DESIGN ANALYSIS OF SUITABLE CUTTER HEADER ASSEMBLY FOR POKKALI PADDY HARVESTER

By

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THESIS

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2021

DECLARATION

I, hereby declare that the thesis entitled **"Design Analysis of Suitable Cutter Header Assembly for Pokkali Paddy Harvester"** is a bona-fide record of research done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Tavanur

Date: 09.12.21

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CERTIFICATE

Certified that this thesis entitled **"Design Analysis of Suitable Cutter Header Assembly for Pokkali Paddy Harvester"** is a record of research work done independently by **Rathinavel S (2019-18-015)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of **Rathinavel S (2019-18-015),** a candidate for the degree of **Master of Technology in Agricultural Engineering** with major field in **Farm Machinery and Power Engineering,** agree that this thesis entitled **"Design Analysis of Suitable Cutter Header Assembly for Pokkali Paddy Harvester"** may be submitted by **Rathinavel S (2019-18-015),** in partial fulfillment of the requirement for the degree.

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EXTERNAL EXAMINER

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Rathinavel S

DEDICATED TO

FARMERS OF POKKALI SYSTEM,

MY ADVISORY COMMITTEE,

FMP & BE

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LIST OF ABBREVIATIONS AND SYMBOLS

A	:	Area of piston head
Ah	:	Ampere-hour
AHP	:	Analytical Hierarchy Process
AIIE	:	American Institute of Industrial Engineers
C_{eff}	:	Effective field capacity
C_{th}	:	Theoretical field capacity
CIAE	:	Central Institute of Agricultural Engineering
cm	:	centimetre
d	:	Number of uncut plant per square metre
DE_{input}	:	Direct Energy as input
dS m^{-1}	:	deciSiemens per metre
e	:	Number of plant per square metre before reaping
EC	:	Electrical Conductivity
EE	:	Embodied Energy
eqn	:	Equation
et al.	:	and others
EV	:	Electric vehicle
F	:	Force
FC	:	Fuel Consumption
F_C	:	Field capacity
FE_{input}	:	Fuel energy as input
ft	:	Feet
GJ	:	Gigajoules
gm	:	gram
g cm^{-3}	:	gram per cubic centimetre
H	:	Reel Height Position
h	:	Hour, Height of left over crop stubble
ha	:	hectare
ha^{-1}	:	per hectare

HE_{input}	:	Human Energy as input
hp	:	Horse power
HoQ	:	House of Quality
I	:	Moment of Inertia
ICAR	:	Indian Council of Agricultural Research
IDA	:	Influence Diagram Approach
IE_{input}	:	Indirect Energy as input
IEA	:	International Energy Agency
IRRI	:	International Rice Research Institute
J	:	Joule
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kJ	:	kilojoules
kg	:	kilogram
kg cm^{-2}	:	kilogram per square centimetre
km h^{-1}	:	kilogram per hour
kg ha^{-1}	:	kilogram per hour
kg l^{-1}	:	kilogram per litre
kg m^{-3}	:	kilogram per cubic metre
KLDC	:	Keara Land Development Cooperation
kN m^{-2}	:	kilogram Newton per square metre
KVK	:	Krishi Vigyan Kendra
QFD	:	Quality Function Deployment
M & M	:	Mahindra & Mahindra
m	:	metre, Mass of the reel
m^3	:	cubic metre
MAH-400CB	:	Hydraulic Motor Model Number
Max.	:	Maximum
MJ	:	Mega joules
MJ kg^{-1}	:	Mega joules per kilogram

mg g^{-1}	:	milligram per gram
ml	:	millilitre
mm	:	millimetre
mm s^{-1}	:	millimetre per Second
MS	:	Mild Steel
MSL	:	Mean Sea Level
m s^{-1}	:	metre per second
N	:	Newton, Number of revolution of crank pitman, Number of labours required
n	:	Number of bats
NPV	:	Net Present Value
Nos	:	Numbers
L	:	Crop height, Life Span, Litre
L_c	:	Length of the cutter bar
l	:	litre
P	:	Power Required
pH	:	Presence of Hydrogen
P_r	:	Size (pitch) of reel
PV	:	Present Value
R	:	Radius of gyration, Cutting index
rad s^{-1}	:	radians per second
R_r	:	Radius of reel
RRS	:	Rice Research Station
R_h	:	Radius of piston head
rpm	:	revolutions per minute
S	:	Knife edge stroke
T	:	Torque required, Time
t	:	Distance between the ends of adjacent fingers, Time of a single reel revolution
TE_{input}	:	Total Energy as input
TNAU	:	Tamilnadu Agricultural University

ut	:	tangential velocity of tip of the bats
V	:	volt
V_k	:	Average knife velocity
V_m	:	Forward speed
VoC	:	Voice of Customers
X	:	1000 Seed Weight
x_t	:	Path travelled in single rotation of reel
Y	:	Number of seedlings in one Acre
Z_r	:	Reel Stagger
ωr	:	Angular velocity of reel
α	:	Angular displacement
&	:	and
^{0}	:	degrees

CHAPTER - I

INTRODUCTION

'Pokkali' is a system of rice cultivation including prawn cultivation in the Kerala's saline tracts as like *'Kole'* and *'Kaipad'* paddy cultivation system. The system cultivation is under saline and flooded conditions. Majorly the system is found in Thrissur, Ernakulam and Alapuzha districts of Central Kerala. Radhika *et al.* (2021) reported that pokkali paddy received a Geographical Indication (GI) Tag and organic certification during the year 2007.

1.1 History of Pokkali System

It's traditionally said that a wild paddy grass seed from Western Ghats, reached the coastal regions of Kerala about three thousand years ago. The seed sustained the salinity and flooded conditions of coastal region, started growing which further came as a traditional farming system as pokkali. The name of the system "Pokkali" arrived due to its height, "pokkali" means "one who flares up". Pokkali rice system includes paddy varieties of tall cultivars *such as Chootu Pokkali, Cheruvirippu, Chettivirippu, Anakodan, Eravapandi, Kuruva, Bali, Orpandy, Pokkali* and *Orkayama* and they are the traditional cultivars grown in the tracts of Central Kerala. Tall height growing hybrids *(Vytilla 1, Vytilla 2, Vytilla 3, Vytilla 4 and Vytilla 5),* Short height growing hybrids *(Vytilla 6, Vytilla 7, Vytilla 8,* and *Vytilla 10)* are the high yielding (2000 to 3000 kg ha^{-1}) Pokkali paddy varieties released by the Kerala Agricultural University. *Vytilla 11* is latest variety released from Kerala Agricultural University. Shrimp farming (known as "*Chemmeen Kettu*" or "*Chemmeen Vattu*" or "*Adappu*" is done for five months duration) is practiced from December to mid of April each year and for the new year of Malayalam calendar *Visu* 1^{st} (April 14^{th} or 15^{th}) the land is prepared for paddy cultivation. Local prawn varieties such as *Naran, Choodan* etc and sometimes tiger prawn and crabs were also cultivated. Soon after shrimp farming, the land is prepared and allowed to dry which results in cracks, through which the harmful gases held in the soil are released out. Thereby the salinity level of the soil decreases which helps in preserving the soil and groundwater. When the paddy was harvested, the uncut stalks left in the field which decays and enriches the soil with organic matter under the saline water conditions. The pokkali system thus follows both the paddy cultivation and shrimp farming to protect and preserve the ecology and environment. In Kerala, these cultivars in pokkali system are also known for their peculiar taste and nutritional value especially higher level of protein content. As there are no chemical fertilizations or pesticides, several medicinal benefits are stated for the pokkali rice such as rice gruel water of pokkali rice for Cholera patients and pokkali rice bran for piles patients. Pokkali paddy varieties have undergone modifications and cross over with other cultivars to give new varieties. IRRI (International Rice Research Institute), Philippines, by deriving the genes from cultivars in pokkali system has developed many rice lines with higher yield.

1.2 Pokkali Paddy Cultivation

The ecosystem is unique in pokkali fields. One of the abiotic stress factors, limiting the plant growth is Salinity. When the monsoon persists, (June to mid-October/early November) salinity level of pokkali fields will be less, due to the presence of rain water. Hence during this non-saline condition, pokkali paddy cultivation is carried out. In a favourable condition, seeds will be traditionally prepared by pre-process such as soaking and directly broadcasted to produce seedlings which are raised on the mounds, are transplanted later. The seed rate is about 100 kg ha^{-1} for *'Vytilla'* varieties. The pokkali paddy attains a height of 40-45 cm in 30-35 days. No pesticides or fertilizers are used and it's completely an organic method of paddy production. Hand weeding is done sometimes before and after transplanting. Harvesting is carried out by cutting the ear heads above the water level in the field after the maturity period of 120 days. The paddy straw is left over in the fields. During saline condition from mid November to mid-April, shrimp cultivation is carried out. The shrimps are fed by pokkali paddy straw, which left over after cultivation. Plate 1.1 shows the Pokkali paddy fields during the month of March while shrimp cultivation is in progress. The left over shrimps and shrimp wastes decomposes and enriches the soil for the next paddy season.

The bottom mud on the Pokkali field may be used as fertilizer for coconut in the regions of North Malabar. Mounds will be formed with base one meter and height half meter for serving as an in-situ nursery, but recently the mound size becomes less due to climatic and labour shortage issues. The water has a pH of 7 to 8.5. The soil pH ranges from 3 to 4.5. The soil Electrical Conductivity (EC) of pokkali system during the November to May (high saline phase) varies from the range of 12 – 24 dS m^{-1} and during June to October (low saline phase) EC ranges from 4 – 6 dS m^{-1}. Plates 1.3 to 1.8 and Fig. 1.1 shows the various operations in sequence in pokkali cultivational system of paddy.

Plate 1.1 Pokkali fields during the month of March

1.3 Environmental Importance of Pokkali System

In the environmental point of view, the pokkali paddy cultivation plays a major role on preserving the ground water table. Also pokkali system forms a unique ecosystem and sustaining both paddy and prawn cultivation becomes inevitable for the following reasons. Discontinuing the pokkali paddy cultivation will greatly affect the prawn farming. The juvenile prawn requires the high protein supplement which is received from the decaying stubbles. Pokkali paddy cultivation is quite essential to prawn farming, otherwise the flooded pokkali fields become more acidic and lacks oxygen availability for prawn farming (Das and Stigter, 2005). In monoculture of prawn, the yield gradually starts to decline after the higher yield during initial years (Krishna *et al.*, 2006).

1.4 Challenges in sustaining pokkali system

Pokkali farming demands mechanization of diking i.e., bund preparation and rebuilding to prevent water movement), harvesting of pokkali paddy, extension of industrial zones and fish farms, attack of predators such as rodents, Moorhen (bird eating grains in pokkali fields), climate change, and poor economic outcomes catalysed the declining area of pokkali fields. Plate 1.2 shows the Moorhen bird predating pokkali paddy grains.

Earlier pokkali fields were extended in 25000 ha, a few decades ago (Joy, 2013) and area is now reduced to less than or equal 6274 ha (Joseph, 2016) because of the above reasons. Even some cases, cultivated paddy are not harvested due to the economic constraints of farmers in case of manual harvest. Even Government has promoted programmes for preventing the pokkali system declining in paddy cultivation by offering subsidies and inputs but still the unsolved non-economic constraints dominates obstructing the farmers to bring more area under cultivation. KLDC (Keara Land Development Cooperation) works under the administrative control of the Government of Kerala - Agriculture Department, provided a comprehensive plan with a name *"Jaiva Vypin Project"* for developing pokkali paddy cultivation in the district of Ernakulam.

Plate 1.2 Moorhen birds (breeding & predating) at pokkali paddy field

(a) **(b)**

Plate 1.3 (a) Shrimp cultivation at pokkali field (b) Diking (strengthening the bunds)

(a) **(b)**

Fig. 1.1 (a) Strengthening of bunds (b) Mound making for seed bed

(a) **(b)**

Plate 1.4 (a) Seedling on mounds after sowing (b) Transplanting operating

(a) **(b)**

Plate 1.5 (a) Matured pokkali paddy crop (b) Harvesting operation

(a) **(b)**

Plate 1.6 (a) Full plant of pokkali paddy (b) Cut portion of harvested pokkali paddy

(a) **(b)**

Plate 1.7 (a) Transportation of cut stalks to the bunds (b) Crop stalks to be threshed

(a) (b)

Plate 1.8 (a) Threshed paddy straw (b) Pokkali paddy grains

1.5 Importance of Pokkali Paddy Harvester

Usually the harvesting of pokkali paddy takes place by the second half of October. Unlike other cultivars, paddy matured in pokkali system is harvested in standing water condition after 120 days. Pokkali paddy plants grow up to 2 m and lodges to collapse one another with only the panicles standing upright. Conventionally, the harvest operation is done manually using sickles. The pokkali field soils are deep, dark or pale bluish black coloured, impervious nature and clayey in texture that are sticky on wetting and forms cracks on drying. Also the pokkali paddy fields are in deep water, inundated and marshy, which makes the labourers, mainly women feel difficulties during harvesting. Such situations make the pokkali cultivation to be difficult and thereby area to be reduced. Hence, there is a great demand for pokkali paddy harvester to reduce the drudgery caused by pokkali field conditions. The harvesting machine should be amphibious to suit the varying pokkali field conditions like swampy, marshy and completely flooded conditions.

1.6 Constraints in Pokkali Paddy Harvester Development

There are numerous harvesters available for Paddy harvest. Modern Combine harvesters are very efficient and performance is considered superior. But those combines cannot be used for harvesting pokkali paddy. Design and development of harvester suited to the salinity and flooded condition in pokkali fields is quite different from other harvesters, as harvester should be an amphibian machine, which can be operated in land, water and marshy lands. Several factors are to be considered for designing a harvester for pokkali paddy. Hence, the design, development and working of the harvester in fields remain a challenging task for successful mechanization in pokkali paddy harvesting.

A KAU Pokkali Paddy Harvester was designed and developed in KCAET Tavanur. Another commercial amphibious weed harvester (Truxor DM 5045) is used for harvesting pokkali paddy. Both the machines were studied in detail and discussed in next chapters. These machineries had drawbacks and require modifications to meet the demands suitably and conveniently. Hence a research project was undertaken to design a cutter header assembly for a pokkali paddy harvest.

A research project was undertaken in the view of above discussion with the following objectives:

1. To study the existing designs of cutter header assembly of the available Pokkali Paddy Harvesters
2. To develop different computer aided designs of cutter header assembly
3. To select the best practical design through industrial engineering modeling techniques/analysis using quality function deployment (QFD).

CHAPTER II

REVIEW OF LITERATURE

This chapter comprehensively discuss the research work carried out by various researchers in pokkali paddy cultivation, paddy harvesters including cutter bar, reel, performance evaluation and design of cutter header assembly for pokkali paddy harvesters to get an inference about the previous research outcomes on these areas.

2.1 Pokkali Paddy Cultivation

Pokkali paddy cultivation is followed under the pokkali System of farming in the Kerala, India under saline water stagnant condition. The rice produced from this cultivation is organic, nutritious and has peculiar features on quality. Cultivation operations and crop – field characteristics are considerably differ from other Paddy cultivation practices. The comprehensive research outcomes on the pokkali paddy cultivation are as follows.

Pillai (2003) studied about fishery and production of shrimps from perennial and seasonal fields of Kerala. Sea water enters twice in a day into the pokkali fields during high tides through the sluice and estuary. At night times, bulbs / hurricanes / petromaxes etc was fitted the mouth of the sluice for attracting shrimp seeds into the fields.

Gayathri and Raveendran (2009) studied the capability of coastal paddy fields in Kerala remains not used. In this study, it is discussed that closely two third area of the field in pokkali system covered in the Ernakulam region. Other districts such as Kannur, Alapuzha etc., with paddy farming on water logged condition paves the way for salt tolerant varieties of paddy which grow upto two meters, bend each other and collapses. The panicles are alone cut for harvest; rest of the stalk serves as the prawn feed.

