11	3.58	4.47
1.5 km h^{-1} (S3)	3.12	2.93	2.83	2.96
Mean V	5.74	4.72	4.23	
CD (P=0.05)	NS			
SE(m)	0.39			
SE(d)	0.55			

4.5.5.2 Conveying loss of spinach

Conveying loss is one of the major factors that affect the performance of the harvester. It was occurred during conveying the harvested leaves from cutter bar to storage tank. Conveying loss was calculated by using formula as described in Chapter –III in section 3.4.5.2. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. Minimum average conveying loss was observed at forward speed 0.5 km h^{-1} (S1) of about 4.44%, followed by 5.63% and 7.30% at forward speed 1.0 km $h^{-1}$and 1.5 km h^{-1}, respectively. Due to air velocity minimum conveying loss was observed at 4 m s^{-1} air velocity of about 4.55%, followed by 5.73% and 7.10% at air velocity 3 m s^{-1}

and 5 m s^{-1}, respectively as presented in Table 4.73. The detail ANOVA is given in Table 4.74.

Table 4.73: Effect of forward speed and air velocity on conveying loss (%) by leafy harvester in harvesting of spinach

Forward speed, km h^{-1}		Air velocity, m s^{-1}	
Level	Conveying loss, %	Level	Conveying loss, %
0.5 km h^{-1} (S1)	4.44	3 m s^{-1} (V1)	5.73
1.0 km h^{-1} (S2)	5.63	4 m s^{-1} (V2)	4.55
1.5 km h^{-1} (S3)	7.30	5 m s^{-1} (V3)	7.10
CD (P=0.05)	0.72	CD (P=0.05)	0.72
SE(m)	0.24	SE(m)	0.24
SE(d)	0.34	SE(d)	0.34

The interactive effect of forward speed vs air velocity is given in Table 4.75. The lowest conveying loss (3.14%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be highest (8.63%) at forward speed of 1.5 km h^{-1} and at air velocity of 5 m s^{-1}. It was also observed that as the air velocity increased from 3 m s^{-1} to 4 m s^{-1} the conveying loss decreased to be 16.29%, but when it was increased from 4 m s^{-1} to 5 m s^{-1} the conveying losses increased to be 40.55%. It may be due to at lower air velocity air thrust was not effectively move the harvested leaves to the conveyor after cutting and at higher air velocity harvested leaves blown from the conveyer.

Table 4.74: ANOVA of conveying loss (%) of leafy crop harvester at spinach

S.V.	D.F.	S.S.	M.S.S.	F-cal
Replication	2	0.341		
Forward speed (S)	2	37.316	18.658	36.704
Air velocity (V)	2	29.394	14.697	28.912
S×V	4	1.832	0.458	0.901
Error	16	8.133	0.508	
Total	26	77.016		

4.5.5.3 Harvesting efficiency of spinach

Harvesting efficiency is one of the most important that describe the performance of the harvester. Harvesting efficiency of developed leafy crop harvester was calculated by considering harvesting loss and conveying loss of chickpea. Harvesting efficiency was calculated by using formula as described in Chapter –III in section 3.4.5.3. The data related to the calculation of conveying loss were collected at different forward speed, cutting height and at three air velocities. The data was analyzed by using OPSTAT statistical package in three way randomized factorial design software developed by HAU, Hissar. The maximum average header loss was observed to be 89.89% at forward speed of 1.0 km h^{-1} and 90.73% at air velocity of 4 m s^{-1} (Table 4.76).

Table 4.75: Interactive effect of forward speed (S) and air velocity (V) on conveying loss (%) by developed harvester in spinach

Factors	3 m s^{-1} (V1)	4 m s^{-1} (V2)	5 m s^{-1} (V3)	Mean S
0.5 km h^{-1} (S1)	4.81	3.14	5.36	4.44
1.0 km h^{-1} (S2)	5.23	4.36	7.31	5.63
1.5 km h^{-1} (S3)	7.14	6.14	8.63	7.30
Mean V	5.73	4.55	7.10	
CD (P=0.05)	NS			
SE(m)	0.41			
SE(d)	0.58			

Table 4.76: Effect of forward speed and air velocity on harvesting efficiency (%) by leafy harvester in harvesting of spinach

Forward speed, km h^{-1}		Air velocity, m s^{-1}	
Level	Harvesting efficiency, %	Level	Harvesting efficiency, %
0.5 km h^{-1} (S1)	88.30	3 m s^{-1} (V1)	88.53
1.0 km h^{-1} (S2)	89.89	4 m s^{-1} (V2)	90.73
1.5 km h^{-1} (S3)	89.74	5 m s^{-1} (V3)	88.67
CD (P=0.05)	1.03	CD (P=0.05)	1.03
SE(m)	0.34	SE(m)	0.34
SE(d)	0.48	SE(d)	0.48

The detail of the ANOVA is given in Table 4.77. It was observed that forward speed and air velocity significantly affect the harvesting efficiency at 5% level of significance. The interactive effect of forward speed vs air velocity is in Table 7.78. The highest harvesting efficiency (91.53%) was obtained at forward speed of 1.0 km h^{-1} and at air velocity of 4 m s^{-1}, whereas, it was observed to be lowest (86.82%) at forward speed of 0.5 km h^{-1} and at air velocity of 3 m s^{-1}.

Table 4.77: ANOVA of harvesting efficiency (%) of leafy crop harvester at spinach

S.V.	D.F.	S.S.	M.S.S.	F-cal
Replication	2	0.148		
Forward speed (S)	2	13.800	6.900	6.644
Air velocity (V)	2	27.389	13.695	13.186
S×V	4	6.017	1.504	1.448
Error	16	16.617	1.039	
Total	26	63.973		

Table 4.78: Interactive effect of forward speed (S) and air velocity (V) on harvesting efficiency (%) by developed harvester in spinach

Factors	3 m s^{-1} (V1)	4 m s^{-1} (V2)	5 m s^{-1} (V3)	Mean S
0.5 km h^{-1} (S1)	86.82	89.74	88.35	88.30
1.0 km h^{-1} (S2)	89.04	91.53	89.11	89.89
1.5 km h^{-1} (S3)	89.74	90.93	88.54	89.74
Mean V	88.53	90.73	88.67	
CD (P=0.05)	NS			
SE(m)	0.59			
SE(d)	0.83			

4.5.6 Field capacity

Theoretical field capacity of the developed leafy crop harvester at 0.5 km h^{-1}, 1.0 km h^{-1} and 1.5 km h^{-1} forward speed were observed about 0.03, 0.06 and 0.09 ha h^{-1}, respectively. Actual field capacity of developed leafy crop harvester were observed 0.02 ha h^{-1}, 0.05 ha h^{-1} and 0.07 ha h^{-1} at forward speed 0.5, 1.0 and 1.5 km h^{-1}, respectively (Table 4.79).

4.5.7 Field efficiency

Field efficiency of the developed leafy crop was found 82.17, 83.24 and 81.90% at forward speed 0.5, 1.0 and 1.5 km h^{-1}, respectively.

4.5.8 Fuel consumption

Fuel consumption of the leafy crop harvesting was estimated by top fill method by filling petrol upto to mark level. Average Fuel consumption of developed leafy crop harvester was found about 0.79 l h^{-1}.

Table 4.79: Field capacity and field efficiency of harvester at different forward speed

S.No.	Parameters	Speed of operation		
		0.5 km h^{-1}	1.0 km h^{-1}	1.5 km h^{-1}
1	Theoretical field capacity, ha h^{-1}	0.03	0.06	0.09
2	Effective field capacity, ha h^{-1}	0.025	0.050	0.074
3	Working hour per hectare	40.60	20.03	13.58
4	Turning loss, h ha^{-1}	7.27	3.36	2.47
5	Field efficiency, %	82.17	83.24	81.90

4.5.9 Comparison between harvesting methods

Comparative study was conducted between various leafy crop harvesting methods. Different parameters were taken to evaluate the performance of various harvesting methods which are harvesting efficiency (%), cleaning efficiency (%), yield (t ha^{-1}), field capacity (ha h^{-1}) and harvesting capacity (t h^{-1}). Performance of selected four harvesting methods were evaluated and discussed below of selected leafy crops.

4.5.9.1 Harvesting efficiency

The harvesting efficiency of different harvesting methods at different leafy crop was evaluated in the field and presented in Table 4.80. The harvesting efficiency was observed significantly higher (α=0.05) in manual harvesting method for selected leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach of about 99.21, 98.23, 98.41, 98.34 and 98.21% respectively, whereas it was observed to be 96.82, 94.51, 93.61, 94.81 and 90.34%, respectively for developed leafy crop harvester.

4.5.9.2 Cleaning efficiency

The cleaning efficiency of different harvesting methods at different leafy crop was evaluated in the field and presented in Table 4.81. The cleaning efficiency was observed highest in manual harvesting method for selected leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach of about 98.91, 98.62, 98.11, 98.23 and 98.71% respectively, whereas it was observed to be 95.21, 92.68, 95.07, 95.34 and 94.56%, respectively for developed leafy crop harvester.

Table 4.80: Mean table of harvesting efficiency (%)

Treatment	Chickpea	Green amaranthus red	Red amaranthus	Spinach	Fenugreek
T1	99.21	98.23	98.41	98.34	98.21
T2	98.34	97.36	97.21	97.36	96.36
T3	92.82	92.74	92.87	91.57	89.62
T4	96.82	94.51	93.61	94.81	90.34
CD (P=0.05)	3.647	4.103	3.975	3.784	4.202
SE(m)	1.171	1.317	1.276	1.215	1.349
SE(d)	1.656	1.862	1.804	1.718	1.907
CV (%)	2.704	3.077	2.986	2.843	3.221

T1 = Manual harvesting, T2 = Manual harvesting with sickle, T3 = Battery operated leafy crop harvester, T4 = Developed leafy crop harvester

Table 4.81: Mean table of cleaning efficiency (%)

Treatment	Chickpea	Green amaranthus red	Red amaranthus	Spinach	Fenugreek
T1	98.91	98.62	98.11	98.23	98.71
T2	96.64	96.21	96.31	96.46	97.31
T3	95.63	93.65	95.15	95.51	94.36
T4	95.21	92.68	95.07	95.34	94.56
CD (P=0.05)	NS	NS	NS	NS	3.088
SE(m)	1.063	1.477	1.074	1.111	0.991
SE(d)	1.504	2.089	1.518	1.572	1.402
CV (%)	2.461	3.466	2.496	2.578	2.303

T1 = Manual harvesting, T2 = Manual harvesting with sickle, T3 = Battery operated leafy crop harvester, T4 = Developed leafy crop harvester

4.5.9.3 Yield

The yield of different harvesting methods at different leafy crop was evaluated in the field and presented in Table 4.82. The yield was observed highest in manual harvesting method for selected leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach of about 98.91, 98.62, 98.11, 98.23 and 98.71% respectively, whereas it was observed to be 2.51, 10.43, 10.21, 8.13 and 2.98 t ha^{-1}, respectively for developed leafy crop harvester.

4.5.9.4 Field capacity

The field capacity of different harvesting methods at different leafy crop was evaluated in the field and presented in Table 4.83. The field capacity was observed significantly higher (α=0.05) in developed leafy crop harvester for selected leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach of about 0.051, 0.050, 0.050, 0.049 and 0.049 ha h^{-1}, respectively. The average value of field capacity in developed leafy crop harvester due to all selected leafy crop was observed to be 0.050 which was 896.00, 730.00 and 241.10% percent higher than manual harvesting, manual harvesting with sickle and battery operated leafy crop harvester, respectively.

4.5.9.5 Capacity of harvesting

The capacity of harvesting of different harvesting methods at different leafy crop was evaluated in the field and presented in Table 4.84. The capacity of harvesting was observed significantly higher (α=0.05) in developed leafy crop harvester for selected leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach of about 0.145, 0.398, 0.512, 0.520 and 0.127 t h^{-1}, respectively. The capacity of harvesting of developed leafy crop harvester in chickpea was observed to be 876.92, 693.75 and 252.78% percent higher than manual harvesting, manual harvesting with sickle and battery operated leafy crop harvester, respectively.