Jayan and Sathyanathan (2010) reviewed the farming practices prevalent in the water logged tracts of Kerala. Study states that the fields are situated below the mean sea level (MSL) and having the issues of water-logging and have no addition of chemical fertilizers and/or pesticides in the pokkali paddy fields which make them different from the other farming practices in Kerala.

Sasidharan *et al.* (2012) studied temporal and spatial integration of rice, prawn and fish in the wetlands of coastal tracts in southern part of India, especially in Kerala. The traditional system of farming tall rice varieties (*Oryza Sativa*) during the monsoon periods and shrimp cultivation during summer periods, called locally as 'pokkali' in the central Kerala, and is a sustainable rice production system blended with natural occurrences like salt water inundation in the Kerala's low lying coastal regions. Varieties and their yields such as *'VTL 3'* with 2.4 tonnes ha^{-1} and mutant of '*Chettivirippu'* with 3.9 tonnes ha^{-1} were discussed.

Antony *et al.* (2014) investigated the rotational effect of paddy farming and prawn cultivation under pokkali system on the characteristics of soil at two spots of pokkali fields named Kadamakkudy and Chellanam of Kerala. Study found that the pH of the soil varied highly acidic to slightly alkaline in Chellanam but alkaline in Kadamakkudy. The least value of conductivity and salinity were observed on the first half of the June month. The highest value of total organic carbon was 1.05% and 6.225% in Chellanam and Kadamakkudy respectively found on the second half of April month. The highest phosphate value was 0.1578 mg g^{-1} in Chellanam and 0.2125 mg g^{-1} in Kadamakkudy with a standard deviation and mean of 0.14 ± 0.05 and 6.87 ± 7.67 respectively. The soil nitrogen content also showed the same trend as phosphate. The soil carbon content found a slight increasing trend. Negligible sulphur content of the soil 0.18 per cent is showed. Sudhan *et al.* (2016) says that colour of soil is pale or dark bluish black and the texture is found to be clayey.

Mumthaz and George (2017) discussed the significance of pokkali Fields in the Kerala village, Kadamakkudy. They shows that Alkalinity level was found to be lowest in the month of July, while it is highest in the month of February.

Also they stated that, in order to preserve the richness of biodiversity in the pokkali system the fields must be sustained.

Ranga (2006) reported that other than climatic constraints, shortage of farm labour and non-availability of suitable farm machinery are two major constraints on economic viability of paddy cultivation in pokkali fields. Sudhan *et al.* (2016) stated that skilled manual labours were employed for the mound (45 cm diameter and 60 cm height) preparation. Adithya (2020) states that the pokkali paddy cultivation is declining, earlier 25000 ha reduced to 5500 ha as due to various factors. Joy (2013) says Vallarpadam Container Shipment has made irrevocable damage to Kerala's coastal areas of pokkali practicing regions.

Ranjith *et al.* (2019) stated that average farm size of farmers in pokkali system was only 1.65 ha. The average income of pokkali farmers were around `3.9 lakhs ha^{-1} of pokkali-prawn cultivation. More than 70 per cent of the farmers are marginal and small farmers' category indicating constrained production in general. Using Garrett's ranking technique; the problems of farmers were analyzed. Analysis states that, in production process, labour shortage and higher labour wage rates were the major constraints. Also constraints in mechanization of farm operations rose as a serious problem of pokkali cultivation system. Perishable nature of the prawn and market price fluctuations are the main constraints in marketing process.

2.2 Paddy Harvesters

According to Kumar and Kalita (2017), in the developed countries, most of the crops were harvested using combine harvesters. Gathering, cutting and uniform conveyance (reel positioning and speed setting), threshing (concave clearance setting and adjustments of threshing speed), separation using rotor or straw walkers, air aspiration (setting of fan speed) to blow out chaff, light particles and mold spores, sieve opening and shaking allowing separation by density and size of threshed kernels. Justice *et al.* (2021), in India, leading brands of combine harvesters are Claas, Preet, Kartar, Vishal, Swaraj, New Holland and the imported John Deere, Kubota and Yanmar machines. According to IRRI (2015) more than 75% of the paddy harvesting is done by combines nowadays. Combine harvesting machines work best with fields which are well-drained, somewhat level and with a field layout that minimizes the number of turns in a field.

Sangwijit and Chinsuwan (2010) reported that in combine harvesters, the losses are observed at two main units i.e. cutting unit and threshing unit. Samon and Duff (1973) reported that five, seven and ten days delayed harvest resulted in 3 %, 6 % and 11% decrease in paddy yield, respectively. Paulsen *et al.* (2014) discussed that fast driving is one of the most common causes of higher combine losses. Fouad *et al.* (1990) discussed that self-propelled rice combines forward speed if raised from 0.8 to 2.9 km h^{-1}, will increase grain losses. Konno *et al.* (2017) stated that harvesting operation showed increased fuel consumption as the total working time increased.

Alizadeh and Allameh (2013) stated that while reaping and threshing were done individually, the harvested crop mass is subjected to environmental impacts and significant to moisture content changes and losses. Comparing indirect methods (Reaping and threshing), direct method (Combined harvesting) had less losses on paddy harvest, especially head feed type combine harvester.

Hasan *et al.* (2020), tested different harvesting machineries such as reaper, mini-combine and small to medium size rice combines. The study stated that, a combine harvester can save 71% of the labour over manual harvest, and also significantly less harvesting losses over manual reaping. Effective field capacity of combine harvester was observed to be more than reaper. The study concluded that combine harvester will be an appropriate option for paddy harvest at southern delta regions of Bangladesh country.

Celik (2006) designed and developed a push type cutter bar mower for the forage harvest. The study reported that, when forward speed increases, the effective field capacity will increased and fuel consumption will decrease. At a speed of 2 km h^{-1}, it was noticed that blockage occurred in cutter bar unit because of the high density of forage and insufficient power from the engine. In this regard, the engine power should be more than 25% of the cutting unit's power requirement.

Jawlekar *et al.* 2020 developed a low cost combine harvester for Rabi crops and performed the analysed the performance with rice and wheat crop in India adequate to small farmers.

2.2.1 Cutter bar

Pekitkan *et al.* (2020), a Turkish study analysed shearing force and shearing energy of paddy stem as a function of blade angle, blade type and cutting speed. When decrease in the blade edge angle from 90° to 50°, the shearing force and cutting energy values for paddy stalk has increased. At 90° cutting edge of blade, highest force and energy values were measured as 25.47 N and 5.8 N cm. The effect of loading speed on the cutting forces, cutting energy, cutting strength and specific cutting energy were found significant. The highest values of shearing force and cutting energy was found at 2 m s^{-1} loading speeds, the lowest values were found at a cutting speed of 6 mm s^{-1}.

According to Koloor and Borgheie (2006), both blade type and edge angle are important factors which reduces shearing force, cutting energy and increases effective cutting performance of cutter bar.

A research conducted in Iran by Zareishahamat *et al.* (2019) says, due to the lack of suitable machinery for harvesting, 0.2 million ha was not harvested in each year. Hence research was carried out to design, construction and evaluation of reaper in order to apply in the small farms. The designed machine has 1 meter cutter bar length. The research also reports that increasing the forward speed of the machine causes crop losses and decreased field efficiency.

Das (1998) says that stroke length of 76.2 mm is used for the grass, cereal crops and thin stalk commercial crops. According to Kathirvel *et al.* (2011) cutting efficiency and uniformity were affected by stroke length.

Reddy (2018) studied the cutterbar assembly of KAU pokkali paddy harvester. Cutter bar used was standard - serrated type. Cutterbar was operated by a hydraulic motor (MR50) through a crank pitman mechanism. It is a reciprocating type cutter bar. Length is 2.1 m and number of knife sections are 27, each having a stroke length of 76.2 mm was provided. A standard size twin guard is provided on either ends of the cutter bar in order to gather the crop and fed it to the cutting knife. Knife sections are serrated and the serration pitch provided was 1.2 mm. Clearance between ledger plate and knives were maintained at 0.3 mm. The velocity of knife section was hence 0.833 m s^{-1} when the forward speed of the machine was 3 km hr^{-1}. According to Klenin *et al.* (1985) the angle between cutting edge and axis of knife section (α) was 31^0 and the knife velocity was 1.5 m s^{-1}. The cutting index falls between 1.3 and 1.4 with available cutter knife.

2.2.2 Reel

According to Quick and Buchele (1978), the use of employing a revolving reel on reaping operation of cereal crops was apparently originated by John Common of England, during 1811-1812. Oduori *et al.* (2012) stated that nowadays, the tined reel was the standard equipment on most designs of combine harvester.

Naydenov *et al.* (2020) explained that the type of mechanical impact on crop has very strong effect on losses of seed. Hence the impact provided by the reel should be so adjusted to reduce the losses.

The reel is of two types. Pickup reel for lodged crops and bat type reel for standing erect crops. Habib (2014) pointed out that in case of lifting lodged crops above the cutter bar, pickup reel can be effective. A reel is a hexagonal, pentagonal, and tetragonal or any related shape traverse a cycloidal path, and also moves in the linear direction to form a combined circular and linear effect of trajectory. Qing *et al.* (2021) designed a reel assembly for harvesting oilseed rape with improved trajectory of tine, working process and function. Zhuang and Li (2020) studied the simulation of reel for suiting high stubble rice harvesting.

Griffin (1981) stated that, the reel holds the crop stalk against the cutter bar as it cut during cutting. Adjustments of position and speed of reel have to be made carefully for the reel to push the crop against to the cutter bar, also to the auger platform.

Reel axis has to be placed 230 mm to 300 mm ahead of cutter bar. Mostly the crop cutting height will be 150 to 250 mm. Reel teeth clearance may be 50 to 75 mm. Jalali and Abdi (2014) said a reel height of 87 cm for better results. Another research work by Tomchuk (2020), states that while harvesting, reel height was adjusted for a uniform transportation of crop into the cutter bar through a control panel. Behrouzi *et al.* (1995) stated that seeds drop when the reel wheel get in contact with crop. Reel placement must be 150 to 250 mm high from the cutter bar level.

The clearance between the tines of the reel and cutterbar must be at least 25 mm. The reel bats must be just below the lowest heads; if the reel bats are too low; heads may hang up on the bats and be carried around on the reel. If the reel is too high, grains will be shattered by the reel. The reel should be low enough in down crops to lift the crop and sweep the crop through the cutterbar. Reel must be in the same height across the width of the header. This height adjustment can be done by the means of the threaded adjusters. Also the reel must be aligned at supports so the distance forward from the cutter bar at any point is same. The reel teeth or tynes will be facing downward always, so as to push the crop into the cutterbar. In average conditions, tine pitch will be five degrees rearward. This reel teeth facing downwards can be actuated by mechanisms such as planar four bar mechanism. Considering reel fore and aft position, reel should not hit the cutterbar or auger in its lowest position. The exact positioning depends on the crop parameters such as height, lodging conditions etc.

According to the research by Griffin (1976), El-Shal and Morad (1991), investigation on the influence of the reel speed and forward speed of harvester on paddy loss during harvesting needs to be taken care. Reel speed may be 25% and 50% greater for wheat and barley crops respectively.

For a typical reel size of diameter 1.1 m this works out as a rule of thumb in rpm of reel at six times the machine forward speed in kilometres per hour. If the diameter of the reel increases, then by the same proportion the ratio should decrease. For automatic speed adjustment of reel in relation to travel speed of combine, certain attachments exist in some combine harvesters.

Habib (2014) found that machine losses increased with the increase in reel speed, reached 6.04%, 3.45% and 3.49% obtained at 40, 30 and 20 rpm respectively. Increased reel speed can cause increased header losses, crop processing losses in sunflower combine harvester. Also they suggested a reel speed of 30 rpm at the forward speed of 6 km h^{-1} for the sunflower harvesting. Jalali and Abdi (2014) stated that in combine harvester’s losses, reel speed and travel speed are most effective. They showed that maximum loss occurred at the highest reel speed and ground speed. Increase in reel height increase head grain losses. For a given forward speed of 1 km h^{-1}, 25 rpm speed for reel is mentioned. From the observation, no significant difference exists between the reel speed of 25 and 32 rpm. Rahimi and Khosravani (2003) mentioned that header loss were minimum with reel rotational speed lower than 21 rpm. Taha (2017) observed clean seeds percentage has decreased while increasing reel speed from 25 rpm to 35 rpm.

Huang *et al*. (2020) developed a prototype for harvesting rice crop with double cutter bar and reel header, employing a reel speed of 45 rpm. 1.25 is the normal reel index. Harvesting machines with automatic reel speed controllers have a reel index ranging from 1.1 to 2 typically. Once a setting is chosen, reel speed is automatically adjusted to varying forward speed of the harvesting machine. Such auto reel controllers need calibration for varied tyre sizes or header/reel types. Reel index has to be reduced for lodged and tangled crop.

Bawatharani *et al.* (2013) says that a reel index of 1.7 would be the ideal for minimum header losses and acceptable field capacity, field efficiency for paddy combine harvesters of the paddy variety Bg 94-1 in Srilanka. A reel index value of 2.5 makes the reel to rotate with less advancement into the crop mass and for single rotational cycle, increased the amount of panicles gathered. When the number of impacts made to the panicles was higher and resulting in the tines hit the panicles harshly, increases the losses. Chinsuwan *et al.* (1997) reported that at lower reel index, the tine failed to sweep the entire paddy towards the header. Whereas the higher reel index makes the tynes to hit the panicles violently resulting in increased losses. Behrouzi-Lar *et al.* (1995) states that reel index about 1.25 - 1.5 for minimum head loss. Oduori *et al.* (2012) stated that the suitable value of reel index may vary with the crop and its conditions, but recommended reel index values lower than 1.5. But other research, Junsiri and Chinusuwan (2009) reported that the header losses were less when the reel index was between 1.5 and 3.0. Another study by Richey (1961), recommended 1.1 to 3.4 as a reel index for a 1.1 m diameter reel over a range of ground speeds.

Bawatharani *et al.* (2013) discussed that there was a decreasing trend of velocity of reel impact with respect to the increased reel index. Oduori *et al*. (2008) reported that, in order to minimize losses, manipulation of both magnitude and the direction of tine bar velocity are to be involved.

Hunt (1983), the cutting operation is accomplished by a cutter bar and reel loss obtained from (shattering loss) grain lying on the ground or out of reach of the cutter bar (cutter loss)

Kassa and Ing (2014) designed a reel mechanism for Tef crop. Deflection angle and deflection force with respect to reel were analysed and applied for reel design. The reel design included the determination of the bat count, angular displacement of the reel, rotational speed of reel, frame requirement, Chain and sprocket design, and Bearing design. Mathematical formulae and softwares were used for designing. Suitable materials were chosen for analysing the loads at various steps.

2.2.3 Pokkali Paddy Harvesters

The Machines were based on the concept of Archimedes principle for maintaining the stability while floating in water. Archimedes' principle states that "*a component immersed in a fluid is subjected to an upwards force equal to the weight of the displaced fluid*". This force of buoyancy located in the centre of the submerged hull is called as centre of buoyancy. Centre of gravity and centre of buoyancy of the floating body must lie on the same vertical. For a small angle of inclination the initial and the inclined water planes intersect along a line passing through the centroid of the water plane. Under various inclinations the centre of buoyancy moves along a curve whose centre of curvature is defined metacentre. Biran and Pulido (2014) stated that, for a surface floating body, the equilibrium is stable if the metacentre is located above its centre of gravity

Reddy (2018) studied about the design analysis of KAU Pokkali Paddy Harvester to design a scale down model of the existing one. At KCAET, Tavanur pokkali paddy harvester (KAU Pokkali Paddy Harvester) was developed which can perform reaping, conveying and collection operations. The machine is 9.6 x 2.2 x 2.2 m (length x width x height) and weighs three tonnes. The harvesting machine is self propelled and amphibian (to be operated in water and land). The track belts and conveyor belts were made of polypropylene material, air barge on Mild Steel, rollers on GI sheets, cutterbar on high carbon steel and legs/cleats were on marine aluminium. The reel has five bats, 0.84 m diameter; 0.52 m pitch; and reel speed index of 1.7. Conveyor belts are 3 mm thick and use a hydraulic motor MAH-400CB. The harvester size and weight are much which affects transportability and manuerability in fields. So there comes a need for alternatives. A study on scale down model of existing machine was taken. The study concluded that scale down design with 24 hp engine, dimensions including 6.2 x1.7 x 1.7 m (length x width x height), cutter header assembly with 1.8 m width of operation, 0.30 m reel pitch and reel index of 1.2 was designed.