Table 4.82: Mean table of yield (t ha^{-1})

Treatment	Chickpea	Green amaranthus red	Red amaranthus	Spinach	Fenugreek
T1	2.58	10.89	11.23	8.51	3.48
T2	2.62	11.36	10.92	8.32	3.36
T3	2.46	10.21	10.19	7.91	3.21
T4	2.51	10.43	10.21	8.13	2.98
CD (P=0.05)	NS	NS	NS	NS	0.317
SE(m)	0.117	0.317	0.299	0.206	0.102
SE(d)	0.166	0.448	0.423	0.292	0.144
CV (%)	10.297	6.608	6.291	5.612	6.991

T1 = Manual harvesting, T2 = Manual harvesting with sickle, T3 = Battery operated leafy crop harvester, T4 = Developed leafy crop harvester

4.5.10 Body parts discomfort scoring and overall discomfort rating

Body parts discomfort score were noted for different harvesting *viz.* manual harvesting (T1), manual harvesting with sickle (T2), battery operated leafy crop harvester (T3) and developed leafy crop harvester (T4). The body parts discomfort score was based upon the numerals given by the operator during the operation according to pain or discomfort occurred in different body parts. The average body part discomfort score of ten workers for different harvesting method presented in Table 4.85. The BPDS was estimated as 6.16, 5.41, 4.31 and 3.02 for manual harvesting (T1), manual harvesting with sickle (T2), and battery operated leafy crop harvester (T3) and developed leafy crop harvester (T4) respectively. It was observed that the developed leafy crop harvester overall discomfort rating was reduced by 50.93% over manual harvesting method.

Table 4.83: Mean table of field capacity (ha h^{-1})

Treatment	Chickpea	Green amaranthus red	Red amaranthus	Spinach	Fenugreek
T1	0.005	0.005	0.005	0.005	0.005
T2	0.006	0.006	0.006	0.006	0.006
T3	0.015	0.015	0.015	0.014	0.014
T4	0.051	0.050	0.050	0.049	0.049
CD (P=0.05)	0.001	0.001	0.001	0.001	0.002
SE(m)	0.000	0.000	0.000	0.000	0.001
SE(d)	0.001	0.000	0.001	0.001	0.001
CV (%)	0.005	4.148	4.900	5.696	6.328

T1 = Manual harvesting, T2 = Manual harvesting with sickle, T3 = Battery operated leafy crop harvester, T4 = Developed leafy crop harvester

Table 4.84: Mean table of capacity of harvesting (t h^{-1})

Treatment	Chickpea	Green amaranthus red	Red amaranthus	Spinach	Fenugreek
T1	0.013	0.052	0.056	0.042	0.017
T2	0.016	0.070	0.068	0.050	0.020
T3	0.036	0.148	0.150	0.116	0.046
T4	0.127	0.520	0.512	0.398	0.145
CD (P=0.05)	0.009	0.028	0.022	0.021	0.012
SE(m)	0.003	0.009	0.007	0.007	0.004
SE(d)	0.004	0.013	0.010	0.010	0.005
CV (%)	13.384	10.084	8.046	10.172	15.100

T1 = Manual harvesting, T2 = Manual harvesting with sickle, T3 = Battery operated leafy crop harvester, T4 = Developed leafy crop harvester

Table 4.85: Body part discomfort score of different harvesting methods

S.No.	Body parts	Body part discomfort score				
		Manual harvesting (T1)	Manual harvesting with sickle (T2)	Battery operated leafy crop harvester (T3)	Developed leafy crop harvester (T4)	Per cent increase (+) or decrease (-) of T4 over T1
01	Neck	4.65	5.00	4.90	2.05	55.91
02	Clavicle left	5.50	5.20	2.15	1.06	80.73
03	Clavicle right	5.60	5.10	2.35	1.04	81.43
04	Left shoulder	4.70	4.80	3.25	4.80	-2.13
05	Right shoulder	5.90	4.50	3.65	5.00	15.25
06	Left arm	4.70	3.85	5.30	2.35	50.00
07	Right arm	6.40	5.50	4.40	3.40	46.88
08	Left elbow	6.20	6.20	4.40	2.05	66.94
09	Right elbow	6.40	5.30	4.05	2.05	67.97
10	Left forearm	4.25	4.40	4.65	5.10	-20.00
11	Right forearm	7.30	5.15	5.30	4.30	41.10
12	Left wrist	5.30	6.30	4.30	2.00	62.26
13	Right wrist	5.70	6.00	4.50	3.30	42.11
14	Left palm	4.50	3.10	3.35	2.50	44.44
15	Right palm	4.50	3.35	3.40	2.05	54.44
16	Upper back	4.20	3.55	3.54	2.45	41.67
17	Middle back	5.20	4.60	3.50	2.80	46.15
18	Lower back	7.10	5.20	5.10	4.20	40.85
19	Buttocks	7.90	7.10	6.10	1.01	87.22
20	Left thigh	7.90	7.20	5.40	3.05	61.39
21	Right thigh	8.30	7.60	6.90	2.35	71.69
22	Left knee	6.00	6.10	2.50	2.55	57.50
23	Right knee	7.50	6.60	2.80	2.35	68.67
24	Right leg	8.10	6.80	5.40	4.60	43.21
25	Left leg	8.10	6.50	5.50	4.65	42.59
26	Left foot	7.10	5.60	4.75	4.20	40.85
27	Right foot	7.20	5.60	4.95	4.30	40.28
	Total score	166.20	146.20	116.39	81.56	50.93
	ODR	6.16	5.41	4.31	3.02	50.93

4.6 Cost Analysis

The fabrication cost of the developed leafy crop was estimated about ₹43245.00/-. Cost of the operation of the developed leafy vegetable harvester was found to be ₹ 3259.31/- per hectare, a detail of cost analysis was estimated and given in Table 4.86 and Fig. 4.46.

Table 4.86: Cost of operation of leafy crop harvester

S.No.	Particulars	Amount
1	Capital cost, ₹	43245.00
2	Life, year	10
3	Life, h year^{-1}	250
4	Fixed cost	
	a. Depreciation at 10% salvage value, ₹ h^{-1}	15.57
	b. Interest 10% per annum, ₹ h^{-1}	9.51
	c. Shelter 2% of initial cost, ₹ h^{-1}	3.46
	d. Total fixed cost, ₹ h^{-1}	28.54
5	Variable cost	
	a. Fuel rate, ₹ l^{-1}	90.00
	b. Fuel consumption, l h^{-1}	0.80
	c. Fuel cost, ₹ h^{-1}	72.00
	d. Lubrication, ₹ h^{-1}	14.40
	e. Repair cost 5% of initial cost, ₹ h^{-1}	8.65
	f. Labour required	1
	g. Working hour, h ha^{-1}	14.29
	h. Labour cost, ₹ day^{-1}	315.00
	i. Labour cost, ₹ h^{-1}	39.38
	j. Total variable, ₹ h^{-1}	134.42
6	Cost of operation , ₹ h^{-1}	162.97
7	Cost of operation, ₹ ha^{-1}	2328.08
8	Breakeven point, h y^{-1}	77.84
9	Payback period, y	1.89

A detail cost analysis of different method studied during the research was depicted in Appendix – F. Cost of operation of different harvesting methods were compared and given in Table 4.87. It was observed that the developed prototype is more economical as compared to the others methods widely used in Chhattisgarh.

The cost of leafy crop harvesting by manual hand harvesting (T1), harvesting with sickle (T2) and harvesting with battery operated harvester (T3) 141.62%, 101.35% and 22.133%, respectively were found higher than the developed leafy crop harvester (T4).

Breakeven point and payback period of the developed prototype was found to be 77.84 h y^{-1} and 1.89 years respectively by taking annual use of 250 hours and life of the machine as 10 years.

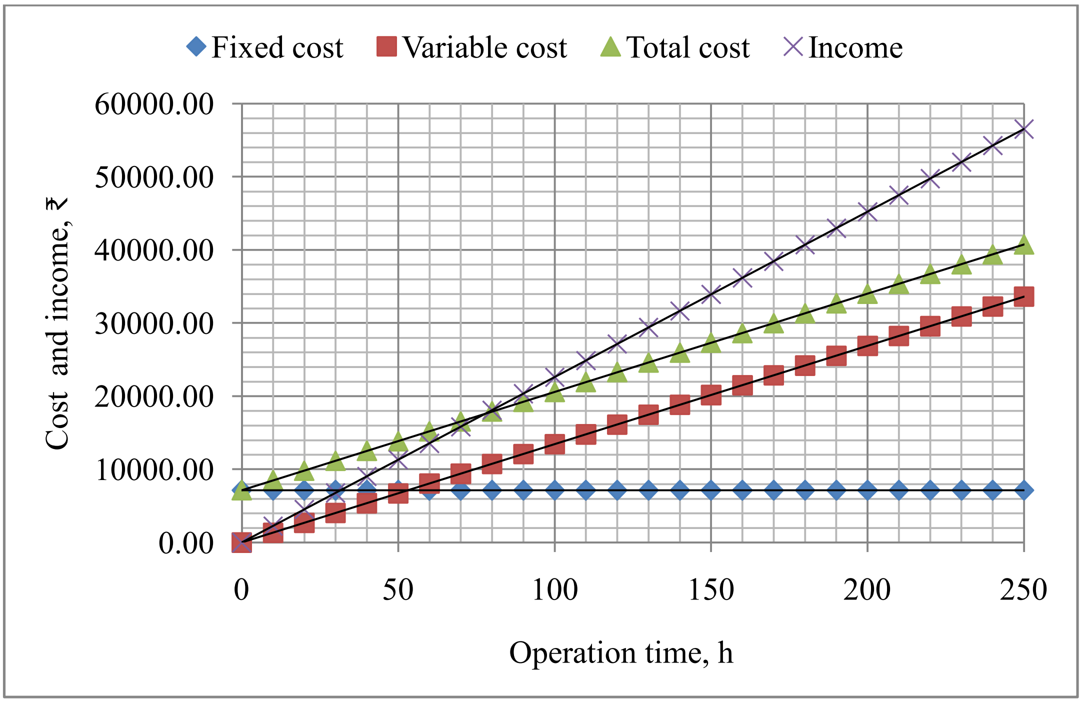


Fig. 4.46: Breakeven point of leafy crop harvester

Table 4.87: Cost of operation of different harvesting methods

Harvesting method	Cost of operation, ₹ ha^{-1}	Per cent higher than developed leafy crop harvester
Manual harvesting (T1)	7875.00	141.62%
Manual harvesting with sickle (T2)	6562.50	101.35%
Battery operated leafy crop harvester (T3)	3980.56	22.13%
Developed leafy crop harvester (T4)	3259.31	-

CHAPTER-V
SUMMARY YAND CONCLUSTIONS

Leafy green vegetables are an important part of a healthy diet. These types of vegetables are enrich in vitamins, minerals, carbohydrates, fats, important proteins, vitamins, essential amino acids, and fiber but having very low in calories. Harvesting of green leafy vegetable crops are normally a time consuming and tedious operation in manual harvesting. Nipping of chickpea leaves was also done in continuously bending posture by female workers which cause the drudgery to worker and it is too much time during operation. Therefore it is proposed to develop a mechanical green leafy crop harvester to reduce drudgery, time of operation, labour requirement and cost of operation. Following steps are taken under consideration to achieve this goal:

1. To study crop geometry of selected leafy crops *viz.* chickpea, amaranthus, spinach and fenugreek.
2. To study the status and associated problems of existing harvesting/nipping techniques of selected leafy crops.
3. To design and development of leafy crop harvester.
4. Performance evaluation of the developed machine.

A purposive survey was conducted to know the status of practices involved in leafy crop harvesting. The biometric and engineering properties of the leafy vegetables crop were observed in the field. Problems occurred during leafy crop harvesting also observed in the field. A purposive study was conducted in the field to observe the effect of different harvesting methods on the growth parameters (plant height, number of branches and yield) of leafy vegetable crops. Drudgery involved in the different harvesting methods was evaluated by Body Part Discomfort Score in CR-10 scale. It was observed that generally 2-3 harvesting done in selected leafy crops (chickpea, amaranthus, spinach and fenugreek) during its life. Nipping in the chickpea crop was one of the most important operations, which help to improve its growth parameters. Manual harvesting of leafy crop was very time consuming and tedious process. The problems occurred during leafy crop harvesting would be reduced by mechanical approach in harvesting. Development of prototype consist selection of power source, power required for cutter bar, selection of cutter bar, design of conveying system, transmission system, storage tank and frame. A prototype of leafy crop harvester was fabricated in the workshop of SVCAET, FAE, IGKV, Raipur (C.G.). An experiment was conducted to evaluate the performance of the developed leafy crop harvester by taking various independent parameters (forward speed, cutting height and air velocity) and analyzed by using Factorial Randomized Block Design. Various harvesting parameters (*viz.* header loss, conveying loss and harvesting efficiency), machine parameters (field capacity, field efficiency, fuel consumption) were evaluated to test the performance of the machine. A comparative study between existing harvesting method and developed leafy crop harvester were also conducted by considering harvesting efficiency, cleaning efficiency, yield of crop, field capacity and capacity of harvesting. The finding of the experimental study is discussed below.