2.2.4 Performance Evaluation of Harvesting Machine

Hunt (1995) and Noby *et al.* (2018) gives the field efficiency, cutting efficiency, and field capacity of a harvesting machine is given by the following equation.

$$\text{Field efficiency} = e = \frac{C_{eff}}{C_{th}} \times 100$$

$$C_{eff} = \frac{A}{T}$$

$$C_{th} = \frac{wS}{10}$$

Where, C_{eff} = Effective field capacity (ha h^{-1}),

C_{th} = Theoretical field capacity (ha h^{-1}),

T = Total time for the reaping operation (including lost time), (h),

A = Area coverage (ha),

S = Rated forward speed of machine (km h^{-1}),

W = Rated width of the cutter bar (m),

$$\text{Cutting efficiency (\%)} = \frac{e-d}{e} \times 100$$

Where, e = number of plant per square meter before reaping

d = number of uncut plant per square meter

According to Kalsirislip and Singh (1999), for a combine harvester equipped with a 3 m width head stripper, field capacity and field efficiency of 0.66 ha $h^{-1}$and 74% for standing crop and 0.3 ha h^{-1} and 72% for lodged crop respectively were found. According to Bora and Hansen (2007), field performance of a portable reaper showed that field capacity was 0.15 ha h^{-1}. Aung *et al.* (2014) stated that average cutting efficiency of 98% and actual field capacity of 0.24ha h^{-1} were found in another study for the power reaper. Veerangouda *et al*. (2010) stated that field capacity of a tractor operated combine harvester varied from 2.88 to 3.60 ha h^{-1}. According to Ujala *et al.* (2020), field capacity of the straw reaper (tractor mounted) was found to be 0.20 ha h^{-1}.

2.3 Design of Cutter Header Assembly

A design process involves various steps for developing a product such as preliminary studies, material selection, optimization of design parameters, and finalization of design and further developments. Each step has set of operations in it to give a output in the development of a product. Each step undergone in this research project was discussed in detail in next chapter and each step is reviewed in a detail as follows.

2.3.1 Preliminary Studies

Preliminary studies on an agricultural crop can be of various kinds such as data collection, sample collection, field experiments, lab studies, or survey among farmers. Based on the research nature, seasonal variations and crop availabilities, a suitable method can be adopted for preliminary studies.

Khan *et al.* (2020) conducted a survey by direct interview with farmers for investigating of the problems faced by vegetable growers regarding post-harvest practices in the district Faisalabad in India. The collected data were analyzed using IBM SPSS software and concluded the results. Results discussed the socio economic details of the farmers, different cultivation operations followed and their ranking on usage, awareness level regarding mechanization. Further, the study suggested the development ways for the cultivation methods followed.

2.3.2 Optimization of Design Parameters

Design parameters such as size, shape, topology working mechanism etc., have to be optimized for minimization of losses and maximization of grain recovery.

Kamat *et al.* (2014) explained the different path traced by adjustable four bar linkage mechanism by changing one or more hardware component. Natesan (1994) explained that, four bar mechanism can be of two types namely Grashof and Non Grashof mechanisms. A four bar mechanism may consists of crank, follower and coupler. Also the linkages may be of various kinds such as Evans linkage, Chebyshev linkage, Watts linkage and Roberts linkage. Khurmi and Gupta (2005) stated the Grashof's law, for a planar four bar linkage, the sum of the shortest and the longest link cannot be greater than the sum of the remaining two links lengths, if there is a continuous relative motion between two members.

American Institute of Industrial Engineers (AIIE, 1955) defines Industrial engineering as “the term concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems”.

Definition of Industrial engineering is stated by Nadler (1955) as “the art of utilizing scientific principles, psychological data, and physiological information for designing, improving, and integrating industrial, management, and human operating procedures".

The prime motive of the industrial engineering is to increase the productivity by elimination unproductive and waste operations to effectively utilize the available resources. Latest industrial engineering techniques laid its focus on energy conservation, automation and reduced environmental impact.

Various types of industrial engineering techniques are

1. Motion study
2. Time study
3. System analysis
4. Ergonomics
5. Method study
6. Material handling analysis
7. Inventory control, job evaluation
8. Production planning and control
9. Financial and non financial incentives
10. Value analysis
11. Operation research techniques

Moktadir *et al.* (2017) attempted to identify the bottlenecks in leather industry and suggest appropriate system to increase productivity using work study analysis. The study carried out by applying questioning methodology where recording and analysis of critical steps of manufacturing of all and other related information has been done in particular production line. As a result, in the improved method was suggested which reduced the considerable amount of work content. Then time study has been conducted by stopwatch and found the basic time required for all operation sequences and each workstation's capacity per day has been estimated. Using work method study and work measurement in the industry, productivity was improved by 12.71%.

Mathew and Sahu (2018) solved the problem on material handling equipment selection using multi criteria decision making methods and spearmen rank correlation coefficient for identifying the relationships.

Telsang (1998) stated that, out of these techniques, system analysis deals with various elements and sub systems that contribute to the whole system, thereby along with their interdependencies in order to make an effective and efficient design and improvement in the whole system.

2.3.3 Finalization of Design

Out of different optimal solutions arrived for a problem, best one can be made by decision making process. Some of the methods out of various decision making processes are as follows,

1. Analytical Hierarchy Process (AHP)
2. Affinity Diagram method (Fishbone Diagram or Brainstorming)
3. Quality Function Deployment (House of Quality Matrix method)
4. Trial and Error Method
5. Influence Diagram Approach (IDA)
6. Conjoint analysis
7. Net Present Value (NPV) and Present Value (PV)

According to Saaty and Vargas (2001), AHP includes the following steps:

1. Breaking down a complex unstructured problem into its components
2. Arranging the factors in a order following specific hierarchy
3. Assigning numerical values to each factor based on their relative importance

4. Analyzing the judgment for determining priorities to be assigned to all the factors.

Zarini *et al.* (2021) selected the best sprayer for citrus gardens in Mazandaran (Iran) using AHP. Atomizer sprayer, Motorized Backpack sprayer, Air blast sprayer and Wheelbarrow sprayer are the four different sprayers evaluated in this research. The selection criteria include spray quality, tank capacity, field capacity, amount of consumable solution per hectare and costs. As a result, Atomizer sprayer is selected as appropriate for citrus gardens. Dirpan and Alim (2015) used the AHP to select a best post harvesting method for Citrus fruits in Japan out of several post harvest methods such as modified atmosphere packaging, controlled atmosphere storage, hot water treatment, coatings and etc.

Karolemeas *et al.* (2021) used Analytical Hierarchy Process to identify suitable locations for Electric Vehicle (EV) charging points in urban regions of Greece. In this study they found the parameters for locating EV charging points as marked parking spaces, transport hubs and point of interest. As an outcome study came with a spatial model function for the location suitable for EV charging ports in Greece.

Ivanova *et al.* (2020) in their research explained that affinity diagrams or fish bone diagrams are a management tool that allows organizing information about the causes and effective decisions. In quality management, affinity diagram is utilized to analyze the raw material of questionnaires and all types of surveys. But the affinity diagram method applicable only for non-numeric information as the associated method relies not on logical constructs, but on associations of decision makers.

Pareek and Satapathy (2020) explored the work life sphere of Odisha Womenpreneurs under Mission Shakti initiative in Cuttack. In this study interview method was followed to collect response from 56 women entrepreneurs from Cuttack. Using affinity diagram, the analysis of the collected data was evaluated. The study found that the impact of women entrepreneurs on growing economy as well a view into the work life sphere of womenpreneurs in Odisha under Mission Shakti. Kumar *et al.* (2019) used affinity diagram to analyse the design aspects of coconut climbers in Kerala.

Trial and error method is repeating, varied attempting process carried out until efficient design is arrived. It can be applied for the cases were this method can only work, but for the other cases if faster method exists than this can be adopted.

Influence diagram approach helps to improve the safety features of the entity by human reliability assessment. Khakzad (2021) used the method of influence diagram and mathematical programming as a decision support technique in the case of optimizing fire fighting. But he found that mathematical programming is efficient than influence diagram.

Conjoint analysis is a decision making tool which breaks a product into different components and asks the customers to choose preferred component from the various alternative components available. Mazurova (2017) aims to execute a comprehensive study of the influence of three factors, brand, colour and position on customer choice in e commerce. In order to answer main research questions, researcher conducted experiments with 96 different combinations of the three attributes, and through statistical analysis, such as conjoint analysis, t-test analysis and Kendall analysis, identified that the most influential factor to the online consumer decision making process is brand, the second most important attribute is the colour, which was estimated half as important as brand, and the least important attribute is the position on the screen.

According to ReVelle (1998), Quality Function Deployment (QFD) technique has different names such as matrix product planning, decision matrices or customer driven engineering, as referred by quality professionals.

According to Shahin (2005), QFD is a structured process, a set of interlinked engineering and management charts, a visual language which uses different management tools. QFD establishes customer value using the ‘voice of the customer’ and transforms that same to design, fabrication, and production process characteristics. The result is a process of systems engineering, which prioritizes and links the product development process so that it assures design quality as demanded by the customer (Dean, 1998). QFD involves a development of House of Quality (HoQ) to complete the task. The different stages and procedure of making HoQ was given in a review work.

Kumar *et al.* (2019) studied the QFD methodology and applied it for their performance evaluation on coconut palm climbing aid along with Analytical hierarchy process. In this study, the survey conducted revealed the details of the customer or climber requirements. The related technical requirements of the aid and ergonomical factors were deduced from the survey. The relative importance of each climber requirements was determined by analytical hierarchy process. The relationship between the climber requirements and technical requirements were sought from climbers. This relationship was rated on scale and represented in QFD chart. The total weight of each technical requirement was determined and their relative weight. The customer or climber assessment was rated on five point scale revealed that the training, cost free climbing aid, quantity of work output were rated high, over four point by climbers for customer requirements. Easy to use, quality of machine, working posture and easiness in climbing up and downwards, discomfort hip and hands were rated above three point. However, the weight of aid in carrying, repair and safety were rated at point 2.5 and below which indicated that the factors have to be improved and needs immediate attention. The correlations between the technical requirements were compared in the roof of QFD chart. The correlations were either positive or negative in nature and other factors were not related at all from the chart. The engineering assessment of technical requirements and directions for improvements are given in QFD charts. The design and improvements in fabrication are discussed with inputs received from the climbers who are traditional professionals.

CHAPTER III

MATERIALS AND METHODS

In this chapter, the methodology of the research was discussed which includes the study on existing machines and design, preliminary studies, optimization of design with procedure of computer aided design and selection of design.

3.1 Studies on existing machines and design

The machines used in the study are KAU Pokkali Paddy Harvester and Truxor DM 5045 (Amphibian weed harvester used for pokkali paddy harvesting). Reddy (2018) studied the design analysis of KAU Pokkali Paddy Harvester and designed a scale down prototype of the same. KAU Pokkali Paddy Harvester and its scale down design have no other differences except the size. The details of the existing machines are discussed in the following section.

3.1.1 KAU Pokkali Paddy Harvester

The KAU Pokkali Paddy Harvester consists of engine, float, track belt, cutter header assembly, hydraulic system and conveying system. Fig. 3.1 shows the side view of KAU pokkali paddy harvester with its parts and Fig. 3.2 shows the isometric view of the same.

3.1.1.1 Engine

The engine was a 45 hp diesel four stroke engine Mahindra make (M&M) providing power to the entire machine for various operations. Engine was mounted at the top and in between two air chambers, rear of the operator cabin. The engine powers the hydraulic pump and entire machine operations were powered by engine through hydraulic system.

3.1.1.2 Air chamber

Floating barges (Floats) or air barges (air chambers) are of same term which is just an air filled structure. Floats or air chamber are provided to exert an upward buoyancy force when the machine enters the water body. Based on the Archimedes principle, the floats were constructed, and additionally the air chamber was also provided to the machine. The float has the overall dimension of the 4800 x 600 x 800 mm (length x width x height) mm and constructed with MS sheet metal (gauge-12). Additional air chamber of size 4860 x 1012 x 500 mm (length x width x height) was provided with MS sheet metal (gauge-12) construction. The MS sheet metals were 2 mm thick.

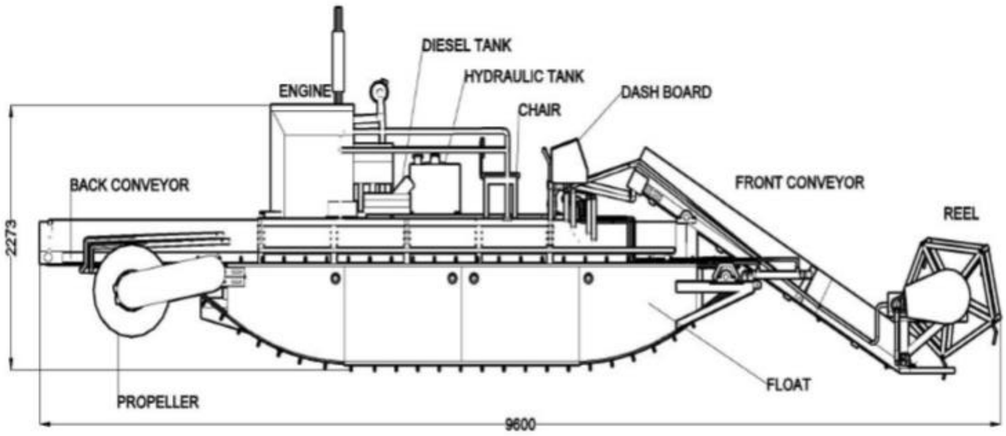


Fig. 3.1 Side view of KAU pokkali paddy harvester (Reddy, 2018)

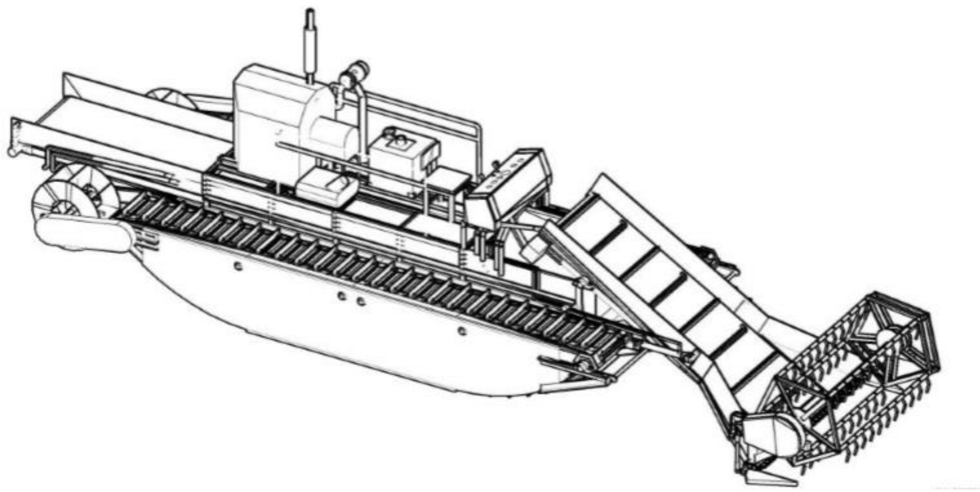


Fig.3.2 Isometric view of KAU pokkali paddy harvester (Reddy, 2018)

3.1.1.3 Track belt

Track belts are provided to facilitate traction in the soil surface. They are made up of polypropylene material of 10 mm thick. There were 52 numbers of grousers along with ledger plates made up of marine aluminium.

3.1.1.4 Paddle

The paddle is provided for the propulsion of the machine. A paddle is a revolving structure comprises of 8 angular blades connected to the shaft driven by chain and drive mechanism.

3.1.1.5 Hydraulic system

The hydraulic system consists of a hydraulic pump, pressure gauge, valves, filters, and pipe structures. The system uses the seamless tubes with higher tensile strength, high wall thickness, better bending quality, etc. which makes such tubes most suitable for use in high pressure hydraulic systems. The systems and actuators of the harvester were controlled by the hydraulic system through hydraulic pumps or cylinders. Engine drives the hydraulic system, resulting in pressurised oil supplied to the required system in the harvester like cutter header assembly, track belts, paddle etc. The capacity of the double acting pump in the hydraulic system of the harvester is 61 l min^{-1}, with hydraulic tank capacity 150 l (2.5 times the capacity of the hydraulic pump). Suitable hydraulic motor and cylinder were used wherever necessary.

3.1.1.6 Cutter header assembly

The cutter header assembly comprises of cutter bar assembly and reel assembly. Width of operation of cutter header assembly is 2100 mm. Cutter bar assembly has cutterbar of reciprocating - standard - serrated type, and was operated by a hydraulic motor through a crank pitman mechanism. Cutterbar comprises 27 numbers of knife sections, each having a stroke length of 76.2 mm. A standard size twin guard is provided on either ends of the cutter bar in order to gather the crop and fed it to the cutting knife. Knife sections are serrated and the serration pitch provided was 1.2 mm. Clearance between ledger plate and knives were maintained at 0.3 mm. The reel adopted was five bat type (pentagonal) 0.84 m diameter consists of pickup tynes. The reel speed index was 1.7 according to the previous study (Reddy 2018). The bats were 2100 mm wide (length of extension of bat shaft) and 50 mm diameter hollow shaft. The reel was powered by hydraulic motor through chain and drive mechanism.

3.1.1.7 Conveying system

The conveying system has two conveyors namely the front conveyor and centre conveyor. Front conveyor (3000 x 1000 mm) collects the cut crops from cutter header assembly and conveys it to centre conveyor. Clearance of 12 - 15 mm between conveyor belt and cutter unit was maintained. The centre conveyor (6330 x 1000 mm) stores the cut crops collected from the front conveyor and disposes whenever required. The conveyors are also operated by the hydraulic system. The conveyor belts were made up of polypropylene materials of 3 mm thickness.

3.1.2 Amphibian Weed Harvester (Truxor DM 5045)

The amphibian weed harvester (Truxor DM 5045 make) is made by a manufacturer Dorotea Mekaniska AB, Sweden. The machine has air barge with attaching hitch point for mounting different tools. The size of the machine is of 4700 x 2060 x 2100 mm (length x width x height). Weight of the machine is 1400 kg. The various components of amphibian weed harvester (Truxor DM 5045) is shown in Plate 3.1. The computerized drawing of Truxor DM 5045 made was given in the Fig. 3.3.

Plate 3.1 Truxor DM 5045

Major Components

1. Engine
2. Diesel tank
3. Front attachment
4. Rear attachment
5. Hydraulic system
6. Hydraulic tank
7. Battery
8. Air Barge
9. Traction belt
10. Pulley
11. Chassis port
12. Platform
13. Engine cabin
14. Operator seat
15. Operator cabin
16. Cabin cover (Canopy)

Important components and systems were discussed as follows.

3.1.2.1 Engine

The engine is Kubota make – V1505-T Turbo diesel of 44.9 hp with 3000 rpm (made in Japan). The forward speed varies from zero to 6 km h^{-1}. Power from the engine is transmitted by hydraulic transmission via hydraulic pump, pulley, chain and sprocket mechanisms. The engine cabin (1700 x 1000 x 950 mm length x width x height) is mounted above and between two air barges. The entire cabin along with operator cabin can be moved from front end to rear end of the machine which is controlled from the operator seat. The cabin is mounted on a rail placed above the air barge platforms to facilitate the movement of entire cabin to and fro. The engine cabin comprises of engine, hydraulic pump, battery, driving cabin etc. Fuel consumption varies from 5 to 6 l h^{-1}.

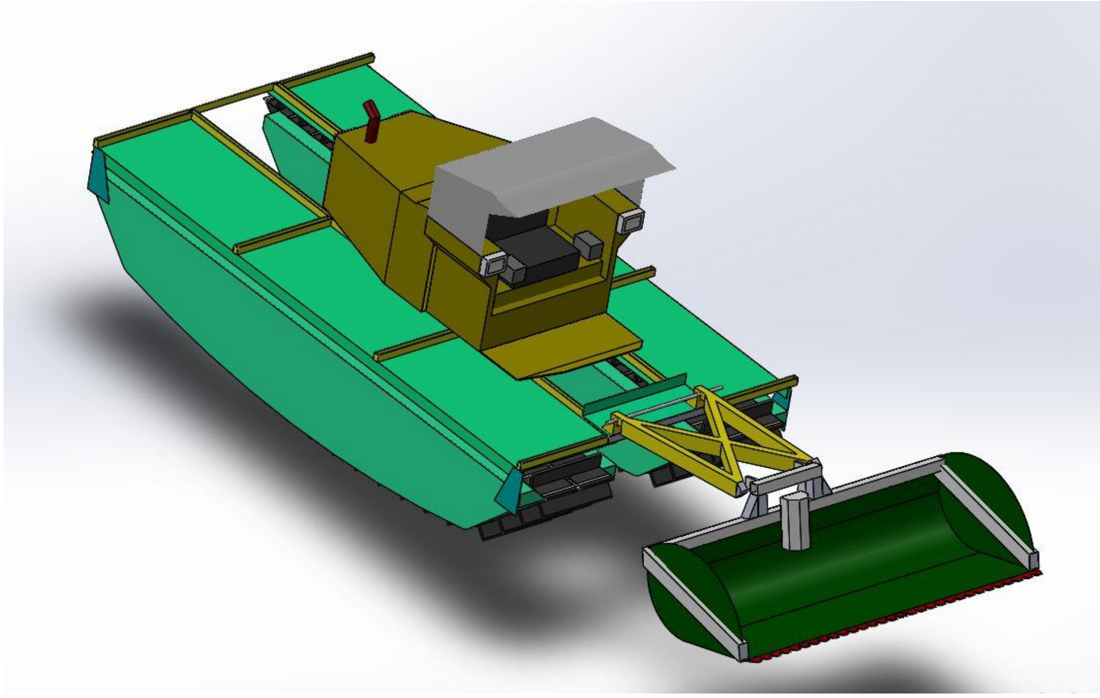


Fig. 3.3 Computerized Model of Truxor DM 5045

3.1.2.2 Air barge

The purpose of the air barges are explained already in the section 3.1.2. Two air barges are present in the machine, each having a dimension of 4000 x 650 x 750 mm (length x width x height). Each air barge consists of two holes at the top centre position for expelling entered water if any by the means of pump situated inside. The air barges are spaced 600 mm away each other. Air barges are trough shaped at the bottom and plain at top surface. This air barge increases the volume of the total machine by holding air within itself. According to the Archimedes principle, the machine is constructed. The volume of the air barge is about 1.6 m^3 each (observed from SolidWorks 2018).

3.1.2.3 Track belt

The caterpillar track is provided with track belt made of rubber material (dry plate) along with guide plate. On both sides of the machine, the caterpillar track surrounds the air barge, as shown in Plate 3.2. The track is made of grousers for propulsion of 530 mm width and 100 mm height with a thickness of 30 mm. Each grouser is spaced 200 mm (outer to outer). The power to caterpillar track is provided from the hydraulic system via hydraulic pump, hydraulic motor and pulley (stainless steel). At the front end of the track belt, adjustable pulley system is given for loosening or tightening the belt.

Plate 3.2 Rear view of Truxor DM 5045 showing Track belt – Grousers – Pulley drive

3.1.2.4 Attachments

The attachments available are rakes, cutters, digger, pump, pile driver, hydraulic hammer, skimmer, tank, spreader, miller, grip bucket, log grab, and wood chipper. The attachments are to be mounted on either front or rear side of the machine. The cutting unit for weed harvesting is attached at the front mounting port connected with hydraulic pumps for lifting/lowering and cutterbar function.

3.1.2.5 Cutter Header Assembly

The weed harvesting attachment of Truxor DM 5045 is referred as cutter header assembly in this research. The attachment is commercially called as Doro Cutter ESM 50 (Plate 3.3 shows the cutter header assembly and the Plate 3.4 shows the working of Truxor DM 5045 with its cutter header assembly). The cutter header assembly of Amphibian weed harvester consists of cutter bar assembly, collection bucket and tilting mount mechanism. The assembly can be raised or lowered from the hitching part of the machine. Assembly can be tilted by tilting provision provided at the cutter header assembly connected with hydraulic system. The mechanism is followed in cutter bar assembly is denoted as Busati double action knife model. The cutter bar is actuated by the hydraulic system. Cutter bar length is 2100 mm. The knife section is of standard cut type which has a stroke length of 76 mm and length of 85 mm. The knife section is a serrated type and ledger plate is provided at the bottom. The collection bucket is made of flexible mesh at the bottom in single layer. In the sides of the bucket is double layered mesh. The mesh is held by the frame structure. The frame structures are made of aluminium alloy of marine type. The weight of the assembly is 110 kg. Overall length of the assembly is 2.25 m. Width and height of the unit is one meter each.

Various components of amphibian weed harvester (Truxor DM 5045) were specified in Table No. 3.1.

Plate 3.3 Amphibian Weed Harvesting Attachment

Plate 3.4 Amphibian Weed Harvester (Truxor DM 5045)

Table No. 3.1 Amphibian Weed Harvester Components and Specifications

S. No	Component	Quantity	Description
1.	Engine	44.9 hp, 114 kg	Kubota V1505 T Turbo Diesel
2.	Diesel Tank	35 l (Max.), 29.75 kg	Density of diesel 0.85 kg l^{-1}
3.	Cutter header assembly	109 kg	Double action Busati knife - Front attachment
4.	Battery	14 kg, 12 V, 45 Ah	Electronic system
5.	Hydraulic Tank	36 l, 33.12 kg	Eco friendly Panolin Oil
6.	Rear DM bracket	16 kg	Rear attachment

3.1.2.6 Stability and Safety

The machine can be sustainable with 1500 kg of load (including machine weight). Any attachment apart from manufacturer recommendation should be liable within the limits to sustain the stability. Minor changes in stability can cause excess fuel consumption and significant stability variation which can make the machine sinks or turn over. Most of the components were constructed with aluminium in the view of weight reduction; some parts such as chain and sprocket are made of stainless steel. Some attachments are made of mild steel alloy. Pumps are provided inside the air barges to expel out the water entered inside the barges accidently. Only single person (operator) is allowed while riding. The sensors are provided for various safety features which make the machine costlier.

3.2 Preliminary Studies

The section includes the survey conducted on farmers to identify the constraints and collection the data required for mechanized harvest of pokkali paddy. It also includes the plant density calculation of pokkali paddy.

3.2.1 Survey on Farmers

The survey carried out at Ernakulam and Alapuzha districts in Kerala by direct interview with the pokkali farmers, visiting their fields. The focus of the interview was based on the mechanization of harvest of pokkali paddy with reference to existing designs, manual harvest and their demands. The questionnaire followed to collect the data of various factors was given in the Appendix I. The questionnaire had socio - economic details of the farmer, cropping information, labour requirements, cost economics, harvesting aspects and technical parameters required for mechanized harvest. With the collected data, the constraints were plotted as an affinity diagram or fish bone diagram to get a clear understanding about the constraints observed for the mechanized harvest of Pokkali paddy through brainstorming method. Further, the farmer requirements were applied in the procedure of quality function deployment technique, which is discussed in the section 3.4.

3.2.2 Calculations on Plant density

Pokkali Paddy varieties (*Chootu pokkali, Virippu* indigenous varieties and '*Vytilla-1, Vytilla-10'* RRS Vytilla varieties) were taken and experimented for estimating the number of seedlings on field.

Plate 3.5 Volume determination of pokkali paddy ('*Vytilla - 1*' variety) using Toluene displacement method

Plate 3.6 *'Vytilla - 10'* variety pokkali paddy seeds

By Toluene displacement method, bulk density of pokkali paddy seeds was calculated by determining the volume. The known volume of toluene is taken in a 100 ml measuring jar. Then known mass of sample was added into the measuring jar. The volume of the sample is observed from the increase in volume of measuring jar. Similarly, 10 repetitions were carried out each four different varieties of pokkali paddy, observations were provided in Appendix II.

$$\text{Bulk density} = \frac{\text{Weight of the Sample}}{\text{Volume of the Sample}} \qquad \text{... 3.1}$$

1000 Seed Weight = X

$$\text{No. of grains in 10 Grams} = \frac{X}{10} \qquad \text{... 3.2}$$

Seed rate = 75 kg ha^{-1}

No. of seeds in 30 Kilogram = Y = X * 3000

No. of seedlings out of 30 kg seeds = Y (Assuming 100% of germination)

No. of seedlings in one Acre = Y

$$\text{No. of seedlings in 1 square meter area} = \frac{Y}{4000} \qquad \text{... 3.3}$$

3.2.3 Other parameters on harvesting

The field parameters including soil (textural classification, colour, bulk density, shear strength, resistance, type, pH, electrical conductivity (EC) and organic matter) and water properties (water stagnation level, salinity, pH and direction of movement), crop parameters apart from the parameters found through Sections 3.2.1 and 3.2.2 were collected from Rice Research Station, Vytilla and previous studies (Sudhan *et al.*, 2016; Mumthaz & George, 2017).

3.3 Design of different computer aided models of cutter header assembly

Four different computer aided models of cutter header assembly for pokkali paddy harvest was designed using the software SolidWorks version 2018.

The cutter header assembly has the following major sub assemblies, namely cutter bar assembly and gathering assembly. Cutter header assembly for pokkali paddy harvest was conceptualized in four different models, namely multiple bat reel system (design I), single bat reel system (design II), vertical axis gathering system (design III), floating header assembly with projected conveyor system (design IV).

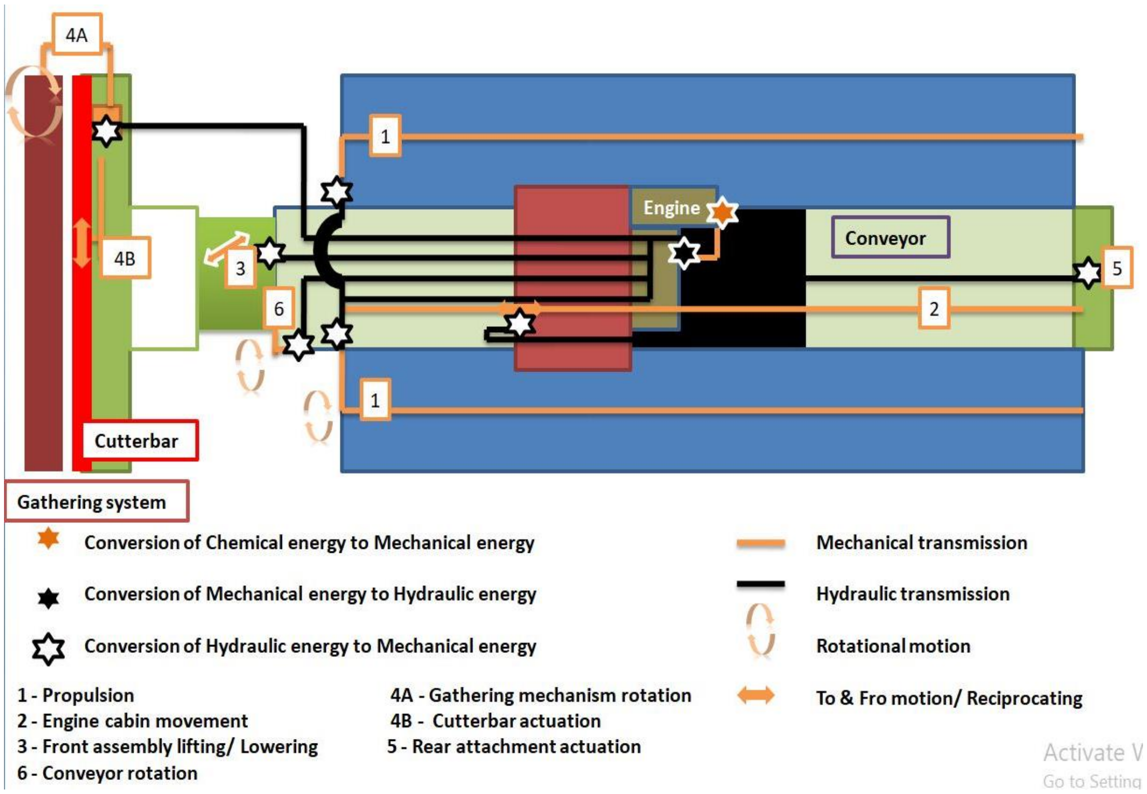


Fig 3.4 Power flow diagram of Truxor DM 5045 for the proposed designed models

Fig. 3.4 shows the power flow diagram of Truxor DM 5045 (Amphibian weed harvester machine) attached with the designed models of cutter header assembly. The chemical energy in the fuel is converted into mechanical power at the engine which is converted into a hydraulic energy at hydraulic pump and runs over the machine for various purposes. Each component receiving hydraulic power is converted into a mechanical power through hydraulic motors.