1. Manual hand plucking of leafy crop harvesting method is widely adopted in Chhattisgarh. Leafy vegetables generally harvested up to 3-5 times economically.
2. Engineering properties of the leafy crop were studied during survey. The mean values of bulk densities were measured to be 74.48±2.88, 75.65±2.81, 73.73±2.14, 67.15±2.06 and 65.45±1.63 kg m^{-3} for chickpea, green amaranthus, red amaranthus, fenugreek and spinach leafy crop, respectively.
3. Terminal velocity of the leafy crops were measured to be 1.32, 1.34, 1.25, 1.24 and 1.20 m s^{-1} for chickpea, green amaranthus, red amaranthus, fenugreek and spinach leafy crop, respectively.
4. A study was also conducted for various type of harvesting methods by the use of hand plucking, mild steel (sickle), fiber knife, stainless steel blade. It was observed that growth parameters like plant height, number of branches and yield of selected leafy crop were highest in harvesting with stainless steel blade.

5. The manual plucking method is more tedious in operation. It takes time and also increases the cost of harvesting.
6. A leafy vegetable harvester was designed and developed at SVCAET&RS successfully. The machine has basically three major components *viz.* cutting unit, conveying unit and storage unit.
7. The cutting unit takes power from a petrol operated 1 hp engine, whereas the conveying unit was powered from the ground drive wheel. The whole machine was supported by a sturdy frame.
8. A canvas belt was selected as coefficient of friction is more for leafy crops.
9. A stainless steel reciprocating knife section cuts the plant leaves and blown it to the conveying belt vide a air jet blower. The conveyer belt convey the material to the storage tank having capacity of 5 kg.
10. The machine was tested in field at three forward speed, three cutting heights and three air velocities. It was observed from the tests that mean value of header loss was found to be minimum at forward speed 1.5 km h^{-1}, 100 mm cutting height and air velocity at 5 m s^{-1} for different leafy crops *viz.* chickpea, green amaranthus, red amaranthus, fenugreek and spinach.
11. The mean value of conveying loss was found to be minimum at forward speed 0.5 km h^{-1}, 200 mm cutting height and air velocity at 4 m s^{-1} for different leafy crops *viz.* chickpea, green amaranthus, red amaranthus. Spinach was tested only at 100 mm cutting height and conveying loss was observed minimum at forward speed 0.5 km h^{-1} and air velocity 4 m s^{-1}.
12. The harvesting efficiency was recorded maximum at forward speed 1.0 km h^{-1}, 150 mm cutting height and air velocity at 4 m s^{-1} for different leafy crops *viz.* chickpea, green amaranthus, red amaranthus, and fenugreek. Spinach was tested only at 100 mm cutting height and conveying loss was observed minimum at forward speed 1.0 km h^{-1} and air velocity 4 m s^{-1}.
13. Harvesting efficiency in chickpea was observed maximum in manual harvesting method (99.21%). Similarly cleaning efficiency was observed maximum in manual harvesting method (98.91%). Harvesting efficiency and cleaning efficiency of developed leafy crop was observed to be 96.82% and 95.21%, respectively in chickpea leafy crop.

14. Yield of chickpea was observed maximum in manual harvesting with sickle of about 2.62 t ha^{-1} followed by manual harvesting (2.58 t ha^{-1}), developed leafy crop harvester (2.51 t ha^{-1}) and with battery operated leafy crop harvester (2.46 t ha^{-1}).
15. Yield of other vegetable leaves are found as 10.43, 11.23, 8.51 and 3.48 t ha^{-1} for green amaranthus, red amaranthus, spinach and fenugreek respectively with the developed harvester.
16. The maximum field capacity was observed to be 0.051 ha $h^{-1}$of the developed leafy crop harvester.
17. The capacity of harvesting in chickpea, green amaranthus, red amaranthus, spinach and fenugreek crop were found to be maximum as 0.127, 0.52, 0.512, 0.398 and 0.145 t h^{-1} for the developed harvester.
18. The Overall Discomfort Rate (ODR) was obtained minimum (3.02) with developed leafy crop harvester which was observed to be 50.93%, 44.18% and 29.93% less than the manual harvesting, harvesting with sickle and battery operated leafy crop harvester.
19. The fabrication cost of the developed leafy crop was calculated to be ₹ 43245.00/-. Cost of the operation of the developed leafy crop harvester was found ₹ 3259.31/- per hectare.
20. Breakeven point and payback period of the developed leafy crop harvester was found 77.84 h y^{-1} and 1.89 year, respectively.

Conclusions

1. Geometry of leafy crop and engineering properties were measured which were helpful to decide components of the machine. In survey growth parameters were measured in respect to various harvesting methods and best result was observed with stainless steel blade.
2. The developed leafy crop harvester was worked satisfactorily in field condition. The harvesting efficiency was observed maximum at forward speed 1.0 km h^{-1}, 150 mm cutting height and at air velocity at 4 m s^{-1} for different leafy crops *viz.* chickpea, green amaranthus, red amaranthus, and fenugreek.

3. The developed leafy crop harvester was able to reduce the human effort and drudgery involved in leafy crop harvesting. It was also reduced the cost of operation of about 58.61% over manual harvesting of leafy crop.

Future suggestions

1. The machine may be developed in such way that it (single machine) can be used for harvesting different kinds of leafy vegetable. Adjustment may be made accordingly in cutter bar design and belt conveyor.
2. Arrangement may be provided for changing the machine to a self propelled type unit.
3. The width of the machine may be increased for higher efficiency in future.

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APPENDIX-A

Table A-1: Bulk density of selected leafy crop

Leafy crop	Bulk density, kg m^{-3}	SD	SEm±	CV (%)
Chickpea	74.48±2.88	3.29	1.47	4.42
Green amaranthus	75.65±2.81	3.20	1.43	4.23
Red amaranthus	73.73±2.14	2.44	1.09	3.31
Fenugreek	67.15±2.06	2.35	1.05	3.31
Spinach	65.45±1.63	1.86	0.83	2.84

Table A-2: Terminal velocity of the leaves of different leafy crops

Leafy crop	Terminal velocity, m s^{-1}	SD	SEm±	CV (%)
Chickpea	1.20±0.06	0.07	0.03	5.85
Green amaranthus	1.24±0.07	0.07	0.03	6.01
Red amaranthus	1.25±0.05	0.05	0.02	4.22
Fenugreek	1.34±0.06	0.07	0.03	4.22
Spinach	1.32±0.04	0.04	0.02	3.28

Table A-3: Angle of repose leafy crops

Leafy crop	Angle of repose, °	SD	SEm±	CV (%)
Chickpea	46.16±0.57	0.65	0.29	1.41
Green amaranthus	46.35±1.36	1.55	0.69	3.35
Red amaranthus	45.00±1.66	1.90	0.85	4.22
Fenugreek	45.46±2.05	2.34	1.05	4.22
Spinach	44.45±1.00	1.15	0.51	2.58

Table A-4: Coefficient of friction of leafy crops

Leafy crop	Coefficient of friction			
	Canvas	Cotton	Rubber	Mild steel
Chickpea	0.73	0.68	0.64	0.56
Green amaranthus	0.65	0.62	0.61	0.51
Red amaranthus	0.77	0.71	0.68	0.57
Fenugreek	0.69	0.65	0.63	0.60
Spinach	0.68	0.65	0.63	0.51

Table A-5: Crushing resistance of leafy crops

Leafy crop	Rupture force, N	SD	SEm±	CV (%)
Chickpea	1.24±0.07	0.07	0.03	6.01
Green amaranth	1.25±0.05	0.05	0.02	4.22
Red amaranth	1.32±0.04	0.04	0.02	3.28
Fenugreek	1.34±0.06	0.07	0.03	4.22
Spinach	1.20±0.06	0.07	0.03	5.85

APPENDIX-B

Table B-1: Anthropometric data part-1 (1-9)

S No	1 Weight	2 Stature (Base to vertical height)	3 Acromial height	4 Eye height (Base to eye)	5 Elbow height	6 Vertical reach	7 Arm reach forward	8 Metacarpal height	9 Arm span
1	56.21	1640	1364	1525	1029	2083	841	691	1699
2	57.64	1645	1369	1530	1034	2088	846	696	1704
3	56.15	1643	1367	1528	1032	2086	844	694	1702
4	52.64	1644	1368	1529	1033	2087	845	695	1703
5	60.54	1652	1376	1537	1041	2095	853	703	1711
6	62.41	1654	1378	1539	1043	2097	855	705	1713
7	56.94	1651	1375	1536	1040	2094	852	702	1712
8	68.64	1671	1395	1556	1060	2114	872	722	1732
9	64.14	1667	1391	1552	1056	2110	868	718	1728
10	52.21	1630	1354	1515	1019	2073	831	681	1689
11	53.64	1635	1359	1520	1024	2078	836	686	1694
12	52.15	1633	1357	1518	1022	2076	834	684	1692
13	48.64	1634	1358	1519	1023	2077	835	685	1693
14	56.54	1642	1366	1527	1031	2085	843	693	1701
15	58.41	1644	1368	1529	1033	2087	845	695	1703
16	52.94	1641	1365	1526	1030	2084	842	692	1702
17	64.64	1661	1385	1546	1050	2104	862	712	1722
18	60.14	1657	1381	1542	1046	2100	858	708	1718
19	48.21	1620	1344	1505	1009	2063	821	671	1679
20	49.64	1625	1349	1510	1014	2068	826	676	1684
21	50.21	1628	1358	1513	1023	2071	835	679	1693
22	51.64	1633	1363	1518	1028	2076	840	684	1698
23	50.15	1631	1361	1516	1026	2074	838	682	1696
24	46.64	1632	1362	1517	1027	2075	839	683	1697
25	54.54	1640	1370	1525	1035	2083	847	691	1705
26	56.41	1642	1372	1527	1037	2085	849	693	1707
27	50.94	1639	1369	1524	1034	2082	846	690	1706
28	62.64	1659	1389	1544	1054	2102	866	710	1726
29	58.14	1655	1385	1540	1050	2098	862	706	1722
30	46.21	1618	1348	1503	1013	2061	825	669	1683
31	58.21	1643	1367	1528	1032	2086	844	694	1702
32	59.64	1648	1372	1533	1037	2091	849	699	1707
33	58.15	1646	1370	1531	1035	2089	847	697	1705
34	54.64	1647	1371	1532	1036	2090	848	698	1706

S No	1 Weight	2 Stature (Base to vertical height)	3 Acromial height	4 Eye height (Base to eye)	5 Elbow height	6 Vertical reach	7 Arm reach forward	8 Metacarpal height	9 Arm span
35	62.54	1655	1379	1540	1044	2098	856	706	1714
36	64.41	1657	1381	1542	1046	2100	858	708	1716
37	58.94	1654	1378	1539	1043	2097	855	705	1715
38	70.64	1674	1398	1559	1063	2117	875	725	1735
39	66.14	1670	1394	1555	1059	2113	871	721	1731
40	54.21	1633	1357	1518	1022	2076	834	684	1692
41	53.21	1632	1356	1517	1021	2075	833	683	1691
42	54.64	1637	1361	1522	1026	2080	838	688	1696
43	53.15	1635	1359	1520	1024	2078	836	686	1694
44	49.64	1636	1360	1521	1025	2079	837	687	1695
45	57.54	1644	1368	1529	1033	2087	845	695	1703
46	59.41	1646	1370	1531	1035	2089	847	697	1705
47	53.94	1643	1367	1528	1032	2086	844	694	1704
48	65.64	1663	1387	1548	1052	2106	864	714	1724
49	61.14	1659	1383	1544	1048	2102	860	710	1720
50	49.21	1622	1346	1507	1011	2065	823	673	1681
5th	48.4035	1623.35	1348.45	1508.35	1013.45	2066.35	825.45	674.35	1683.45
Mean	56.5006	1644.2	1369.4	1529.2	1034.4	2087.2	846.4	695.2	1705
95th	65.915	1668.65	1392.65	1553.65	1057.65	2111.65	869.65	719.65	1729.65

Table B-2: Anthropometric data part 1 (10-18)