3.3.1 Design of Multiple Bat Reel system (Design I)

Any cereal crop harvesting machines such as paddy and wheat harvesters have the reel mechanism in its header assembly for the efficient collection and conveyance of the crop stalk into the cutting unit. In order to gather the crop and convey it into the cutting unit, a reel is adopted as in combine harvesters with slight modifications required to the pokkali field conditions. A reel may consist of hexagonal, pentagonal or tetragonal shape based on the number of bats, pick up tynes. The tyne actuation mechanism is also used to actuate the tynes in order to pick up the crop. Reel index, reel rotational speed in rpm, angular velocity, diameter, size of pitch, type of tyne actuation mechanism, number of tynes, tyne spacing are the parameters to be fixed in the design. The performance of reel is greatly based on reel speed index, diameter of the reel, rotational speed, staggered area and pitch. Hence it's important to understand the relation between each and other parameter.

u_t = tangential velocity of tip of the bats, m s^{-1}, λ = Reel index

v_m = forward velocity, m s^{-1}

ω_r = angular velocity of reel, rad s^{-1}

R_r = radius of reel, m

P_r = Size (pitch) of reel, m

x_t = Path travelled in single rotation of reel on shaft with whole, m

t = time of a single reel revolution, s

α = Angular displacement

Z_r =Reel Stagger

n = Number of bats

F = Reel force, N

L = Crop height, m

H = Reel Height Position, m

h = Height of left over crop stubble, m

$$\text{Reel Index} = \lambda_i = \frac{u_t}{v_m} \quad \text{... 3.4}$$

$$\text{Tangential velocity of bats} = u_t = \omega_r R_r \quad \text{... 3.5}$$

$$\text{Reel radius} = R_r = \frac{\lambda_i \, v_m}{\omega_r} \quad \text{... 3.6}$$

$$\text{Angular velocity of bats} = \omega_r = \frac{2\pi N}{60} \quad \text{... 3.7}$$

Distance travelled in one rotation, $x_t = v_m t$ ... 3.8

$$\text{Time for single revolution} = t = \frac{2\pi}{\omega_r} \quad \text{... 3.9}$$

$$x_t = \frac{V_m 2\pi}{\omega_r} \quad \text{... 3.10}$$

$$\lambda_i = \frac{\omega_r R_r}{V_m} \quad \text{... 3.11}$$

$$x_t = \frac{2\pi R_r}{\lambda_i x_t} \quad \text{... 3.12}$$

7.

$$\text{Size of Pitch} = P_r = \frac{x_t}{n} \quad \text{... 3.13}$$

$$\text{Number of bats, } n = \frac{2\pi}{\alpha} \quad \text{... 3.14}$$

$$\text{Angular displacement} = \alpha = \omega t - \cos^{-1}\left\{\frac{Z_r}{R + \cos\omega t}\right\} \quad \text{... 3.15}$$

$$R_0 = \frac{V_m}{\omega_r} \quad \text{... 3.16}$$

$$R_r = R_0 \lambda_i \quad \text{... 3.17}$$

Height of reel axis position from cutting unit,

$$H = L_c - h + \frac{R}{\lambda i} \quad \text{.. 3.18}$$

Reel index is defined as the ratio of reel peripheral speed to forward travel speed and is typically 1.25 to 1.5 under most conditions in upright crops (Kepner *et al.,* 1978). The absolute velocity of the reel should be greater than the forward speed of the harvester. The reel should touch the crop below the centre of gravity of the crop

$$\text{Plant density per unit length of reel bat} = \frac{\text{Plant density per unit area}}{P_r} \quad \text{... 3.19}$$

Pr - Pitch of the reel (distance covered by the each bat on single rotation)

Mass handled by reel bat = Plant density per unit length x Individual plant mass per unit length

Power required for a reel

$$P = \frac{2\pi NT}{60} \quad \text{... 3.20}$$

P - Power required for a reel (N)

N – Number of revolution per minute (RPM)

T – Torque involved (Nm)

$$T = \frac{I\,\omega^2}{2} \quad \text{... 3.21}$$

I – Moment of Inertia (kg m^2)

ω - Angular velocity

$$I = mR^2 \quad \text{... 3.22}$$

m – Mass of the reel (kg)

R – Radius of gyration (m)

Hydraulic system required for lifting the reel assembly

$$\text{Pressure} = \frac{\text{Force}}{\text{Unit area}} \quad \text{... 3.23}$$

$$\text{Unit area} = \frac{\text{Force}}{\text{Pressure}} \quad \text{... 3.24}$$

Pressure (P) available at the outlet port of Truxor DM 5045 is given as 110 bar

$$\text{Force} = mg \quad \text{... 3.25}$$

$$A = \pi R^2_h \quad \text{... 3.26}$$

$$A = \frac{mg}{P} \quad \text{... 3.27}$$

... 3.28

$$R_h = \left\{\frac{mg}{P\pi}\right\}^{1/2}$$

A – Area of piston head (m^2)

R_h – Radius of piston head (m)

m – Mass of reel assembly (kg)

The various reel speed index with its derived variables were calculated using Microsoft Excel software and tabulated in the Appendix III for hexagonal, pentagonal, tetragonal reel types with varied diameters. The reel model cutter header assembly was designed with a width of 2100 mm (assumed to be same as machine width), diameter of 250 mm (as the cut portions are to be small and also to reduce the weight of the assembly, smaller diameter reel is assumed), and four bats with projected tynes for pick up. The tyne actuation mechanism used was cam and follower type. The tynes were always holding a contact angle when the position is at front of the reel and keeps upright at the back side of the reel i.e. near cutterbar. This facilitates the reel can be placed as near to the cutterbar. The reel assembly can be lifted with a hydraulic system to various heights depending on the crop and field conditions. The mass of the reel may be approximately 50 kg. Calculations on power requirement of the gyration of reel are given in the Appendix III.

The power from the prime mover is received at the hydraulic motor which transmits the hydraulic power to the motion. Rotational motion from the hydraulic motor can be transmitted into reel assembly through chain and sprocket mechanism. Same motor output can be divided and utilized for the cutterbar assembly.

According to Kanafojski and Karwowski (1976), the knife edges can be of three kinds i.e., reciprocating cutting knife edges, rotating knife edges and continuous plane motion knife edge. Out of these, continuous plane type is not used for harvesting purposes, which can be neglected. Cutter bar assembly with reciprocating cutting knife edge is of three different types.

They are,

1. Standard type (Conventional)
2. Low cut type
3. Medium cut type

Among these standard type cutter bar with reciprocating knife was chosen for harvesting cereal crop.

The velocity of knife section is expressed as,

$$V_k = R \times V_m \qquad \text{...3.29}$$

Number of Knife Sections:

$$\text{Number of knife sections} = \frac{L_c}{\text{size of knife section}} \qquad \text{...3.30}$$

Size of knife section (t): In the conventional (standard) type of cutter bar the knife edge stroke ‘S’ is equal to the distance t between the ends of adjacent fingers (between the axes of symmetry of two adjacent fingers).

$$S = t = 76.2 \text{ mm} \qquad \text{...3.31}$$

Where,

V_k = Average knife velocity, m s^{-1}

V_m = Forward speed of harvester, m s^{-1}

R = Cutting index

L_c = Length of the cutter bar, cm

S = Knife edge stroke, mm

t = Distance between the ends of adjacent fingers, mm

Crank revolution count is given by the equation (Celik, 2006),

$$V_k = \frac{Sn_c}{30} \qquad \text{...3.32}$$

n_c = Number of crank revolutions

The angle between cutting edge and axis of knife section (α) shall be 31^0 the velocity should be 1.5 m s^{-1}. The value of R (cutting index) shall be in the range of 1.3 to 1.4 with available cutter knife (Klenin, 1985)

The Fig. 3.5 shows the working diagram of crank pitman of cutter bar assembly. The point 'O' is the centre point of crank which is operated from the power transmission system of 'N' rpm. The mechanism of slider crank is used for converting the rotary motion of the crank into reciprocation motion of cutter bar through pitman.

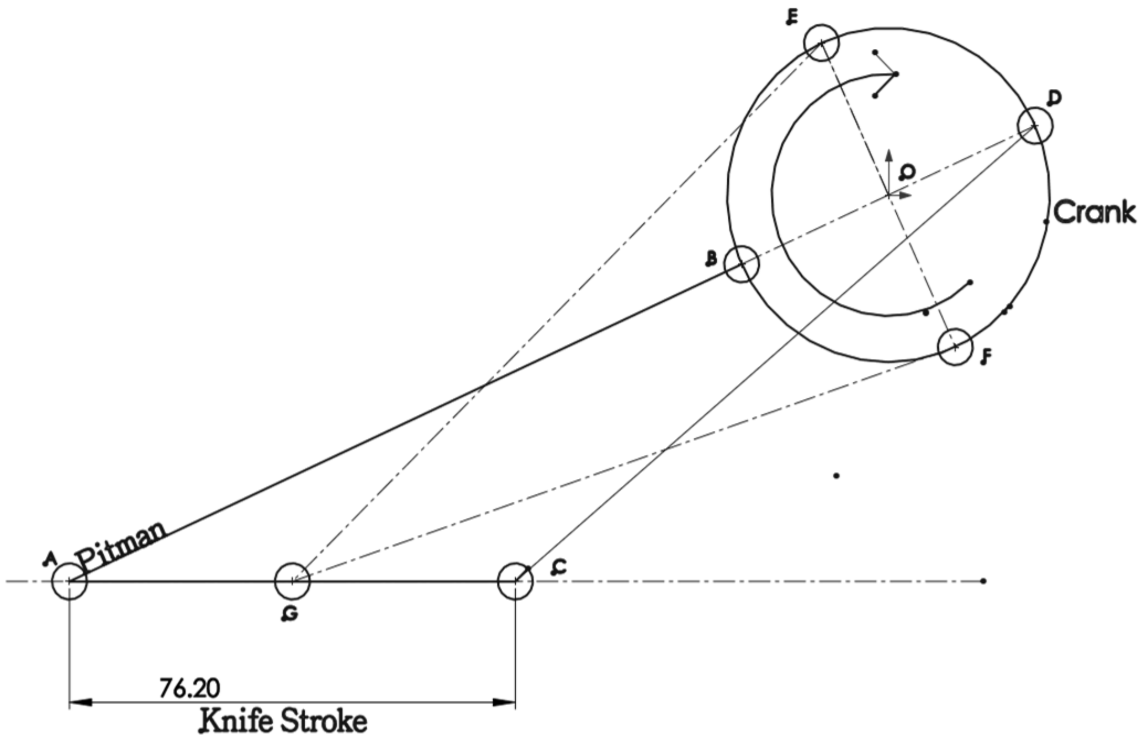


Fig. 3.5 Crank – Pitman motion for standard cutter bar assembly

In Fig. 3.5, the line 'AB' marks the pitman position at the start of the stroke and line 'CD' indicates the pitman position at the end of one stroke. Line EG and FG indicates the midpoint between start and end of the strokes. The cutterbar so have two strokes per each revolution of crank.

Power required by the cutter bar assembly is thus given as follows,

$$\text{Power required} = \frac{2\pi NT}{60} \qquad ...3.33$$

N = Number of revolution of crank pitman (rpm)

T = Torque required (N m)

Cutterbar was also 2100 mm wide mounted on the cutter header platform in which the reel is mounted. Cutter bar assembly has cutting knife and ledger plate which can be actuated by crank and pitman to be powered by a hydraulic motor. Cutterbar assembly is mounted on the front side of the cutter header platform. To the rear of the cutter bar assembly, front conveyor was mounted.

3.3.2 Design of Single bat reel system (Design II)

The compact system at header avoids the problem of stability imbalance in the floating harvester. Hence the reel system can be minimized with a single bat with lengthened pick up tynes can be tested. The normal reel type having a single bat instead of multiple bats as in previous design is conceptualized based on the weight reduction and increased tyne size. The major components are tynes, bat, and actuation mechanism.

The design model is built with single bat of 2100 mm width and tynes projected of length 150 mm. The angle of orientation, tyne spacing and length of the tyne has to be optimized from the field experiments. The radius of gyration is set to be 125 mm (assumed to have a diameter of 250 mm rotation. The reel rotational speed will be more than the multiple bat reel design as observed from the reel design calculations. The power from the hydraulic motor is transmitted by reducing gears and double crank mechanism. The power requirement of the system is also less compared with the multiple bat system. The power requirement for running single bat reel is expressed by the equation 3.20 and results are given in Appendix III. The kinematic design of the single bat reel actuation four bar mechanism is explained as follows. Different path formulations can be made by changing the link lengths. According to Kamat *et al.* (2014)**,** for an ellipse path, links should be designed in such a way differing the crank length from all other links and length of all other links should be equal. For a circular path, opposite links should be of same length. Similarly, for each path different design criteria are followed. For tracing the path followed by the point in a four bar link of a particular set of dimensions, the points t various position of crank revolution at 360^0 has to be found out, and line or curve connecting these found points gives the path followed by the link or point. Various sets of dimensions can be tried as iterative process to get the desired path.

The cutterbar assembly analysis was same as in section 3.3.1, discussed in case of multiple bat reel system.

3.3.3 Design of vertical axis gathering system (Design III)

The vertical axis reel gathering mechanism consists of bats aligned in vertical axis on two sets, one on right and other on the left. The major parameters which are to be described in this mechanism is number of sets, number of bats, radius of gyration, angle of inclination, angle of attack, projected tynes, and actuation mechanism.

The design consists of two sets of vertically oriented bats each covering a length of 1000 mm. There are four numbers of bats on each set, placed two above the cutter bar assembly and two below the cutter bar assembly. The bats were fixed on the vertical bar of 500 mm (assumed as the maximum height of cut stalk portion), with a bat spacing of 100 mm (assumed to be same spacing as in the horizontal type reel). The bat doesn’t have pickup tynes or projections, which can be further added on necessity. The bat has a curvature at the end, comes in the middle of vehicle axis.

The vertical bar is actuated by the crank and pitman mechanism through supporting frames. The crank and pitman is individually available to both the sets and derive power from the hydraulic motor through gears and shafts.

The cutterbar size is selected as 2100 mm and rest of the analysis was same as discussed in case of multiple bat reel system in section 3.3.1.

3.3.4 Design of floating header with projected conveyor system (Design IV)

The floating type cutter header assembly is based on the concept of stability maintenance of the harvesting machine. The floating cutter header assembly consists of floats, cutter bar assembly, frame connecting prime mover, cutter header assembly and conveyor with special pick up construction. The design float will be based on buoyancy force and stability. According to Archimedes principle, the weight of the cutter header assembly must be less than the weight of the water displaced by the floats. The shape of the float should have minimum damage to the crops or not destroy the crops.

The assembly has two floats which are spaced 2200 mm apart, on each side by holding the frame. The frame is fixed between the two floats, just below the top surface of the float. The hydraulic motor which powers the cutter bar assembly was placed on the frame, midpoint between the two floats to maintain stability. The cutter bar assembly is operated by the hydraulic motor which is located at the lower part of the frame, which cuts the crop at just below the water surface. The cut crops will be picked by the conveyor just behind the cutter bar assembly, also extending few centimetres below the cutter bar assembly. The conveyor belt is having projections on the surface to pick the crop stalk which has cut, and the conveyor is also mesh type to drain the water.

The cutterbar width is 2100 mm. The height can be adjusted and fixed as per the field changes. The cutterbar assembly analysis was same as in section 3.3.1, discussed in case of multiple bat reel system.

3.3.5 Energy inputs in Pokkali Harvesting

The energy involved in the harvesting process is calculated for both manual and mechanical harvesting with newly designed assembly and existing weed harvesting attachment suitable for Truxor DM 5045. The procedure of energy calculation (Pari *et al.* 2016) is as follows.

3.3.5.1 Manual harvesting

No. of labours (days) involved in harvesting on ha: N

Energy consumption (food) of human per day: HE_{input}

(Considered from Patzek (2004) as 4000 kcal per day per person)

Yield of grains per ha : Q_{yield}

(Yield of indigenous pokkali paddy variety, 1500 kg ha^{-1})

Total Energy involved in manual harvesting: $TE_{input} = N \times FE_{input}$ ... 3.34

3.3.5.2 Mechanical harvesting

Mass of the Truxor DM 5045 with harvesting assembly: M_{truxor}

(Considered from section 3.1.2 along with approximate mass of harvesting assembly to be added – 1600 kg)

Major construction material: Marine Aluminium

Embodied energy of construction material: EE_{input}

(As per IEA, 2009 Aluminium has 211 MJ kg^{-1} which is more than steel 22.7 MJ kg^{-1})

Life of the machine: L

(Assumed value similar to combine harvesters and crawler tractors as 6000 h)

Fuel Consumption, FC_{truxor}

(Observed from section 3.1.2.1, maximum fuel consumption is 6 l h^{-1})

Energy involved in fuel consumption: FE_{input}

(As per Cervinka (1980) 47.8 MJ l^{-1} for diesel fuel)

Energy involved in lubrication = FE_{input} x 15%

(As per ASABE, 2006 – 15% of fuel energy)

Energy consumption for labour (operator): HE_{input}

(As per manual harvesting)

Field capacity (ha h^{-1}), $F_c = \frac{\text{Forward speed x operational width x \% efficiency)}}{10000}$ ... 3.35

Forward speed - 1500 m h^{-1}, Operational width - 2.1 m, Actual field capacity – 4 to 5 h acre^{-1}

$$\text{Time per ha, } T_c = \frac{1}{F_c} \quad \text{... 3.36}$$

Direct energy consumption,

$$DE_{input} = (1.15 \text{ x } FC_{truxor}\ x\ T_c\ x\ FE_{input}) + \frac{HE_{input}}{F_c} \quad \text{... 3.37}$$

(1.15 is the factor for 15% included for lubrication energy)

Indirect energy consumption, $IE_{input} = \frac{EE_{input}\ X\ M_{truxor}}{L \text{ x } F_c}$ ... 3.38

Total energy involved mechanical harvesting, $TE_{input} = DE_{input} + IE_{input}$ ... 3.39

Harvesting energy required per yield = $\frac{Q_{yield}}{TE_{input}}$ ... 3.40

3.4 Selection of best design

There are four phases involved in the selection process, namely, Quality Function Deployment (QFD) technique, Analytical Hierarchy Process (AHP), Questionnaire and Survey process and Statistical analysis.

3.4.1 Quality Function Deployment technique analysis (QFD)

QFD was selected for finalizing the design of cutter header assembly based on the voice of customer identification, expert and farmers rate on different designs to select suited model for the pokkali paddy harvest. The method of QFD technique is done by framing a **'House of Quality'** (HoQ), which is represented in the Fig. 3.6. The procedure of the QFD by framing HoQ followed as per previous study (Shahin, 2005). The voice of customers (customer requirement) from farmers and expert opinion were collected through the survey by direct interview with questionnaire (Appendix IX) to select a best model. Requirements and suitable designs made (as in section 3.3) which is further evaluated by expert committee through questionnaire along using rating chart. Expert committee includes 19 respondents (Appendix IX) from the Farmers, ICAR – Institutes, KVKs, Rice Research Stations, State Agricultural Universities and Industries. They were selected based on the experience and knowledge on pokkali system and design of agricultural machineries. Further the best design was found and suggested for further design and developments. Detailed procedure is explained as follows.

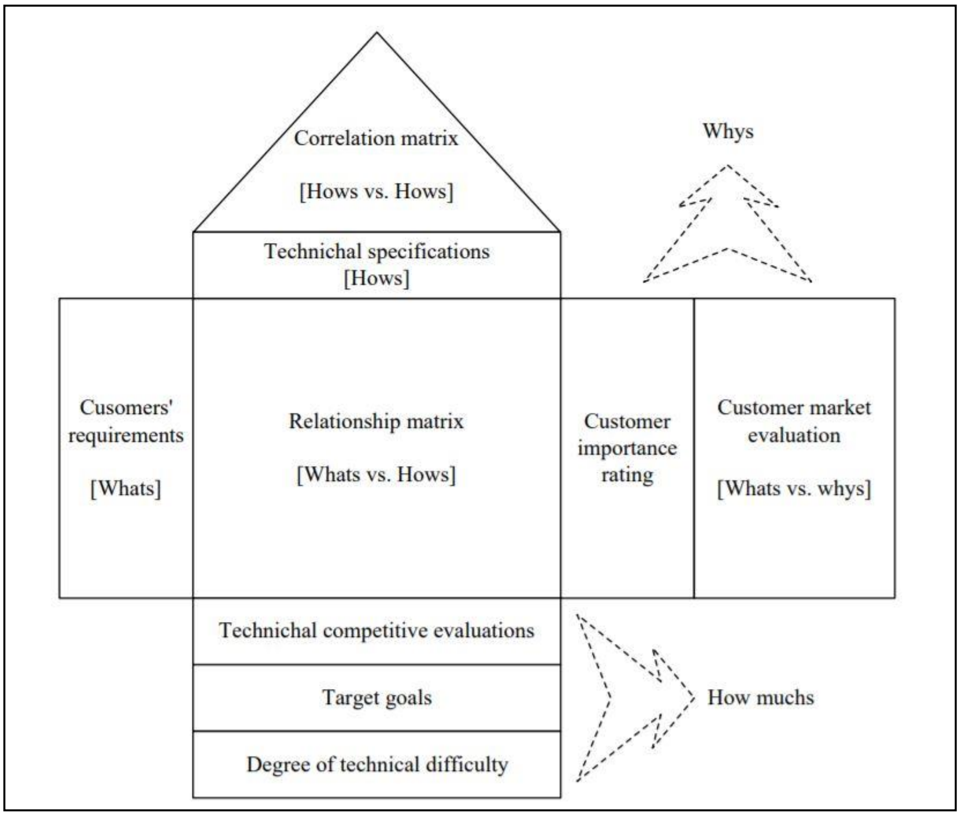


Fig. 3.6 House of Quality (HoQ) (Menks *et al.*, 2000)

Step 1: Customer requirements ('Whats'): Requirements of the customers (called as 'Voice of Customers' (VoC), in this study is from farmers who were considered as the customers) were identified from the survey conducted among pokkali paddy farmers as mentioned earlier in the section 3.2. The questionnaire of the same is given in the Appendix IX. The customer requirements were classified into major and minor criteria. Under three major criteria (Harvesting performance, Machine performance and Component evaluation), ten minor criteria are placed. The minor criteria under three major criteria are as follows,

1. **Harvesting performance:** Under the major criterion of harvesting performance, minor criteria includes cutting performance, gathering performance, collection and conveying, cut stalk losses, uncut stalk losses

2. **Machine performance:** Under the major criterion machine performance, minor criteria include manuevarability, transportability, stability and field capacity.

3. **Component evaluation:** Under the major criteria component evaluation, minor criterion includes importance of components.

Step 2: Customer importance rating: Different requirements of the customers have to be given weightage based on the importance of the requirement. For determining weightage for minor criteria was carried out by a method called as **Analytical Hierarchy Process (AHP)**. The AHP method was carried out for minor criteria which are plotted on both row and column in a table as illustrated in Appendix IV. These matrixes indicate a preference or priority for each decision alternative in terms of how it contributes to each criterion. This was done for each major criterion separately.

The pair wise comparison was done between each and every minor criterion within the major criteria. When the parameters (minor criteria) have equal importance upon each other, the rating provided is 1. Hence the diagonal values tend to be unity always. When the row parameter important than column parameter in a cell, value between 2 to 9 is preferred depending on level of importance. In the next step of AHP, the column values are summed to give a column total. By dividing each column value with its corresponding column total, normalized pair wise comparison matrix is formed. Now the average of a row in a normalized pair wise comparison matrix gives the relative priority of the parameter in corresponding row. The sum total of priority values should yield a value of one, otherwise the result is inconsistent. Also the consistency is checked with consistency ratio. Once the weightages are found, it is multiplied with the corresponding column values and further the summation of row values are taken. These are called as weighted row summation. Now each weighted row summation is divided with corresponding weightage calculated earlier. The fraction of weighted row summation and weightage values gives 'n' number of values, whose mean is considered to be $\lambda_{max.}$ Using the formula below, the consistency index ('CI') is determined.

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1} \qquad \text{... 3.41}$$

Further the random number was selected from the Random index table in the Appendix IV. The fraction of consistency index and random number gives the consistency ratio which should be less than 0.1 for a consistent result. If the result is inconsistent, the process should be repeated for different weightage. If the result is consistent, the priority values are considered as weights for the minor requirements. These weights are used for weighted sum calculation in further analysis in house of quality building.

Step 3: Technical specifications (Hows): Based on the requirements of the farmer, the technical requirements (engineering parameters) for the cutter header assembly of pokkali paddy harvesting machine were listed as per the HoQ. This has to be done by the engineer by analysing the VoC and technical requirements to satisfy the VoC. The specifications considered were reel type, cutter bar type, reel speed index, position of operation of cutter header assembly, material of construction and mass density of the assembly.

Step 4 (Relationship matrix): The relationship between VoC and technical specifications is dealt in this section of matrix. Being centre part of the HoQ, it is the element corresponds to "whats" and "hows". It is completed by the expert group of technical people in the field of Pokkali Paddy through **questionnaire**

and survey process. The relationship is stated by 1-3-5-9 rating, out of which 0 is no relationship, 3 is less relationship, 5 is moderate relationship and 7 is higher relationship and 9 extreme relationship. Rows of the matrix were minor criteria and columns were technical requirements (Appendix V). The weightage observed from the step 2 is incorporated to give a weighted relationship matrix (formed by product of weightage and corresponding criterion's row values). The column summation gives the total score of each technical requirement and ranking is observed which decided the design process in future.

Step 5: Correlation matrix (roof of HoQ): Triangular part of HoQ which describes the supports and conflicts in between the 'hows'. Strong positive correlation (++) or weak correlation (-) or no correlation (--) between each technical specification (hows) with other are stated. This was done by the research group of technical people based on past experience and test data available.

Step 6: Target goals: This step provides the how much of 'hows' to be used or supplied. In this case, the design values of various technical parameters are to be chosen by the research team. The goals are necessary to be measured and quantified based on the suggestions from expert evaluation through questionnaire.

Step 7: Technical Competitive evaluation: It is the section for comparing different designs or existing product with the new one. It has to be completed by the user or customer by providing ratings and in this research it is provided by expert committee with 19 respondents. Here, the competing designs were the different design models made in the section 3.3. Out of five star rating on ten minor criteria under the three major criteria for four different design models recieved from the respondents, customer rating matrix is formed with criteria as rows and design models as columns (Appendix VI).

Step 8: Overall importance ratings: The weightage values calculated out of AHP process in the step 2 is incorporated and weighted customer rating matrix us formed (weightage of corresponding criterion is multiplied with row values and column summation is done). Ranking of the design models were made in descending order of column summation. The designs are ranked from 1 to 4.

3.4.2 Statistical Analysis

Statistical analysis was carried out using Microsoft Excel software through one way ANOVA test and Post hoc – Tukey HSD (Honest Significant Difference) test. Analysis of Variance (ANOVA) test conducted on comparing the 19 responses (from QFD - step 7) on individual minor criterion to each of four designs. The level of significance was assumed as 5%. One way ANOVA gives that each minor criterion either have overall significant difference or not between four different models. But the post hoc – Tukey HSD test gives significant/insignificant differences between each and every design models with respect to each minor criterion. Significance was mentioned with alphabet in exponential of mean of the cell with respect to minor criteria and design model. The results of QFD method and statistical analysis were compared and inferred.

3.4.3 Finite Element Analysis

ANSYS Workbench, 2018 software was selected for finite element analysis. Finite element analysis was carried out on the element (bat and/or tyne) which is suspected to be under failure in reel assembly of selected design to check the safety of assembly on loads with different shaft diameters. The minimum thickness hollow shaft is to be selected in order to have minimum weight.

The assumptions were as follows,

1. Crop mass load is uniformly distributed on the assembly and on a single surface (top or bottom surface)
2. Wet biomass availability is assumed to be 10000 kg ha^{-1} during the time of harvest
3. Dynamic water pressure was considered as per the following equation

$$P = \frac{1}{2} DV^2 \qquad ...3.42$$

P = Dynamic water pressure

V = Forward velocity of the component

D = Density of the water

From the second assumption, load (kg ha^{-1}) is observed and converted into pressure (N m^{-2}). The structural static loading was selected with the available pressure value. Materials chosen were structural steel and aluminium. The von Mises stress and total deformations were observed for different diameters and materials. The minimum diameter material with less mass density under safer limits was selected.

The results from QFD results, statistical analysis and FEM analysis were analysed and feasible suggestions are identified to select the suitable design. Further the selected design model of the cutter header assembly can be developed and evaluated for pokkali harvesting.

CHAPTER IV

RESULTS AND DISCUSSION

The results obtained from the various objectives are discussed in this chapter. The results of study on existing machines, preliminary studies, design analysis of different models of cutter header assembly and selection of a best design model are detailed as shown.

4.1 Study on existing machines

Technical aspects of KAU Pokkali Paddy Harvester and Amphibian weed harvester (Truxor DM 5045) were studied. The KAU Pokkali Paddy Harvester was the first made for pokkali paddy, since the size and weight of the harvester are large which made the harvester difficult on practical field use. The main constraint for field application is due to the transportability of the machine to the fields and manuevarability in the field.

The Truxor DM 5045, the imported amphibian weed harvesting machine which can be utilized for various wetland purposes and it was suitably tested on pokkali fields. The size, weight and manuevarability were better on harvesting performance but does not provide the storage of cut crop stalks within itself. The crop stalks were removed completely as a whole, instead of cutting at a required height is also a problem in this case. Also the field capacity was less because of the time lag in depositing the cut stalks on bunds every time after the bucket is filled. Both the machines were amphibious in construction, which enhance them to work both land and water. Several important differences and similarities were observed between the machines get an understanding. The KAU Pokkali Paddy Harvester and amphibian weed harvesting machine (Truxor DM 5045) were specified in the Table No. 4.1.