S No	10 Head circumference	11 Neck circumference	12 Chest circumference	13 Waist circumference	14 Hip circumference	15 Upper arm circumference	16 Wrist circumference	17 Front chest length arc	18 Back length arc
1	612	371	848	773	1079	296	160	431	446
2	617	376	853	778	1084	301	165	436	451
3	615	374	851	776	1082	299	163	434	449
4	616	375	852	777	1083	300	164	435	450
5	624	383	860	785	1091	308	172	443	458
6	626	385	862	787	1093	310	174	445	460
7	623	382	859	784	1090	307	171	442	457
8	643	402	879	804	1110	327	191	462	477
9	639	398	875	800	1106	323	187	458	473
10	602	361	838	763	1069	286	150	421	436
11	607	366	843	768	1074	291	155	426	441
12	605	364	841	766	1072	289	153	424	439
13	606	365	842	767	1073	290	154	425	440
14	614	373	850	775	1081	298	162	433	448
15	616	375	852	777	1083	300	164	435	450
16	613	372	849	774	1080	297	161	432	447
17	633	392	869	794	1100	317	181	452	467
18	629	388	865	790	1096	313	177	448	463
19	592	351	828	753	1059	276	140	411	426
20	597	356	833	758	1064	281	145	416	431
21	600	365	836	767	1067	290	148	425	434
22	605	370	841	772	1072	295	153	430	439
23	603	368	839	770	1070	293	151	428	437
24	604	369	840	771	1071	294	152	429	438
25	612	377	848	779	1079	302	160	437	446
26	614	379	850	781	1081	304	162	439	448
27	611	376	847	778	1078	301	159	436	445
28	631	396	867	798	1098	321	179	456	465
29	627	392	863	794	1094	317	175	452	461
30	590	355	826	757	1057	280	138	415	424
31	615	374	851	776	1082	299	163	434	449
32	620	379	856	781	1087	304	168	439	454
33	618	377	854	779	1085	302	166	437	452
34	619	378	855	780	1086	303	167	438	453

S No	10 Head circumference	11 Neck circumference	12 Chest circumference	13 Waist circumference	14 Hip circumference	15 Upper arm circumference	16 Wrist circumference	17 Front chest length arc	18 Back length arc
35	627	386	863	788	1094	311	175	446	461
36	629	388	865	790	1096	313	177	448	463
37	626	385	862	787	1093	310	174	445	460
38	646	405	882	807	1113	330	194	465	480
39	642	401	878	803	1109	326	190	461	476
40	605	364	841	766	1072	289	153	424	439
41	604	363	840	765	1071	288	152	423	438
42	609	368	845	770	1076	293	157	428	443
43	607	366	843	768	1074	291	155	426	441
44	608	367	844	769	1075	292	156	427	442
45	616	375	852	777	1083	300	164	435	450
46	618	377	854	779	1085	302	166	437	452
47	615	374	851	776	1082	299	163	434	449
48	635	394	871	796	1102	319	183	454	469
49	631	390	867	792	1098	315	179	450	465
50	594	353	830	755	1061	278	142	413	428
5th	595.35	355.45	831.35	757.45	1062.35	280.45	143.35	415.45	429.35
Mean	616.2	376.4	852.2	778.4	1083.2	301.4	164.2	436.4	450.2
95th	640.65	399.65	876.65	801.65	1107.65	324.65	188.65	459.65	474.65

APPENDIX-C

Table C-1: Effect of different harvesting methods on growth parameter of chickpea

Treatment	Branches per plant			Plant height, mm			Yield, t ha^{-1}		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
D1M1	11.65	11.16	11.54	17.35	16.13	16.47	1.87	1.80	1.79
D1M2	10.68	11.02	11.15	19.14	19.76	20.35	1.83	1.82	1.90
D1M3	10.97	10.63	11.10	18.68	18.68	16.28	1.80	1.80	1.65
D1M4	11.90	12.40	12.31	18.07	18.43	19.45	1.71	1.70	1.78
D2M1	14.46	14.50	13.94	19.99	20.56	21.33	2.42	2.43	2.50
D2M2	12.68	12.77	12.26	17.87	19.05	17.61	2.30	2.37	2.29
D2M3	13.61	13.53	13.07	21.03	20.46	19.79	2.31	2.24	2.23
D2M4	15.60	15.22	14.84	22.21	23.53	23.04	2.48	2.56	2.49
D3M1	18.11	17.46	18.16	24.15	23.45	25.00	2.83	2.82	2.90
D3M2	15.80	16.41	16.40	22.98	21.49	22.06	2.61	2.53	2.54
D3M3	15.25	15.84	15.83	19.45	19.80	20.98	2.69	2.70	2.77
D3M4	18.72	18.00	18.66	28.57	28.50	27.23	2.95	3.01	2.92

Table C-2: Effect of different harvesting methods on growth parameter of green amaranthus

Treatment	Branches per plant			Plant height, mm			Yield, t ha^{-1}		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
D1M1	4.75	4.44	4.46	20.95	19.62	20.18	10.70	10.53	10.72
D1M2	3.91	3.89	4.20	20.36	21.28	21.72	10.39	10.60	10.57
D1M3	4.46	4.44	4.75	19.75	19.75	17.35	10.47	10.47	10.32
D1M4	5.16	5.50	5.24	18.93	19.35	20.34	10.33	10.56	10.52
D2M1	7.85	8.05	7.65	25.26	25.90	26.63	10.79	11.00	10.97
D2M2	6.81	7.05	6.69	22.99	24.08	22.56	10.69	10.67	10.50
D2M3	8.01	7.76	7.63	22.96	22.45	21.67	10.89	10.92	10.71
D2M4	8.75	8.55	8.35	25.66	26.81	26.16	11.08	11.26	11.29
D3M1	10.15	9.68	10.02	30.39	29.31	31.05	11.53	11.28	11.48
D3M2	8.55	8.75	8.95	29.45	27.73	28.77	11.10	10.92	11.13
D3M3	9.51	9.95	9.79	26.84	27.54	28.54	11.10	11.33	11.29
D3M4	11.01	10.69	11.15	31.70	31.63	30.36	12.04	12.01	11.83

Table C-3: Effect of different harvesting methods on growth parameter of red amaranthus

Treatment	Branches per plant			Plant height, mm			Yield, t ha^{-1}		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
D1M1	6.00	5.66	5.74	22.15	20.79	21.41	11.76	11.58	11.79
D1M2	4.84	4.86	5.15	21.42	22.42	22.82	11.38	11.61	11.57
D1M3	5.64	5.56	5.90	20.65	20.65	18.25	10.26	10.26	10.11
D1M4	6.37	6.75	6.53	20.19	20.69	21.64	11.46	11.71	11.66
D2M1	9.03	9.20	8.78	26.13	26.83	27.53	11.37	11.60	11.56
D2M2	7.83	8.05	7.67	24.33	25.38	23.82	10.63	10.61	10.44
D2M3	8.96	8.73	8.56	24.16	23.69	22.83	11.22	11.26	11.03
D2M4	9.87	9.65	9.43	26.64	27.81	27.18	11.80	11.99	12.03
D3M1	12.05	11.53	11.97	31.62	30.48	32.25	12.05	11.78	11.99
D3M2	10.21	10.49	10.65	30.55	28.80	29.90	11.73	11.55	11.76
D3M3	11.12	11.60	11.49	27.71	28.47	29.44	11.61	11.84	11.80
D3M4	12.14	11.76	12.25	33.04	32.93	31.62	12.18	12.15	11.97

Table C-4: Effect of different harvesting methods on growth parameter of fenugreek

Treatment	Branches per plant			Plant height, mm			Yield, t ha^{-1}		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
D1M1	7.10	6.73	6.87	27.08	25.56	26.50	7.47	7.34	7.45
D1M2	6.06	6.14	6.40	26.29	27.65	27.87	7.23	7.36	7.37
D1M3	6.67	6.53	6.90	25.73	25.73	23.33	7.30	7.30	7.15
D1M4	7.10	7.50	7.30	24.97	25.77	26.57	7.20	7.35	7.35
D2M1	12.10	12.20	11.70	29.25	30.11	30.73	7.76	7.91	7.91
D2M2	11.00	11.15	10.70	27.31	28.28	26.64	7.35	7.37	7.24
D2M3	11.66	11.49	11.20	26.91	26.53	25.49	7.50	7.49	7.36
D2M4	12.69	12.40	12.11	29.75	30.99	30.43	7.87	8.01	8.00
D3M1	16.05	15.42	16.08	34.70	33.36	35.23	8.60	8.43	8.59
D3M2	14.46	14.94	15.00	33.60	31.75	33.05	8.25	8.11	8.24
D3M3	15.16	15.75	15.74	30.53	31.45	32.34	8.32	8.47	8.47
D3M4	16.64	16.06	16.65	36.16	35.96	34.56	8.91	8.92	8.78

Table C-5: Effect of different harvesting methods on growth parameter of spinach

Treatment	Branches per plant			Plant height, mm			Yield, t ha^{-1}		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
D1M1	6.41	6.06	6.16	11.97	10.92	10.92	3.26	3.17	3.20
D1M2	5.51	5.57	5.84	10.45	10.63	11.44	3.08	3.11	3.17
D1M3	5.24	5.18	5.51	11.45	11.45	9.05	3.20	3.20	3.05
D1M4	6.16	6.53	6.30	10.75	10.63	11.89	3.17	3.20	3.26
D2M1	10.51	10.65	10.19	14.74	14.82	15.83	3.48	3.51	3.57
D2M2	9.50	9.68	9.26	13.74	15.08	13.81	3.20	3.26	3.17
D2M3	9.42	9.20	9.01	14.29	13.51	13.27	3.17	3.11	3.08
D2M4	11.18	10.93	10.68	15.40	16.33	15.46	3.59	3.68	3.62
D3M1	17.75	17.08	17.82	17.89	17.57	18.93	3.69	3.64	3.74
D3M2	15.83	16.37	16.40	18.01	16.66	16.96	3.36	3.27	3.30
D3M3	16.53	17.15	17.17	16.42	16.50	17.81	3.21	3.24	3.30
D3M4	17.53	16.89	17.51	18.74	19.02	18.10	3.71	3.77	3.68

APPENDIX-D

Table D-1: Harvesting parameters of leafy crop harvester in chickpea

	Header loss, %			Conveying loss, %			Harvesting efficiency, %		
Treatments	R1	R2	R3	R1	R2	R3	R1	R2	R3
S1H1V1	3.86	3.56	3.86	2.39	2.00	2.48	93.75	94.43	93.67
S1H1V2	2.26	2.36	2.46	1.53	1.87	1.85	96.20	95.78	95.69
S1H1V3	1.21	1.21	1.36	3.56	2.78	3.32	95.22	96.02	95.32
S1H2V1	4.97	5.23	5.19	1.22	1.61	1.70	93.82	93.16	93.10
S1H2V2	4.05	4.11	3.87	0.82	0.92	0.72	95.12	94.97	95.42
S1H2V3	3.28	3.36	3.14	2.15	2.12	1.79	94.57	94.52	95.07
S1H3V1	7.23	7.36	6.80	1.51	1.38	1.34	91.26	91.26	91.86
S1H3V2	5.58	5.31	5.04	0.65	0.61	0.57	93.77	94.08	94.39
S1H3V3	4.46	4.27	4.35	1.95	1.76	1.84	93.59	93.97	93.81
S2H1V1	1.94	2.06	2.15	3.12	3.64	3.53	94.93	94.31	94.32
S2H1V2	1.46	1.62	1.48	1.82	2.11	2.10	96.73	96.27	96.41
S2H1V3	0.82	0.84	0.98	5.89	5.03	5.61	93.29	94.13	93.41
S2H2V1	3.23	3.03	3.13	2.52	2.20	2.54	94.25	94.77	94.33
S2H2V2	2.43	2.51	2.62	1.02	1.10	1.21	96.54	96.40	96.17
S2H2V3	1.98	1.98	1.68	3.68	3.68	3.38	94.34	94.34	94.94
S2H3V1	4.03	4.31	4.32	1.56	1.72	1.79	94.41	93.97	93.89
S2H3V2	2.97	3.19	3.23	0.70	0.72	0.86	96.33	96.09	95.91
S2H3V3	2.16	2.31	2.16	2.72	2.68	2.34	95.13	95.01	95.49
S3H1V1	0.79	0.63	0.65	5.24	5.44	4.74	93.97	93.93	94.61
S3H1V2	0.52	0.64	0.46	2.90	3.31	3.42	96.59	96.05	96.11
S3H1V3	0.36	0.42	0.54	7.56	6.56	7.21	92.08	93.02	92.25
S3H2V1	1.05	0.92	0.88	4.23	3.74	4.42	94.72	95.34	94.70
S3H2V2	0.70	0.66	0.83	2.61	3.19	3.05	96.68	96.16	96.12
S3H2V3	0.56	0.74	0.62	6.12	5.72	5.02	93.32	93.54	94.36
S3H3V1	1.70	1.82	1.64	3.85	3.63	3.11	94.45	94.55	95.25
S3H3V2	1.11	0.96	0.96	2.98	3.09	2.57	95.91	95.95	96.47
S3H3V3	0.35	0.54	0.43	4.44	4.31	3.88	95.21	95.15	95.69