Table No. 4.1 Specifications of KAU Pokkali Paddy Harvester and Amphibian Weed Harvester (Truxor DM 5045)

S. No	Parameter	KAU Pokkali Paddy Harvester	Amphibian Weed Harvester
1.	Total Mass	3 tonnes	1.4 tonnes
2.	Overall dimension	Length - 9.67 m Width - 2.22 m Height - 2.22 m	Length 4.7 m Width 2.06 m Height 2.1 m
3.	Float dimension	Length - 4.80 m Width - 0.60 m Height - 1.00 m	Length - 4 m Width - 0.75m Height - 0.65 m
4.	Engine	Mahindra make (M&M) 45 hp Diesel	Kubota make 44.9 hp Diesel
5.	Hydraulic oil capacity	150 l Ordinary Hydraulic oil	36 l Panolin Oil
6.	Major construction material	Mild Steel	Marine Aluminium
7.	Storage & Conveying system for harvesting	Yes	No
8.	Engine cabin To & Fro movement	No	Yes
9.	Paddle wheel	Yes	No
10.	Operator availability sensor & Evacuation pump in floating barge	No	Yes
11.	Rear attachments	No	Yes
12.	Use	Floating Paddy Harvester	Multipurpose
13.	Reel	5 bat (0.84 m dia)	No
14.	Manufacturer name	Kelachandra Harvester	Dorotea Mekaniska (Sweden)

4.2 Preliminary studies

Preliminary studies such as survey, crop parameters, and soil - water parameters were carried out as mentioned in section 3.2. The results are discussed in detail in this section.

4.2.1 Survey on farmers

Based on the survey conducted on the farmers as discussed in Section 3.2.1, the constraints and demands on pokkali harvesting were identified and plotted as affinity diagram shown in Fig. 4.1. Information related to field and crop parameters which affected harvesting such as soil type, water level, crop height, cutting height, lodged/erect condition etc were collected through questionnaire. From these constraints, the machine parameters required for pokkali paddy harvesting were deduced.

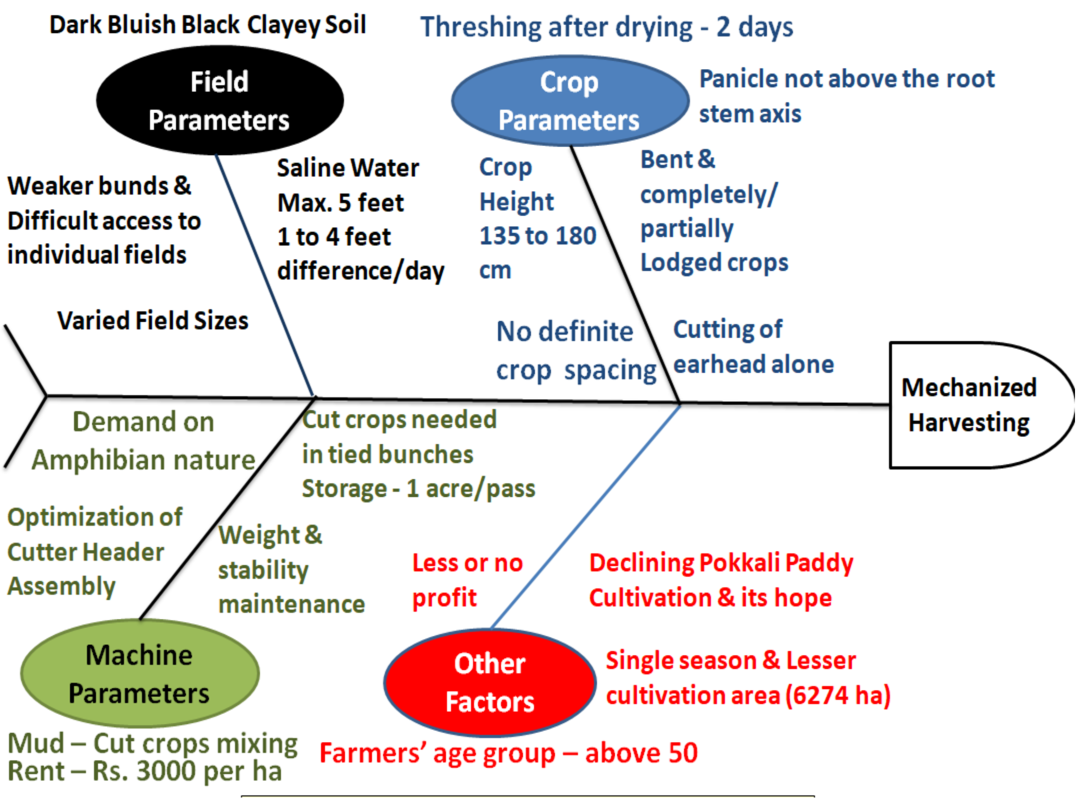


Fig. 4.1 Affinity diagram or Fish bone diagram on Constraints of Mechanization of Pokkali Paddy Harvest

The analysis highlighted the features demanded for a pokkali paddy harvester were such as amphibian nature of the traction, cutting and gathering mechanism suitability, stability, transportation and manuevarability etc.

The cultivation practices and important operations are given in the figures and plates on the Chapter I. Apart from traditional followings, some fields are broadcasted without mound makings and some fields are mound made and transplanted. Harvesting mechanization is the major demand from the farmers, as discussed by the Ranjith *et al.* (2019).

Also labour shortage and lack of experienced labours are constraints, which have a solution through mechanization. About 100 labour hours are required on harvesting of pokkali field, which is one of the labour intensive operations in pokkali paddy cultivation. Farmers with large land holdings demands a self propelled machine for harvesting, whereas for a small land holding farmers, walk behind type harvester is sufficient. Several fields which have weak bunds can break cannot be accessed by the heavy harvesting machines, makes the pokkali field situation, a critical constraint towards mechanization. The farmers prefer tied bundles of harvested crops by the machines. Machine should have a storage capacity for one acre in single go. Average cost of harvesting is ten thousand rupees per acre compared to a rental charge of three thousand rupees on mechanical rice harvesters.

4.2.2 Crop parameters

The harvesting parameters include crop parameters, soil properties and water properties. Bulk density, 1000 seed weight and plant density of indigenous and RRS Vytilla varieties as per the procedure explained in section 3.2.2 and the results are given in the Table No. 4.2 and 4.3 respectively.

Table No. 4.2 Properties of Seeds and Plant density of indigenous varieties

S. No	Property	*Chootu pokkali*	*Virippu*
1.	Bulk density (kg m^{-3})	492.35	477.65
2.	1000 Seed Weight (gm)	028.80	034.50
3.	No. of grains in 10 gm	348.00	290.00
4.	Seed rate (kg ha^{-1})	075.00	075.00
5.	No. of seedlings in unit area (upon 100% germination)	261.00	218.00

Table No. 4.3 Properties of Seeds and Plant density of RRS Vytilla varieties

S. No	Property	*Vytilla 1*	*Vytilla 10*
1.	Bulk density (kg m^{-3})	497.24	532.04
2.	1000 Seed Weight (gm)	028.00	026.00
3.	No. of grains in 10 gm	357.00	374.00
4.	Seed rate (kg ha^{-1})	075.00	075.00
5.	No. of seedlings in unit area (upon 100% germination)	268.00	281.00

From the Table No. 4.2 and 4.3, the plant density (nos. per m^2) is observed in the range of 268 and 281 (approximately 300). Depending on the number of plants present per square meter with individual plant weight has to be used in the design which is discussed in various sections. The crop parameters discussed in Table No. 4.4 compares the Vytilla varieties and indigenous varieties of pokkali system. The crop height, yield varies significantly for both the cases.

Table No. 4.4 Crop parameters of the Pokkali field

S. No	Parameter	Indigenous varieties	Vytilla varieties
1.	Crop height (cm)	170 - 180	130 - 150
2.	Cutting height (cm)	Top 30 to 60 from the panicle	
3.	Crop condition	Lodged/ Erect	Erect
4.	Yield (kg ha^{-1})	1500	3000

4.2.3 Soil and water parameters

The soil and water properties on the pokkali paddy fields are given in the following Table No. 4.5 and 4.6.

Table No. 4.5 Soil properties of the pokkali field

S. No	Property	Value
1.	Textural classification	Clayey
2.	Colour	Dark bluish black
3.	Bulk density	1.658 g cm^{-3}
4.	Shear strength	0.0047 kg cm^{-2}
5.	Resistance	22.42 kN m^{-2}
6.	Type	Acid Saline
7.	pH	3 to 4.7
8.	Electrical conductivity (July to November)	4 to 6 dS m^{-1}
9.	Organic content	1.86%

Table No. 4.6 Water properties of the pokkali field

S. No	Property	Value
1.	Water level (cm)	30 to 150
2.	Salinity	0 to 31 ppt or more
3.	pH	7 to 8.5
4.	Direction of motion	Variable

The soil contains high organic content, acidic in nature due to the peculiar ecosystem. The soil colour dark bluish black which is unique in the pokkali fields. Electrical conductivity is high because of soluble salts. Clayey texture and high organic content makes the field to be marshy and difficult for vehicle manuevarability. The water during the July to November is found to be less saline due to the monsoon rains. But salinity increases during the November to June months, making the field situation that forces the machine construction to be a anti corrosive materials for machine construction. The spatial and temporal variation of water level in the fields varies from one foot to six feet; hence the machine has to work at very low and very high water depth which is to be designed as an amphibious type unlike existing land machines. The direction of water flow can be in any direction depending upon the tidal flow which affects the movement of machine under such situations.

4.3 Design of different computer aided models of cutter header assembly

The design of cutter header assembly was carried out as per the section 3.3. Four different models were designed and discussed in this section with their specifications.

4.3.1 Design of cutter header assembly with multiple bat reel system (Design I)

Specifications of the designed model were provided in Table No. 4.7 and 4.8. The multiple bat reel model was designed as per section 3.3.1. Cutterbar and knife section were shown in the Fig. 4.2. Fig. 4.3 and 4.4 shows the cutter header assembly which is having multiple bat reel system. Fig. 4.5 shows the tyne actuation mechanism having cam and follower type machine elements as discussed in section 3.3.1.

Table No. 4.7 Specifications of Reel for Multiple bat reel system

S. No	Parameter	Range
1.	Reel diameter	0.25 m
2.	Number of bats	4
3.	Tyne actuation mechanism	Cam and follower
4.	Power transmission from motor	Chain and sprocket
5.	Pick up tyne length	7.5 cm
6.	Number of pick tynes per bat	21
7.	Reel speed index	1 to 2
8.	Rotational speed	30 to 60 rpm
9.	Staggered pitch	0.10 to 0.40 m
10.	Plants per bat (Max)	225 Nos.

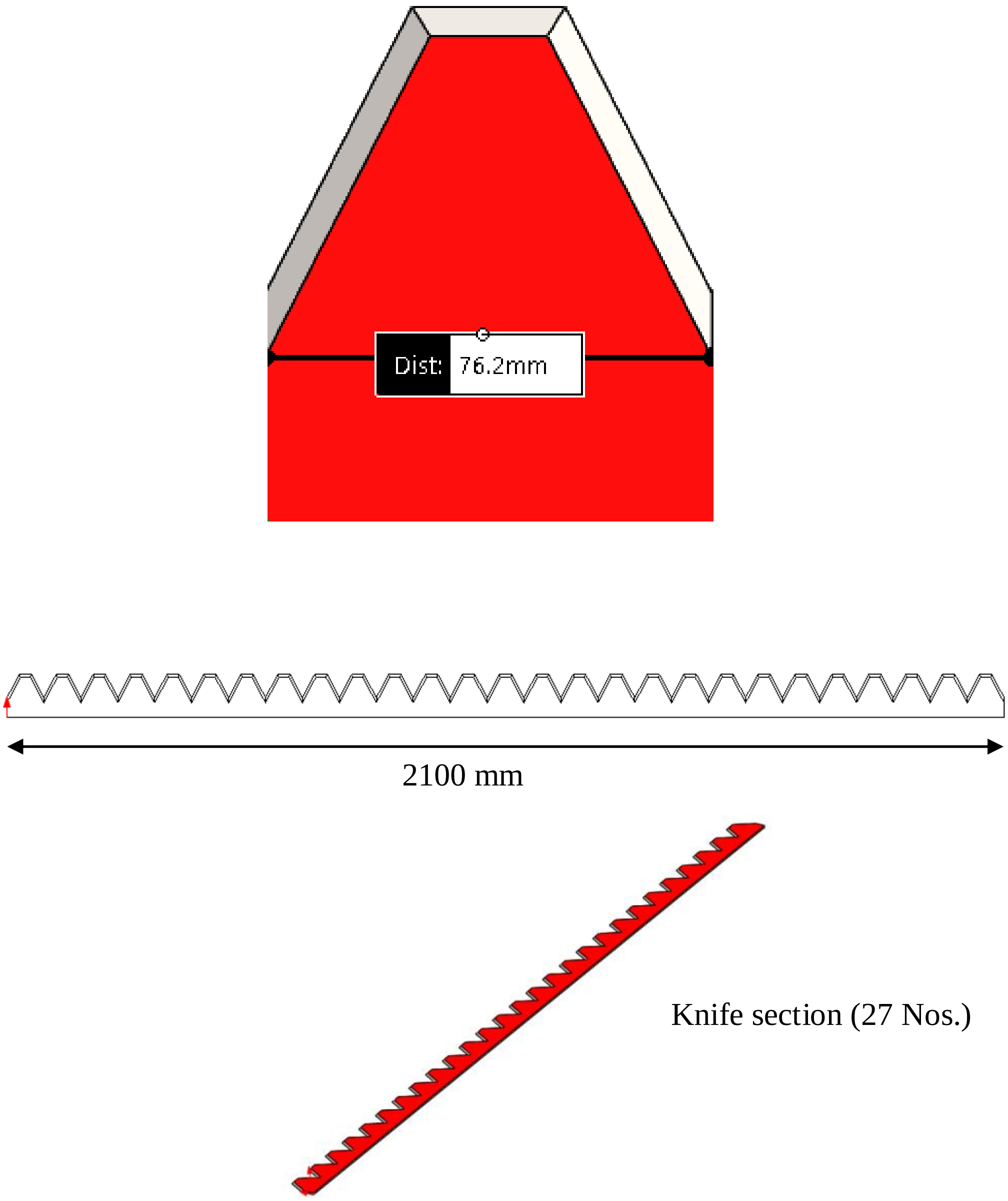


Fig. 4.2 Cutter bar and knife section

Table No. 4.8 Specifications of Cutterbar assembly

S. No	Parameter	Range
1.	Width	2100 mm
2.	Cutterbar Type	Reciprocating
3.	Knife type	Standard – Serrated
4.	Knife shape	Trapezoidal
5.	Stroke length	76.2 mm
6.	Number of knife sections	27
7.	Pitch of serrations	1.2 mm
8.	Knife and ledger plate clearance	0.3 mm
9.	Cutterbar power transmission	Crank & pitman mechanism
10.	Crop cutting height from ground	120 to 150 cm
11.	Angle between cutting edge and axis of knife section	33^0
12.	Rake angle	22^0
13.	Angle between cutting plane and horizontal	0^0
14.	Material of knife	High carbon steel
15.	Crank revolutions	190 to 230 rpm
16.	Forward velocity of machine	1 to 1.5 km h^{-1}
17.	Average knife velocity	0.39 to 0.58 ms^{-1}
18.	Cutting index	1.4