Table D-2: Interaction S×H of header loss (%) on chickpea

Factors	S1	S2	S3	Mean D
H1	2.46	1.48	0.56	1.50
H2	4.13	2.51	0.77	2.47
H3	5.60	3.19	1.06	3.28
Mean S	4.06	2.39	0.80	

Table D-3: Interaction S×V of header loss (%) on chickpea

Factors	S1	S2	S3	Mean S
V1	5.34	3.13	1.12	3.20
V2	3.89	2.39	0.76	2.35
V3	2.96	1.66	0.51	1.71
Mean V	4.06	2.39	0.80	

Table D-4: Interaction H×V of header loss (%) on chickpea

Factors	H1	H2	H3	Mean D
V1	2.17	3.07	4.36	3.20
V2	1.47	2.42	3.15	2.35
V3	0.86	1.93	2.34	1.71
Mean V	1.50	2.47	3.28	

Table D-5: Interactive effect of S× H×V by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.76	5.13	7.13	2.05	3.13	4.22	0.69	0.95	1.72	1.12
V2	2.36	4.01	5.31	1.52	2.52	3.13	0.54	0.73	1.01	0.76
V3	1.26	3.26	4.36	0.88	1.88	2.21	0.44	0.64	0.45	0.51
Mean S	2.46	4.13	5.60	1.48	2.51	3.19	0.56	0.77	1.06	

Table D-6: Interaction S×H of conveying loss (%) on chickpea

Factors	S1	S2	S3	Mean D
H1	2.42	3.65	5.15	3.74
H2	1.45	2.37	4.23	2.68
H3	1.29	1.68	3.54	2.17
Mean S	1.72	2.57	4.31	

Table D-7: Interaction S×V of conveying loss (%) on chickpea

Factors	S1	S2	S3	Mean S
V1	1.74	2.51	4.27	2.84
V2	1.06	1.29	3.01	1.79
V3	2.36	3.89	5.65	3.97
Mean V	1.72	2.57	4.31	

Table D-8: Interaction H×V of conveying loss (%) on chickpea

Factors	H1	H2	H3	Mean D
V1	3.62	2.69	2.21	2.84
V2	2.32	1.63	1.42	1.79
V3	5.28	3.74	2.88	3.97
Mean V	3.74	2.68	2.17	

Table D-9: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	2.29	1.51	1.41	3.43	2.42	1.69	5.14	4.13	3.53	4.27
V2	1.75	0.82	0.61	2.01	1.11	0.76	3.21	2.95	2.88	3.01
V3	3.22	2.02	1.85	5.51	3.58	2.58	7.11	5.62	4.21	5.65
Mean S	2.42	1.45	1.29	3.65	2.37	1.68	5.15	4.23	3.54	

Table D-10: Interaction S×H of harvesting efficiency (%) on chickpea

Factors	S1	S2	S3	Mean D
H1	95.12	94.87	94.29	94.76
H2	94.42	95.12	94.99	94.84
H3	93.11	95.14	95.40	94.55
Mean S	94.22	95.04	94.90	

Table D-11: Interaction S×V of harvesting efficiency (%) on chickpea

Factors	S1	S2	S3	Mean S
V1	92.92	94.35	94.61	93.96
V2	95.05	96.32	96.23	95.86
V3	94.68	94.45	93.85	94.33
Mean V	94.22	95.04	94.90	

Table D-12: Interaction H×V of harvesting efficiency (%) on chickpea

Factors	H1	H2	H3	Mean D
V1	94.21	94.24	93.43	93.96
V2	96.20	95.95	95.43	95.86
V3	93.86	94.33	94.78	94.33
Mean V	94.76	94.84	94.55	

Table D-13: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in chickpea

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	93.95	93.36	91.46	94.52	94.45	94.09	94.17	94.92	94.75	94.61
V2	95.89	95.17	94.08	96.47	96.37	96.11	96.25	96.32	96.11	96.23
V3	95.52	94.72	93.79	93.61	94.54	95.21	92.45	93.74	95.35	93.85
Mean S	95.12	94.42	93.11	94.87	95.12	95.14	94.29	94.99	95.40	

Table D-14: Harvesting parameters of leafy crop harvester in green amaranthus

	Header loss, %			Conveying loss, %			Harvesting efficiency, %		
Treatments	R1	R2	R3	R1	R2	R3	R1	R2	R3
S1H1V1	4.96	4.68	4.94	3.59	3.12	3.46	91.45	92.21	91.59
S1H1V2	3.33	3.49	3.56	2.50	3.00	3.05	94.17	93.51	93.39
S1H1V3	2.35	2.27	2.46	4.72	3.72	4.52	92.93	94.01	93.02
S1H2V1	5.99	6.33	6.37	2.10	2.81	2.92	91.91	90.86	90.71
S1H2V2	5.20	5.21	4.92	1.97	2.12	1.67	92.83	92.67	93.41
S1H2V3	4.43	4.46	4.19	3.28	3.32	2.76	92.29	92.22	93.05
S1H3V1	8.33	8.44	7.92	2.71	2.44	2.38	88.96	89.12	89.70
S1H3V2	6.65	6.41	6.17	1.82	1.71	1.60	91.53	91.88	92.23
S1H3V3	5.56	5.25	5.57	3.15	2.81	2.89	91.29	91.94	91.54
S2H1V1	3.03	3.17	3.25	4.13	4.73	4.73	92.84	92.10	92.02
S2H1V2	2.52	2.72	2.62	2.81	3.31	3.21	94.67	93.97	94.17
S2H1V3	1.96	1.90	2.08	6.99	6.03	6.81	91.06	92.06	91.11
S2H2V1	4.33	4.07	4.29	3.72	3.20	3.64	91.95	92.73	92.07
S2H2V2	3.48	3.66	3.72	2.04	2.18	2.41	94.48	94.16	93.87
S2H2V3	3.08	3.08	2.78	4.88	4.88	4.28	92.04	92.04	92.94
S2H3V1	5.12	5.42	5.42	2.58	2.80	2.99	92.31	91.77	91.59
S2H3V2	4.07	4.29	4.33	1.70	1.82	2.06	94.23	93.89	93.61
S2H3V3	3.34	3.41	3.18	3.82	3.88	3.34	92.85	92.71	93.47
S3H1V1	1.89	1.76	1.72	6.44	6.53	5.75	91.67	91.72	92.52
S3H1V2	1.58	1.74	1.60	3.89	4.51	4.53	94.53	93.75	93.87
S3H1V3	1.50	1.48	1.64	8.65	7.57	8.41	89.85	90.95	89.95
S3H2V1	2.15	1.97	2.03	5.43	4.73	5.53	92.42	93.29	92.45
S3H2V2	1.76	1.80	1.93	3.59	4.31	4.25	94.65	93.89	93.82
S3H2V3	1.71	1.84	1.67	7.23	6.92	6.01	91.06	91.24	92.32
S3H3V1	2.83	2.92	2.71	4.98	4.83	4.08	92.20	92.25	93.20
S3H3V2	2.21	2.09	2.03	4.18	4.20	3.56	93.61	93.71	94.41
S3H3V3	1.52	1.66	1.50	5.52	5.51	4.90	92.96	92.83	93.60

Table D-15: Interaction S×H of header loss (%) on amaranthus green

Factors	S1	S2	S3	Mean D
H1	3.56	2.58	1.66	2.60
H2	5.23	3.61	1.87	3.57
H3	6.70	4.29	2.16	4.38
Mean S	5.16	3.49	1.90	

Table D-16: Interaction S×V of header loss (%) on amaranthus green

Factors	S1	S2	S3	Mean S
V1	6.44	4.23	2.22	4.30
V2	4.99	3.49	1.86	3.45
V3	4.06	2.76	1.61	2.81
Mean V	5.16	3.49	1.90	

Table D-17: Interaction H×V of header loss (%) on amaranthus green

Factors	H1	H2	H3	Mean D
V1	3.27	4.17	5.46	4.30
V2	2.57	3.52	4.25	3.45
V3	1.96	3.03	3.44	2.81
Mean V	2.60	3.57	4.38	

Table D-18: Interaction S×H×V of header loss (%) on green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	4.86	6.23	8.23	3.15	4.23	5.32	1.79	2.05	2.82	2.22
V2	3.46	5.11	6.41	2.62	3.62	4.23	1.64	1.83	2.11	1.86
V3	2.36	4.36	5.46	1.98	2.98	3.31	1.54	1.74	1.55	1.61
Mean S	3.56	5.23	6.70	2.58	3.61	4.29	1.66	1.87	2.16	

Table D-19: Interaction S×H of conveying loss on green amaranthus

Factors	S1	S2	S3	Mean D
H1	3.52	4.75	6.25	4.84
H2	2.55	3.47	5.33	3.78
H3	2.39	2.78	4.64	3.27
Mean S	2.82	3.67	5.41	

Table D-20: Interaction S×V of conveying loss on green amaranthus

Factors	S1	S2	S3	Mean S
V1	2.84	3.61	5.37	3.94
V2	2.16	2.39	4.11	2.89
V3	3.46	4.99	6.75	5.07
Mean V	2.82	3.67	5.41	

Table D-21: Interaction H×V of conveying loss on green amaranthus

Factors	H1	H2	H3	Mean D
V1	4.72	3.79	3.31	3.94
V2	3.42	2.73	2.52	2.89
V3	6.38	4.84	3.98	5.07
Mean V	4.84	3.78	3.27	

Table D-22: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.39	2.61	2.51	4.53	3.52	2.79	6.24	5.23	4.63	5.37
V2	2.85	1.92	1.71	3.11	2.21	1.86	4.31	4.05	3.98	4.11
V3	4.32	3.12	2.95	6.61	4.68	3.68	8.21	6.72	5.31	6.75
Mean S	3.52	2.55	2.39	4.75	3.47	2.78	6.25	5.33	4.64	

Table D-23: Interaction S×H of harvesting efficiency (%) on green amaranthus

Factors	S1	S2	S3	Mean D
H1	92.92	92.67	92.09	92.56
H2	92.22	92.92	92.79	92.64
H3	90.91	92.94	93.20	92.35
Mean S	92.02	92.84	92.70	

Table D-24: Interaction S×V of harvesting efficiency (%) on green amarnthus

Factors	S1	S2	S3	Mean S
V1	90.72	92.15	92.41	91.76
V2	92.85	94.12	94.03	93.66
V3	92.48	92.25	91.65	92.13
Mean V	92.02	92.84	92.70	

Table D-25: Interaction H×V of harvesting efficiency (%) on green amaranthus

Factors	H1	H2	H3	Mean D
V1	92.01	92.04	91.23	91.76
V2	94.00	93.75	93.23	93.66
V3	91.66	92.13	92.58	92.13
Mean V	92.56	92.64	92.35	

Table D-26: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in green amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	91.75	91.16	89.26	92.32	92.25	91.89	91.97	92.72	92.55	92.41
V2	93.69	92.97	91.88	94.27	94.17	93.91	94.05	94.12	93.91	94.03
V3	93.32	92.52	91.59	91.41	92.34	93.01	90.25	91.54	93.15	91.65

Table D-27: Harvesting parameters of leafy crop harvester in red amaranthus

	Header loss, %			Conveying loss, %			Harvesting efficiency, %		
Treatments	R1	R2	R3	R1	R2	R3	R1	R2	R3
S1H1V1	5.26	4.85	5.37	3.94	3.49	3.94	90.80	91.66	90.69
S1H1V2	3.56	3.86	3.86	2.77	3.12	3.17	93.66	93.03	92.97
S1H1V3	2.57	2.39	2.63	4.86	4.17	4.74	92.57	93.44	92.63
S1H2V1	6.06	6.50	6.64	2.47	2.84	2.76	91.47	90.66	90.60
S1H2V2	5.43	5.34	4.95	1.80	1.97	1.69	92.76	92.69	93.37
S1H2V3	4.65	4.59	4.23	3.33	3.38	2.98	92.02	92.03	92.79
S1H3V1	8.43	8.74	7.82	2.86	2.79	2.48	88.71	88.47	89.70
S1H3V2	6.84	6.49	6.14	1.97	1.83	1.69	91.19	91.68	92.17
S1H3V3	5.66	5.23	5.79	3.21	2.80	3.17	91.13	91.98	91.03
S2H1V1	3.14	3.40	3.42	4.30	4.95	4.85	92.57	91.64	91.73
S2H1V2	2.79	3.06	3.03	3.10	3.51	3.47	94.11	93.43	93.50
S2H1V3	2.36	2.20	2.43	7.22	6.35	7.01	90.42	91.45	90.56
S2H2V1	4.56	4.27	4.55	4.04	3.60	4.03	91.40	92.13	91.42
S2H2V2	3.70	4.04	4.02	2.38	2.75	2.79	93.91	93.22	93.19
S2H2V3	3.18	3.18	2.88	4.93	4.93	4.48	91.89	91.89	92.64
S2H3V1	5.10	5.60	5.50	2.59	3.00	3.02	92.31	91.40	91.48
S2H3V2	4.15	4.51	4.48	1.85	2.02	2.16	94.00	93.47	93.36
S2H3V3	3.68	3.71	3.44	4.17	4.13	3.64	92.16	92.16	92.91
S3H1V1	2.18	2.03	2.03	6.56	6.63	6.04	91.26	91.34	91.93
S3H1V2	1.90	2.17	2.14	4.18	4.75	4.87	93.93	93.08	92.98
S3H1V3	1.87	1.73	1.95	9.10	7.91	8.73	89.03	90.36	89.32
S3H2V1	2.67	2.45	2.59	5.77	5.19	5.90	91.56	92.36	91.51
S3H2V2	1.94	2.18	2.21	3.98	4.51	4.47	94.08	93.31	93.32
S3H2V3	2.09	2.12	1.85	7.51	7.14	6.32	90.40	90.74	91.83
S3H3V1	3.16	3.22	2.98	5.18	5.07	4.51	91.65	91.71	92.52
S3H3V2	2.51	2.47	2.25	4.40	4.54	3.81	93.09	92.99	93.94
S3H3V3	1.84	1.94	1.74	6.05	5.76	5.02	92.10	92.30	93.25

Table D-28: Interaction S×H of header loss (%) on amaranthus red

Factors	S1	S2	S3	Mean D
H1	3.82	2.87	2.00	2.89
H2	5.38	3.82	2.23	3.81
H3	6.79	4.47	2.46	4.57
Mean S	5.33	3.72	2.23	

Table D-29: Interaction S×V of header loss (%) on amaranthus red

Factors	S1	S2	S3	Mean S
V1	6.63	4.40	2.59	4.54
V2	5.17	3.75	2.19	3.70
V3	4.19	3.00	1.90	3.03
Mean V	5.33	3.72	2.23	

Table D-30: Interaction H×V of header loss (%) on amaranthus red

Factors	H1	H2	H3	Mean D
V1	3.52	4.48	5.62	4.54
V2	2.93	3.76	4.43	3.70
V3	2.23	3.20	3.67	3.03
Mean V	2.89	3.81	4.57	

Table D-31: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in red amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	5.16	6.40	8.33	3.32	4.46	5.40	2.08	2.57	3.12	2.59
V2	3.76	5.24	6.49	2.96	3.92	4.38	2.07	2.11	2.41	2.19
V3	2.53	4.49	5.56	2.33	3.08	3.61	1.85	2.02	1.84	1.90
Mean S	3.82	5.38	6.79	2.87	3.82	4.47	2.00	2.23	2.46	

Table D-32: Interaction S×H of conveying loss on amaranthus red

Factors	S1	S2	S3	Mean D
H1	3.80	4.98	6.53	5.10
H2	2.58	3.77	5.64	4.00
H3	2.53	2.96	4.92	3.47
Mean S	2.97	3.90	5.70	

Table D-33: Interaction S×V of conveying loss on amaranthus red

Factors	S1	S2	S3	Mean S
V1	3.06	3.82	5.65	4.18
V2	2.22	2.67	4.39	3.10
V3	3.63	5.21	7.06	5.30
Mean V	2.97	3.90	5.70	

Table D-34: Interaction H×V of conveying loss on amaranthus red

Factors	H1	H2	H3	Mean D
V1	4.97	4.07	3.50	4.18
V2	3.66	2.93	2.70	3.10
V3	6.68	5.00	4.22	5.30
Mean V	5.10	4.00	3.47	

Table D-35: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on conveying loss (%) by developed harvester in red amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	3.79	2.69	2.71	4.70	3.89	2.87	6.41	5.62	4.92	5.65
V2	3.02	1.82	1.83	3.36	2.64	2.01	4.60	4.32	4.25	4.39
V3	4.59	3.23	3.06	6.86	4.78	3.98	8.58	6.99	5.61	7.06
Mean S	3.80	2.58	2.53	4.98	3.77	2.96	6.53	5.64	4.92	

Table D-36: Interaction S×H of harvesting efficiency (%) on amaranthus red

Factors	S1	S2	S3	Mean D
H1	92.39	92.16	91.47	92.00
H2	92.04	92.41	92.13	92.19
H3	90.67	92.58	92.62	91.96
Mean S	91.70	92.38	92.07	

Table D-37: Interaction S×V of harvesting efficiency (%) on amaranthus red

Factors	S1	S2	S3	Mean S
V1	90.31	91.78	91.76	91.28
V2	92.61	93.57	93.41	93.20
V3	92.18	91.79	91.04	91.67
Mean V	91.70	92.38	92.07	

Table D-38: Interaction H×V of harvesting efficiency (%) on amaranthus red

Factors	H1	H2	H3	Mean D
V1	91.51	91.46	90.88	91.28
V2	93.41	93.31	92.87	93.20
V3	91.09	91.81	92.11	91.67
Mean V	92.00	92.19	91.96	

Table D-39: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in red amaranthus

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	91.05	90.91	88.96	91.97	91.65	91.72	91.51	91.82	91.96	91.76
V2	93.22	92.94	91.68	93.68	93.44	93.60	93.33	93.57	93.34	93.41
V3	92.89	92.28	91.37	90.81	92.15	92.41	89.57	90.99	92.55	91.04
Mean S	92.39	92.04	90.67	92.16	92.41	92.58	91.47	92.13	92.62	

Table D-40: Harvesting parameters of leafy crop harvester in fenugreek

Treatments	Header loss, %			Conveying loss, %			Harvesting efficiency, %		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
S1H1V1	4.56	4.08	4.44	3.39	2.61	2.97	92.05	93.31	92.59
S1H1V2	3.06	3.26	3.46	2.24	2.46	2.95	94.71	94.27	93.59
S1H1V3	2.21	2.11	2.46	3.95	3.29	4.22	93.85	94.59	93.32
S1H2V1	5.63	6.23	6.23	1.62	2.41	2.00	92.76	91.36	91.76
S1H2V2	4.94	5.01	4.48	1.09	1.72	1.15	93.97	93.27	94.37
S1H2V3	3.94	4.06	3.58	2.30	2.82	2.14	93.76	93.12	94.28
S1H3V1	7.83	7.90	7.16	2.41	1.71	1.91	89.76	90.38	90.94
S1H3V2	5.98	5.61	5.24	1.29	1.21	1.13	92.73	93.18	93.63
S1H3V3	4.96	4.46	4.86	3.15	2.62	2.48	91.89	92.92	92.66
S2H1V1	2.19	2.31	2.55	3.67	3.99	4.43	94.13	93.71	93.02
S2H1V2	1.76	2.12	1.88	2.63	3.31	2.79	95.62	94.57	95.32
S2H1V3	1.17	1.19	1.48	6.68	5.94	6.91	92.15	92.87	91.61
S2H2V1	4.13	3.75	3.91	3.72	3.02	3.22	92.15	93.23	92.87
S2H2V2	2.98	3.26	3.42	1.76	1.66	2.31	95.26	95.08	94.27
S2H2V3	2.48	2.48	1.88	4.58	4.58	3.38	92.94	92.94	94.74
S2H3V1	4.37	4.87	4.92	2.02	1.96	2.59	93.61	93.17	92.49
S2H3V2	3.47	3.79	3.93	0.97	0.75	1.46	95.57	95.45	94.61
S2H3V3	3.03	3.21	2.79	2.85	3.38	2.71	94.12	93.41	94.50
S3H1V1	1.39	1.09	1.09	5.84	5.46	5.02	92.77	93.45	93.89
S3H1V2	0.97	1.24	0.91	3.26	4.01	3.56	95.77	94.75	95.53
S3H1V3	0.70	0.78	1.04	7.70	6.92	7.91	91.60	92.30	91.05
S3H2V1	1.75	1.43	1.47	5.33	4.46	5.00	92.92	94.11	93.53
S3H2V2	1.23	1.23	1.53	3.23	3.67	4.05	95.54	95.10	94.42
S3H2V3	1.49	1.74	1.39	6.26	6.42	5.38	92.25	91.84	93.23
S3H3V1	2.39	2.62	2.25	4.11	4.43	3.55	93.50	92.95	94.20
S3H3V2	2.01	1.75	1.67	3.88	3.45	3.11	94.11	94.80	95.22
S3H3V3	0.92	1.24	0.96	5.00	5.41	4.62	94.08	93.35	94.42

Table D-41: Interaction S×H of header loss (%) on fenugreek

Factors	S1	S2	S3	Mean D
H1	3.29	1.85	1.02	2.06
H2	4.90	3.14	1.47	3.17
H3	6.00	3.82	1.76	3.86
Mean S	4.73	2.94	1.42	

Table D-42: Interaction S×V of header loss (%) on fenugreek

Factors	S1	S2	S3	Mean S
V1	6.01	3.67	1.72	3.80
V2	4.56	2.96	1.39	2.97
V3	3.63	2.19	1.14	2.32
Mean V	4.73	2.94	1.42	

Table D-43: Interaction H×V of header loss (%) on fenugreek

Factors	H1	H2	H3	Mean D
V1	2.63	3.84	4.92	3.80
V2	2.07	3.12	3.72	2.97
V3	1.46	2.56	2.94	2.32
Mean V	2.06	3.17	3.86	

Table D-44: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on header loss (%) by developed harvester in fenugreek

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	4.36	6.03	7.63	2.35	3.93	4.72	1.19	1.55	2.42	1.72
V2	3.26	4.81	5.61	1.92	3.22	3.73	1.04	1.33	1.81	1.39
V3	2.26	3.86	4.76	1.28	2.28	3.01	0.84	1.54	1.04	1.14
Mean S	3.29	4.90	6.00	1.85	3.14	3.82	1.02	1.47	1.76	

Table D-45: Interaction S×H of conveying loss on fenugreek

Factors	S1	S2	S3	Mean D
H1	3.12	4.48	5.52	4.37
H2	1.92	3.14	4.87	3.31
H3	1.99	2.08	4.17	2.75
Mean S	2.34	3.23	4.85	

Table D-46: Interaction S×V of conveying loss on fenugreek

Factors	S1	S2	S3	Mean S
V1	2.34	3.18	4.80	3.44
V2	1.69	1.96	3.58	2.41
V3	3.00	4.56	6.18	4.58
Mean V	2.34	3.23	4.85	

Table D-47: Interaction H×V of conveying loss on fenugreek

Factors	H1	H2	H3	Mean D
V1	4.15	3.42	2.74	3.44
V2	3.02	2.29	1.92	2.41
V3	5.95	4.21	3.58	4.58
Mean V	4.37	3.31	2.75	

Table D-48: Interaction S×H×V of conveying loss on fenugreek

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	2.99	2.01	2.01	4.03	3.32	2.19	5.44	4.93	4.03	4.80
V2	2.55	1.32	1.21	2.91	1.91	1.06	3.61	3.65	3.48	3.58
V3	3.82	2.42	2.75	6.51	4.18	2.98	7.51	6.02	5.01	6.18
Mean S	3.12	1.92	1.99	4.48	3.14	2.08	5.52	4.87	4.17	

Table D-49: Interaction S×H of harvesting efficiency (%) on fenugreek

Factors	S1	S2	S3	Mean D
H1	93.59	93.67	93.46	93.57
H2	93.18	93.72	93.66	93.52
H3	92.01	94.10	94.07	93.39
Mean S	92.93	93.83	93.73	

Table D-50: Interaction S×V of harvesting efficiency (%) on fenugreek

Factors	S1	S2	S3	Mean S
V1	91.66	93.15	93.48	92.76
V2	93.75	95.08	95.03	94.62
V3	93.38	93.25	92.68	93.10
Mean V	92.93	93.83	93.73	

Table D-51: Interaction H×V of harvesting efficiency (%) on fenugreek

Factors	H1	H2	H3	Mean D
V1	93.21	92.74	92.33	92.76
V2	94.90	94.59	94.37	94.62
V3	92.59	93.23	93.48	93.10
Mean V	93.57	93.52	93.39	

Table D-52: Interactive effect of forward speed (S), cutting height (H) and air velocity (V) on harvesting efficiency (%) by developed harvester in fenugreek

	S1			S2			S3			
Factors	H1	H2	H3	H1	H2	H3	H1	H2	H3	Mean D
V1	92.65	91.96	90.36	93.62	92.75	93.09	93.37	93.52	93.55	93.48
V2	94.19	93.87	93.18	95.17	94.87	95.21	95.35	95.02	94.71	95.03
V3	93.92	93.72	92.49	92.21	93.54	94.01	91.65	92.44	93.95	92.68
Mean S	93.59	93.18	92.01	93.67	93.72	94.10	93.46	93.66	94.07	

Table D-53: Harvesting parameters of leafy crop harvester in spinach

Treatments	Header loss, %			Conveying loss, %			Harvesting efficiency, %		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
S1H1V1	8.87	7.26	8.98	4.29	4.83	5.31	86.84	87.91	85.71
S1H1V2	6.16	7.58	7.62	2.81	3.64	2.97	91.04	88.78	89.41
S1H1V3	6.68	5.40	6.79	5.46	4.76	5.86	87.85	89.85	87.35
S2H1V1	5.02	6.23	5.94	5.73	4.58	5.38	89.25	89.19	88.68
S2H1V2	4.07	4.61	3.65	3.76	4.46	4.86	92.16	90.93	91.49
S2H1V3	3.57	4.08	3.09	7.81	7.81	6.31	88.62	88.11	90.60
S3H1V1	3.62	3.06	2.68	6.24	7.54	7.64	90.14	89.39	89.68
S3H1V2	3.28	2.93	2.58	5.37	6.41	6.64	91.35	90.66	90.78
S3H1V3	3.33	2.51	2.65	9.28	9.13	7.48	87.39	88.36	89.88

APPENDIX-E

Table E-1: ANOVA of harvesting efficiency (%) of different harvesting methods on chickpea

S.V.	DF	SS	MSS	F-cal
Replication	4	37.219		
Treatment (T)	3	120.115	40.038	5.843
Error	12	82.229	6.852	
Total	19	239.563		

Table E-2: Mean table of harvesting efficiency (%) in chickpea

Treatment	Mean	Std. Error
Manual harvesting (T1)	99.21	0.256
Manual harvesting with sickle (T2)	98.34	0.498
Battery operated leafy crop harvester (T3)	92.82	2.172
Developed leafy crop harvester (T4)	96.82	0.970
CD (P=0.05)	3.647	
SEm	1.171	
SE(d)	1.656	
CV (%)	2.704	

Table E-3: ANOVA of cleaning efficiency (%) of different harvesting methods on chickpea

S.V.	DF	SS	MSS	F-cal
Replication	4	33.891		
Treatment (T)	3	41.059	13.686	2.421
Error	12	67.833	5.653	
Total	19	142.783		

Table E-4: Mean table of cleaning efficiency (%) in chickpea

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.91	0.375
Manual harvesting with sickle (T2)	96.64	1.058
Battery operated leafy crop harvester (T3)	95.63	1.364
Developed leafy crop harvester (T4)	95.21	1.402
CD (P=0.05)	NS	
SEm	1.063	
SE(d)	1.504	
CV (%)	2.461	

Table E-5: ANOVA of yield (t ha^{-1}) of different harvesting methods on chickpea

S.V.	DF	SS	MSS	F-cal
Replication	4	0.249		
Treatment (T)	3	0.076	0.025	0.371
Error	12	0.822	0.069	
Total	19	1.148		

Table E-6: Mean table of yield (t ha^{-1}) in chickpea

Treatment	Mean	Std. Error
Manual harvesting (T1)	2.58	0.113
Manual harvesting with sickle (T2)	2.62	0.121
Battery operated leafy crop harvester (T3)	2.46	0.113
Developed leafy crop harvester (T4)	2.51	0.115
CD (P=0.05)	NS	
SEm	0.117	
SE(d)	0.166	
CV (%)	10.297	

Table E-7: ANOVA of field capacity (ha h^{-1}) of different harvesting methods on chickpea

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.007	0.002	2561.431
Error	12	0.000	0.000	
Total	19	0.007		

Table E-8: Mean table of field capacity (ha h^{-1}) in chickpea

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.0050	0.0000
Manual harvesting with sickle (T2)	0.0060	0.0000
Battery operated leafy crop harvester (T3)	0.0150	0.0010
Developed leafy crop harvester (T4)	0.0510	0.0010
CD (P=0.05)	0.0010	
SEm	0.0000	
SE(d)	0.0010	
CV (%)	4.9740	

Table E-9: ANOVA of capacity of harvesting (t h^{-1}) of different harvesting methods on chickpea

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.043	0.014	347.979
Error	12	0.000	0.000	
Total	19	0.044		

Table E-10: Mean table of capacity of harvesting (t h^{-1}) in chickpea

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.013	0.000
Manual harvesting with sickle (T2)	0.016	0.001
Battery operated leafy crop harvester (T3)	0.036	0.002
Developed leafy crop harvester (T4)	0.127	0.006
CD (P=0.05)	0.009	
SEm	0.003	
SE(d)	0.004	
CV (%)	13.384	

Table E-11: ANOVA of harvesting efficiency (%) of different harvesting methods on green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	54.253		
Treatment (T)	3	96.651	32.217	3.715
Error	12	104.064	8.672	
Total	19	254.968		

Table E-12: Mean table of harvesting efficiency (%) in green amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.23	0.600
Manual harvesting with sickle (T2)	97.36	0.807
Battery operated leafy crop harvester (T3)	92.74	2.147
Developed leafy crop harvester (T4)	94.51	1.515
CD (P=0.05)	4.103	
SEm	1.317	
SE(d)	1.862	
CV (%)	3.077	

Table E-13: ANOVA of cleaning efficiency (%) of different harvesting methods on green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	73.14		
Treatment (T)	3	107.202	35.734	3.277
Error	12	130.874	10.906	
Total	19	311.216		

Table E-14: Mean table of cleaning efficiency (%) in green amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.62	0.483
Manual harvesting with sickle (T2)	96.21	1.159
Battery operated leafy crop harvester (T3)	93.65	1.916
Developed leafy crop harvester (T4)	92.68	2.225
CD (P=0.05)	NS	
SE(m)	1.477	
SE(d)	2.089	
CV (%)	3.466	

Table E-15: ANOVA of yield (t ha^{-1}) of different harvesting methods on green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	1.58		
Treatment (T)	3	3.914	1.305	2.598
Error	12	6.025	0.502	
Total	19	11.518		

Table E-16: Mean table of yield (t ha^{-1}) in green amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	10.89	0.300
Manual harvesting with sickle (T2)	11.36	0.354
Battery operated leafy crop harvester (T3)	10.21	0.241
Developed leafy crop harvester (T4)	10.43	0.327
CD (P=0.05)	NS	
SE(m)	0.317	
SE(d)	0.448	
CV (%)	6.608	

Table E-17: ANOVA of field capacity (ha h^{-1}) of different harvesting methods on green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.007	0.002	3607.865
Error	12	0.000	0.000	
Total	19	0.007		

Table E-18: Mean table of field capacity (ha h^{-1}) in green amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.0050	0.0000
Manual harvesting with sickle (T2)	0.0060	0.0000
Battery operated leafy crop harvester (T3)	0.0150	0.0010
Developed leafy crop harvester (T4)	0.0500	0.0010
CD (P=0.05)	0.0010	
SE(m)	0.0000	
SE(d)	0.0000	
CV (%)	4.1480	

Table E-19: ANOVA of capacity of harvesting (t h^{-1}) of different harvesting methods on green amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	0.002		
Treatment (T)	3	0.719	0.24	604.553
Error	12	0.005	0	
Total	19	0.726		

Table E-20: Mean table of capacity of harvesting (t h^{-1}) in green amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.052	0.002
Manual harvesting with sickle (T2)	0.070	0.003
Battery operated leafy crop harvester (T3)	0.148	0.004
Developed leafy crop harvester (T4)	0.520	0.018
CD (P=0.05)	0.028	
SE(m)	0.009	
SE(d)	0.013	
CV (%)	10.084	

Table E-21: ANOVA of harvesting efficiency (%) of different harvesting methods on red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	52.636		
Treatment (T)	3	109.394	36.465	4.481
Error	12	97.656	8.138	
Total	19	259.686		

Table E-22: Mean table of harvesting efficiency (%) in red amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.41	0.291
Manual harvesting with sickle (T2)	97.21	0.526
Battery operated leafy crop harvester (T3)	92.87	2.175
Developed leafy crop harvester (T4)	93.61	1.556
CD (P=0.05)	3.975	
SE(m)	1.276	
SE(d)	1.804	
CV (%)	2.986	

Table E-23: ANOVA of cleaning efficiency (%) of different harvesting methods on red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	31.83		
Treatment (T)	3	30.201	10.067	1.747
Error	12	69.154	5.763	
Total	19	131.185		

Table E-24: Mean table of cleaning efficiency (%) in red amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.11	0.403
Manual harvesting with sickle (T2)	96.31	1.146
Battery operated leafy crop harvester (T3)	95.15	1.418
Developed leafy crop harvester (T4)	95.07	1.250
CD (P=0.05)	NS	
SE(m)	1.074	
SE(d)	1.518	
CV (%)	2.496	

Table E-25: ANOVA of yield (t ha^{-1}) of different harvesting methods on red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	1.337		
Treatment (T)	3	4.069	1.356	3.029
Error	12	5.374	0.448	
Total	19	10.78		

Table E-26: Mean table of yield (t ha^{-1}) in red amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	11.23	0.282
Manual harvesting with sickle (T2)	10.92	0.33
Battery operated leafy crop harvester (T3)	10.19	0.25
Developed leafy crop harvester (T4)	10.21	0.291
CD (P=0.05)	NS	
SE(m)	0.299	
SE(d)	0.423	
CV (%)	6.291	

Table E-27: ANOVA of field capacity (ha h^{-1}) of different harvesting methods on red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.007	0.002	2621.285
Error	12	0.000	0.000	
Total	19	0.007		

Table E-28: Mean table of field capacity (ha h^{-1}) in red amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.005	0.0000
Manual harvesting with sickle (T2)	0.006	0.0000
Battery operated leafy crop harvester (T3)	0.015	0.0010
Developed leafy crop harvester (T4)	0.050	0.0010
CD (P=0.05)	0.001	
SE(m)	0.000	
SE(d)	0.001	
CV (%)	4.900	

Table E-29: ANOVA of capacity of harvesting (t h^{-1}) of different harvesting methods on red amaranthus on red amaranthus

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.690	0.230	919.709
Error	12	0.003	0.000	
Total	19	0.693		

Table E-30: Mean table of capacity of harvesting (t h^{-1}) in red amaranthus

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.056	0.002
Manual harvesting with sickle (T2)	0.068	0.002
Battery operated leafy crop harvester (T3)	0.150	0.005
Developed leafy crop harvester (T4)	0.512	0.011
CD (P=0.05)	0.022	
SE(m)	0.007	
SE(d)	0.010	
CV (%)	8.046	

Table E-31: ANOVA of harvesting efficiency (%) of different harvesting methods on fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	4	41.144		
Treatment (T)	3	137.200	45.733	6.201
Error	12	88.502	7.375	
Total	19	266.845		

Table E-32: Mean table of harvesting efficiency (%) in fenugreek

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.34	0.270
Manual harvesting with sickle (T2)	97.36	0.523
Battery operated leafy crop harvester (T3)	91.57	2.235
Developed leafy crop harvester (T4)	94.81	1.068
CD (P=0.05)	3.784	
SE(m)	1.215	
SE(d)	1.718	
CV (%)	2.843	

Table E-33: ANOVA of cleaning efficiency (%) of different harvesting methods on fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	4	35.412		
Treatment (T)	3	26.301	8.767	1.420
Error	12	74.112	6.176	
Total	19	135.825		

Table E-34: Mean table of cleaning efficiency (%) in fenugreek

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.23	0.492
Manual harvesting with sickle (T2)	96.46	1.149
Battery operated leafy crop harvester (T3)	95.51	1.421
Developed leafy crop harvester (T4)	95.34	1.376
CD (P=0.05)	NS	
SE(m)	1.111	
SE(d)	1.572	
CV (%)	2.578	

Table E-35: ANOVA of yield (t ha^{-1}) of different harvesting methods on fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	4	0.755		
Treatment (T)	3	0.992	0.331	1.554
Error	12	2.552	0.213	
Total	19	4.298		

Table E-36: Mean table of yield (t ha^{-1}) in fenugreek

Treatment	Mean	Std. Error
Manual harvesting (T1)	8.51	0.193
Manual harvesting with sickle (T2)	8.32	0.237
Battery operated leafy crop harvester (T3)	7.91	0.171
Developed leafy crop harvester (T4)	8.13	0.207
CD (P=0.05)	NS	
SE(m)	0.206	
SE(d)	0.292	
CV (%)	5.612	

Table E-37: ANOVA of field capacity (ha h^{-1}) of different harvesting methods on fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.006	0.002	1896.201
Error	12	0.000	0.000	
Total	19	0.006		

Table E-38: Mean table of field capacity (ha h^{-1}) in fenugreek

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.005	0.000
Manual harvesting with sickle (T2)	0.006	0.000
Battery operated leafy crop harvester (T3)	0.014	0.001
Developed leafy crop harvester (T4)	0.049	0.001
CD (P=0.05)	0.001	
SE(m)	0.000	
SE(d)	0.001	
CV (%)	5.696	

Table E-39: ANOVA of capacity of harvesting (t h^{-1}) of different harvesting methods on fenugreek

S.V.	DF	SS	MSS	F-cal
Replication	4	0.001		
Treatment (T)	3	0.422	0.141	591.672
Error	12	0.003	0.000	
Total	19	0.425		

Table E-40: Mean table of capacity of harvesting (t h^{-1}) in fenugreek

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.042	0.002
Manual harvesting with sickle (T2)	0.050	0.000
Battery operated leafy crop harvester (T3)	0.116	0.006
Developed leafy crop harvester (T4)	0.398	0.012
CD (P=0.05)	0.021	
SE(m)	0.007	
SE(d)	0.010	
CV (%)	10.172	

Table E-41: ANOVA of harvesting efficiency (%) of different harvesting methods on spinach

S.V.	DF	SS	MSS	F-cal
Replication	4	52.349		
Treatment (T)	3	276.667	92.222	10.141
Error	12	109.13	9.094	
Total	19	438.146		

Table E-42: Mean table of harvesting efficiency (%) in spinach

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.21	0.401
Manual harvesting with sickle (T2)	96.36	0.767
Battery operated leafy crop harvester (T3)	89.62	2.417
Developed leafy crop harvester (T4)	90.34	1.217
CD (P=0.05)	4.202	
SE(m)	1.349	
SE(d)	1.907	
CV (%)	3.221	

Table E-43: ANOVA of cleaning efficiency (%) of different harvesting methods on spinach

S.V.	DF	SS	MSS	F-cal
Replication	4	32.541		
Treatment (T)	3	68.007	22.669	4.615
Error	12	58.942	4.912	
Total	19	159.489		

Table E-44: Mean table of cleaning efficiency (%) in spinach

Treatment	Mean	Std. Error
Manual harvesting (T1)	98.71	0.422
Manual harvesting with sickle (T2)	97.31	0.795
Battery operated leafy crop harvester (T3)	94.36	1.375
Developed leafy crop harvester (T4)	94.56	1.368
CD (P=0.05)	3.088	
SE(m)	0.991	
SE(d)	1.402	
CV (%)	2.303	

Table E-45: ANOVA of yield (t ha^{-1}) of different harvesting methods on spinach

S.V.	DF	SS	MSS	F-cal
Replication	4	0.17		
Treatment (T)	3	0.696	0.232	4.475
Error	12	0.622	0.052	
Total	19	1.489		

Table E-46: Mean table of yield (t ha^{-1}) in spinach

Treatment	Mean	Std. Error
Manual harvesting (T1)	3.48	0.099
Manual harvesting with sickle (T2)	3.36	0.103
Battery operated leafy crop harvester (T3)	3.21	0.099
Developed leafy crop harvester (T4)	2.98	0.096
CD (P=0.05)	0.317	
SE(m)	0.102	
SE(d)	0.144	
CV (%)	6.991	

Table E-47: ANOVA of field capacity (ha h^{-1}) of different harvesting methods on spinach

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.006	0.002	1541.128
Error	12	0.000	0.000	
Total	19	0.006		

Table E-48: Mean table of field capacity (ha h^{-1}) in spinach

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.005	0.000
Manual harvesting with sickle (T2)	0.006	0.000
Battery operated leafy crop harvester (T3)	0.014	0.001
Developed leafy crop harvester (T4)	0.049	0.001
CD (P=0.05)	0.002	
SE(m)	0.001	
SE(d)	0.001	
CV (%)	6.328	

Table E-49: ANOVA of capacity of harvesting (t h^{-1}) of different harvesting methods on spinach

S.V.	DF	SS	MSS	F-cal
Replication	4	0.000		
Treatment (T)	3	0.054	0.018	243.288
Error	12	0.001	0.000	
Total	19	0.055		

Table E-50: Mean table of capacity of harvesting (t h^{-1}) in spinach

Treatment	Mean	Std. Error
Manual harvesting (T1)	0.017	0.001
Manual harvesting with sickle (T2)	0.020	0.001
Battery operated leafy crop harvester (T3)	0.046	0.002
Developed leafy crop harvester (T4)	0.145	0.008
CD (P=0.05)	0.012	
SE(m)	0.004	
SE(d)	0.005	
CV (%)	15.100	

APPENDIX-F

Table F-1: Cost of prototype of developed leafy crop harvester

Parameters	Material	Size	Quantity	Price, ₹
Frame				
Steel	SS	Angle 35x3	16	4,000.00
Harvesting unit				
Cutting unit				7000
Blowing unit				3000
Power transmission				1000
Engine		1.03 kW	1	11,000.00
Transmission system				
Gear box		1:39	1	800.00
Chain drive				
Sprocket 1		27 teeth	1	200.00
Sprocket 1		27 teeth	1	200.00
Chain 1			600 mm	400.00
Universal bearing		20 mm	2	700.00
Flat bearing		20 mm	4	1,600.00
Conveyor				
Belt	canvas	540 mm width	1800 mm	300.00
Shaft 1		25 mm dia.	570 mm	465.00
Shaft 2		25 mm dia.	640 mm	520.00
Shaft 3		25 mm dia.	760 mm	560.00
Universal joint	Mild steel		3 kg	800.00
Windrowing	Mild steel	9 mm bar	12 kg	900.00
Wheel				
a. Wheel 1	Rubber	200 mm	2	1,200.00
b. Wheel 2	Rubber steel	600 mm	2	3,600.00
Labour charges				5,000.00
			Total	43,245.00

Initial Cost of Machine

Cost of prototype of leafy crop harvester = ₹ 43245.00/-

Economic Analysis

Following assumption was made for economic analysis of developed harvester:

a. Expected life of harvester = 10 years
b. Annual use of developed harvester can be calculated as follows
c. Working hour (H) = 250 h y^{-1}, when working hour is 8 h day (for two crops)
d. Salvage value (S)= 10% of initial cost
e. Rate of interest = 10% per annum
f. Labour required =01
g. Petrol cost = 90 ₹ l^{-1}
h. Fuel consumption = 0.8 l h^{-1}
i. Lubrication cost = 20% fuel cost
j. Repair and maintenance = 5% of initial cost
k. Shelter, insurance and tax cost = 2% of initial cost

1.1 Fixed cost

a. Depreciation cost

$$D = \frac{C - S}{H \times L}$$

Where,

D = Depreciation per hour

C = Capital investment

S= Salvage value, 10% of initial cost

H = Number of working hour per year

L = Life of machine in year

$$= \frac{43245 - 4324.50}{10 \times 250} = ₹15.57/-$$

b. Interest

Insurance and taxes are against the losses in many farm machinery and equipment.

$$=\frac{43245+4324.50}{2} \times \frac{0.1}{250} = 9.51 \text{ ₹ } h^{-1}$$

c. Shelter, insurance and tax cost

Shelter is necessarily required against the weather changes. Shelter cost has been calculated at 2% of the average purchase price.

$$= \frac{43245 \times 2}{250 \times 100}$$

= 3.46 ₹ h^{-1}

Then, Total fixed cost = (15.57+9.51+3.46) = 28.54 ₹ h^{-1}

1.2 Variable cost

a. Fuel cost

Petrol;

Cost = 90 ₹ l^{-1}

Fuel consumption is 0.80 ml h^{-1}

= 72.00 ₹ h^{-1}

b. Lubrication cost

Lubrication cost = 20 % of fuel cost

= 72.00 ×0.20 = 14.40 ₹ h^{-1}

c. Repair and maintenance cost

Repair and maintenance @ 5% of initial cost

$$= \frac{43245 \times 5}{250 \times 100}$$

= 8.65 ₹ h^{-1}

d. Labour charge

= 315 ₹ day^{-1}

Labour required = 1

Actual field capacity = 0.05

Total hour for one hectare = 1/0.05

Labour cost= 39.37 ₹ h^{-1}

Total variable cost = 72+14.40+8.65+39.38= 134.42 ₹ h^{-1}

Total cost of harvesting = fixed cost + variable cost

= 28.54 +134.42

= 162.97 ₹ h^{-1}

Average effective field capacity = 0.05 ha h^{-1}

Cost of operation of leafy crop harvester = 162.97/0.05

= 3259.40 ₹ ha^{-1}

e. Break-even point

FC= 250×28.54 = ₹ 7135.43 /-

CH = (162.97+162.94×0.25) ×1.25= ₹ 254.63

BEP = $\frac{7135.43}{254.63-1\quad .97}$ = 77.84 h y^{-1}

BEP = 3.89 ha y^{-1}

f. Payback period

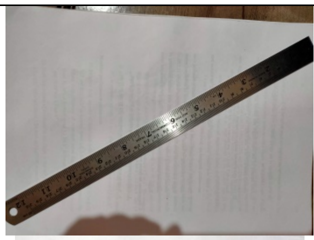
ANP = (CH-C) × AU

ANP = (254.63 – 162.97) × 250 = ₹ 22917.05 /-

Table F-2: Cost of operation of different harvesting methods

Particulars	Developed leafy crop harvester	Manual harvesting	Harvesting with Sickle	Battery operated leafy crop harvester
New Cost, ₹ (P)	43,245.00	-	-	10,000.00
Salvage	4,324.50	-	-	1,000.00
Life, y	10.00	-	-	5
Life, h y^{-1}	250.00	-	-	150.00
Depreciation	15.57	-	-	12.00
Interest	9.51	-	-	3.67
Shelter	3.46	-	-	1.33
Total fixed cost, ₹ h^{-1}	28.54	-	-	17.00
Fuel rate, ₹ l^{-1}	90.00	-	-	0.00
Fuel consumption	0.80	-	-	0.80
Fuel cost, ₹ h^{-1}	72.00	-	-	0.00
Lubrication, ₹ h^{-1}	14.40	-	-	0.00
Repair cost, ₹ h^{-1}	8.65	-	-	3.33
Labour required	1	1	1	1
Working, h ha^{-1}	20.00	200.00	166.67	66.67
Labour cost, ₹ day^{-1}	315.00	315.00	315.00	315.00
Labour cost, ₹ h^{-1}	39.38	39.38	39.38	39.38
Total variable, ₹ h^{-1}	134.42	39.38	39.38	42.71
EFC, ha h^{-1}	0.05	0.005	0.006	0.015
Total cost, ₹ h^{-1}	162.97	39.38	39.38	59.71
Total cost, ₹ ha^{-1}	3,259.31	7,875.00	6,562.50	3,980.56

APPENDIX-G

S.No.	Instrument		Use	Image
1.	Steel scale	0-300 mm	For measurement of row and plant spacing of plant	
2.	Tape	3 m, 30 m	For measurement of field length and plant height	
3.	Vernier caliper	0-300 mm	For measurement of physical dimensions of plant	
4.	Weighing balance -1	0-50 kg LC - 100 g	For measurement of weight of leafy crop in field	
5.	Weighing balance -2	0-15 kg LC - 01g	For measurement of weight of soil sample and leafy crop	
6.	Stop watch	Android app	For measurement of operational time	
7.	Hot air oven	0-200°	For measurement moisture content of soil	

8.	Anemometer	For measurement of terminal velocity of the leaves	
9.	Digital soil meter	For measurement of soil pH and temperature	
10.	Digital tachometer 1-3000 RPM	For measurement of RPM of different rotating component	
11.	Cone penetrometer 129 mm^2 LC – 0.002 mm	For measurement of soil resistance	
12.	Core cutter Length-130 mm Diameter-100 mm	For measurement of soil bulk density	

RESUME

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पुष्पराज

Signature