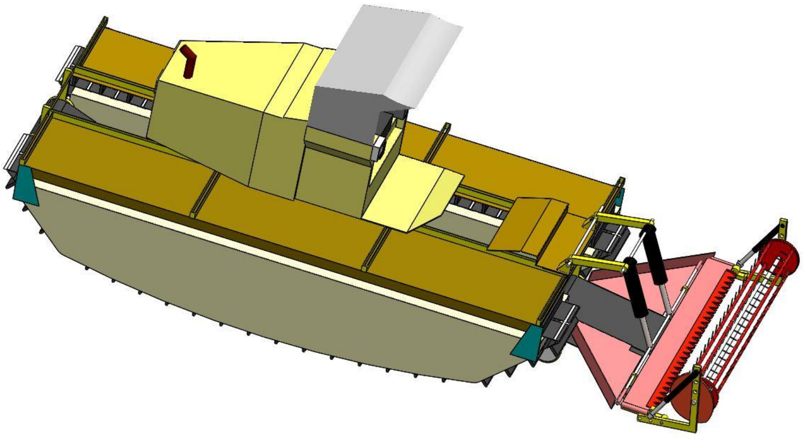
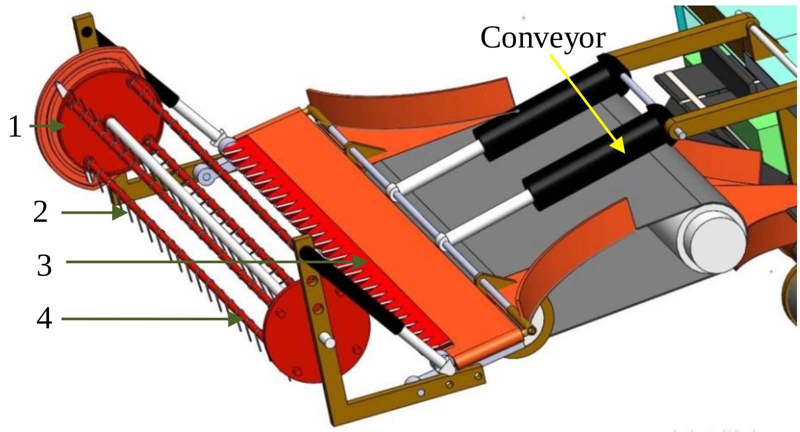
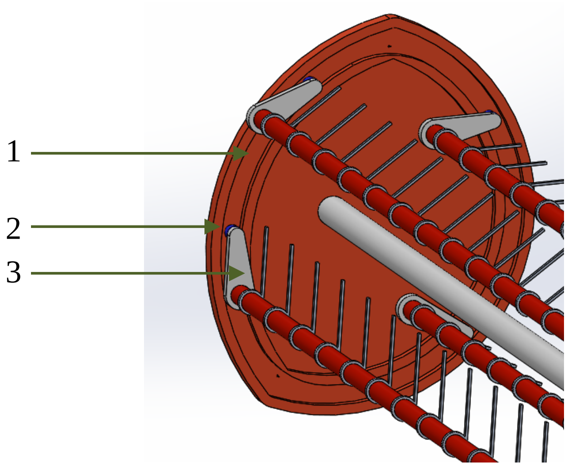


Fig. 4.3 Multiple bat reel model (design 1) with Truxor DM 5045



1. Tyne actuation mechanism
2. Tynes
3. Cutterbar
4. Bat

Fig. 4.4 Multiple bat reel model cutter header assembly



1. Cam path
2. Roller
3. Follower

Fig. 4.5 Cam and follower path for tyne actuation mechanism

4.3.2 Design of cutter header assembly with single bat reel system (Design II)

The design 2 model is attached with single bat reel system as header assembly as shown in Fig. 4.6 and 4.7. The actuation mechanism is through double crank four bar linkage. Specifications of the design were discussed in the Table No. 4.9.

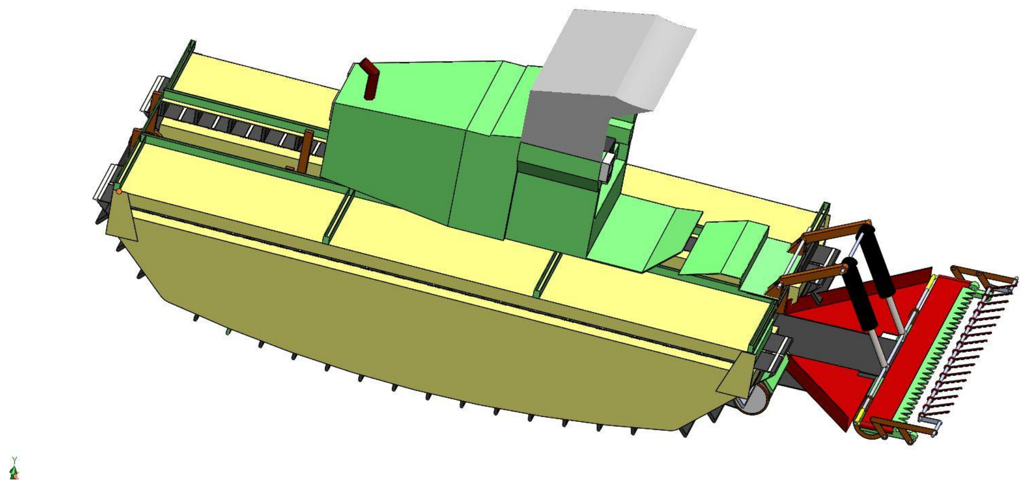


Fig. 4.6 Single bat Reel model with Truxor DM 5045

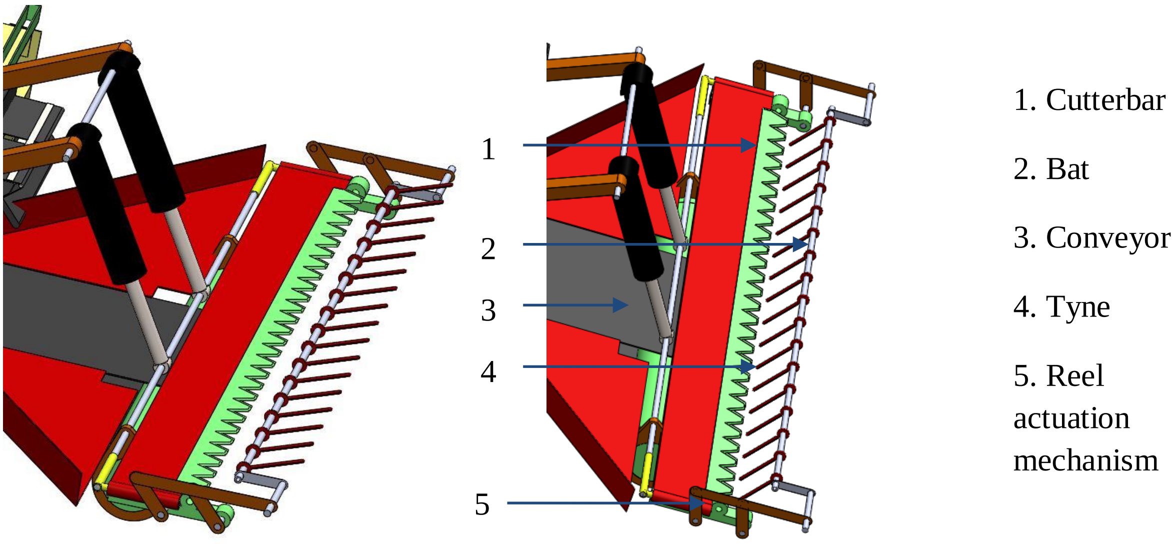


Fig. 4.7 Single bat reel model cutter header assembly

Table No. 4.9 Specifications of single bat reel system

S. No	Parameter	Range
1.	Radius of gyration	0.125 m
2.	Number of bats	1
3.	Tyne actuation mechanism	Four bar mechanism
4.	Pick up tyne length	150 mm
5.	Number of pick tynes per bat	21
6.	Reel speed index	1 to 2
7.	Rotational speed	30 to 60 rpm
8.	Plants per gyration (Max)	450 Nos.

4.3.3 Design of cutter header assembly with vertical axis gathering mechanism (Design III)

` The specifications of the design model 3 are provided in the Table No. 4.10. Fig. 4.8 and 4.9 shows the design 3 as a vertical axis reel type cutter header assembly. Angle of attack and angle of inclination are shown in Fig. 4.10.

Table No. 4.10 Specifications of vertical axis gathering system

S. No	Parameter	Range
1.	Radius of gyration	0.125 m
2.	Number of sets	2
3.	Number of bats	4
4.	Length of each bat	1 m
5.	Tyne actuation mechanism	Crank and pitman
6.	Reel speed index	1 to 2
7.	Rotational speed	30 to 60 rpm
8.	Plants per gyration	450 Nos.
9.	Angle between vertical and reel bar	0^0 - 45^0
10.	Angle between bat axis and line of travel	90^0 - 180^0

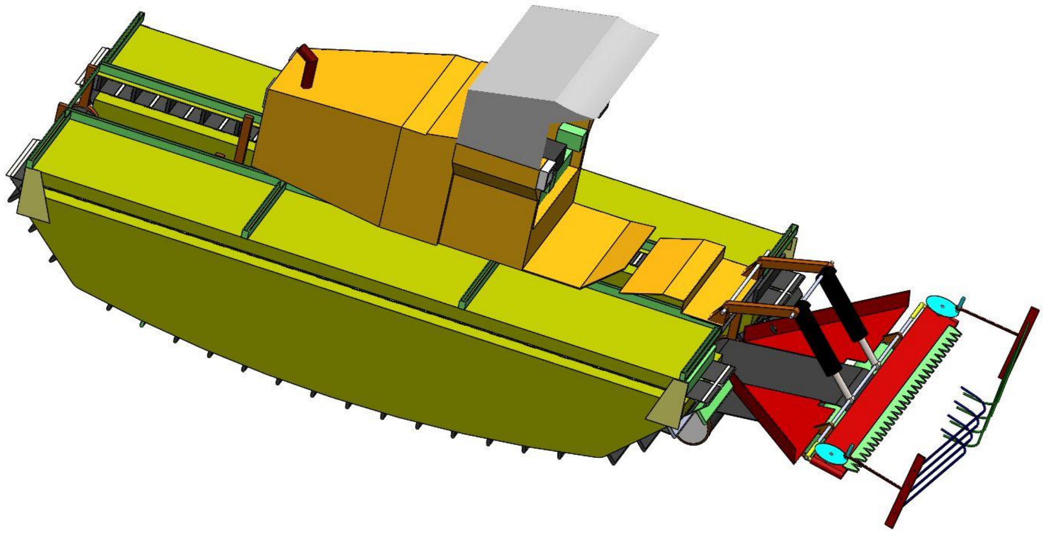


Fig. 4.8 Vertical axis reel model with Truxor DM 5045

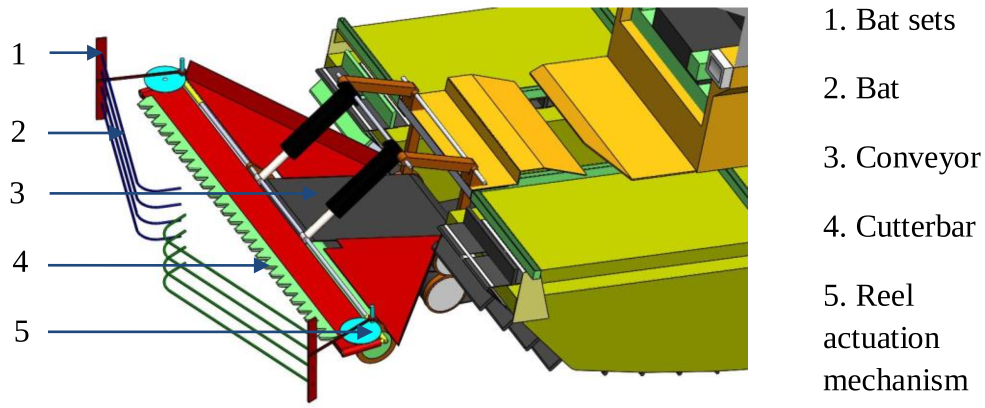


Fig. 4.9 Vertical axis reel model cutter header assembly

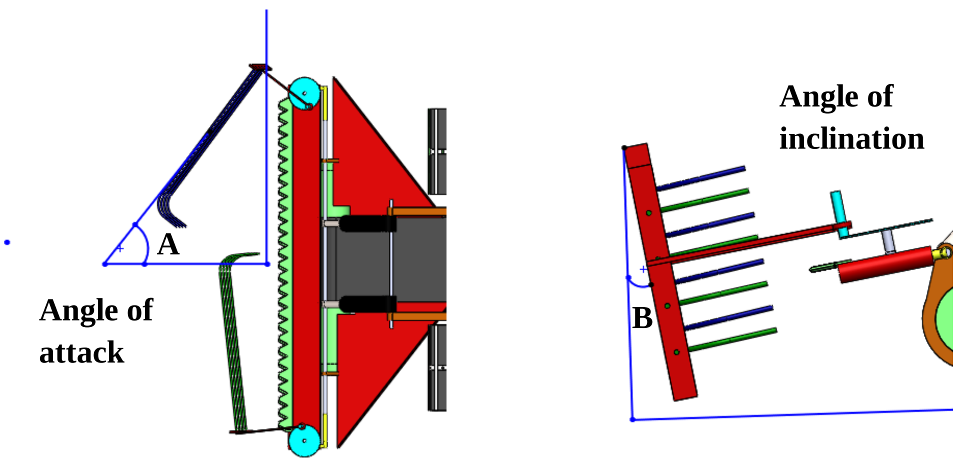


Fig. 4.10 Sketch showing (a) Angle of attack (b) Angle of inclination

4.3.4 Design of cutter header assembly with floating type projected conveyor (Design IV)

Specification of a float mentioned in the floating type cutter header assembly was given in Table No. 4.11. Fig. 4.11 and 4.12 shows the floating type projected conveyor cutter header assembly in different views.

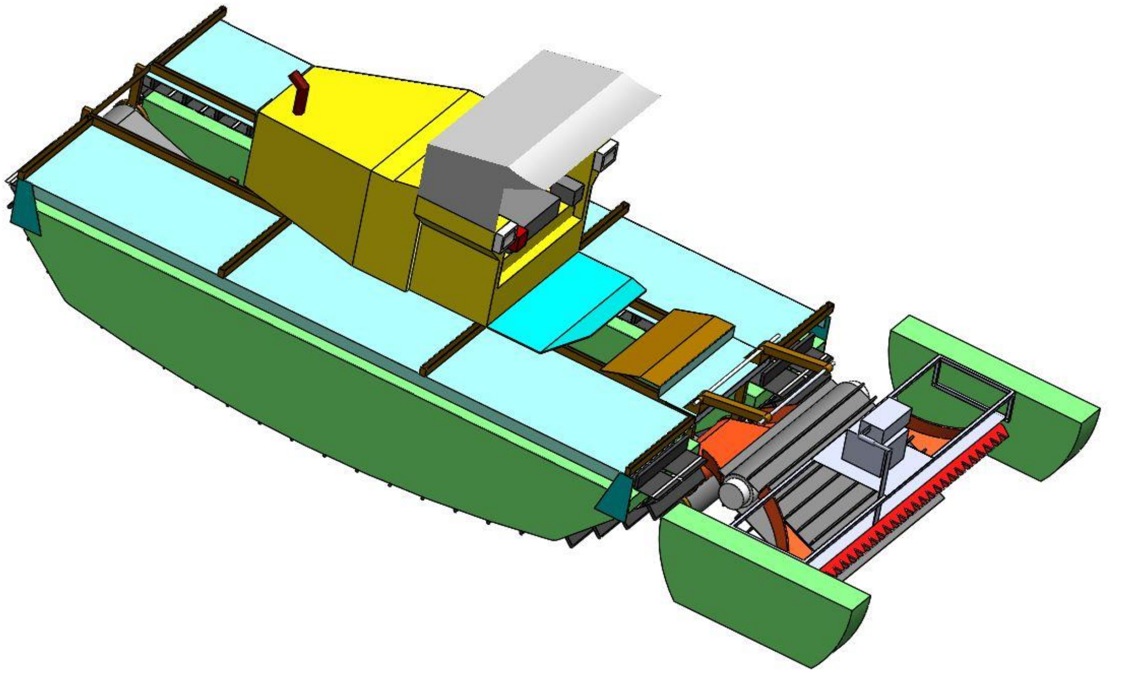


Fig. 4.11 Floating assembly model with Truxor DM 5045

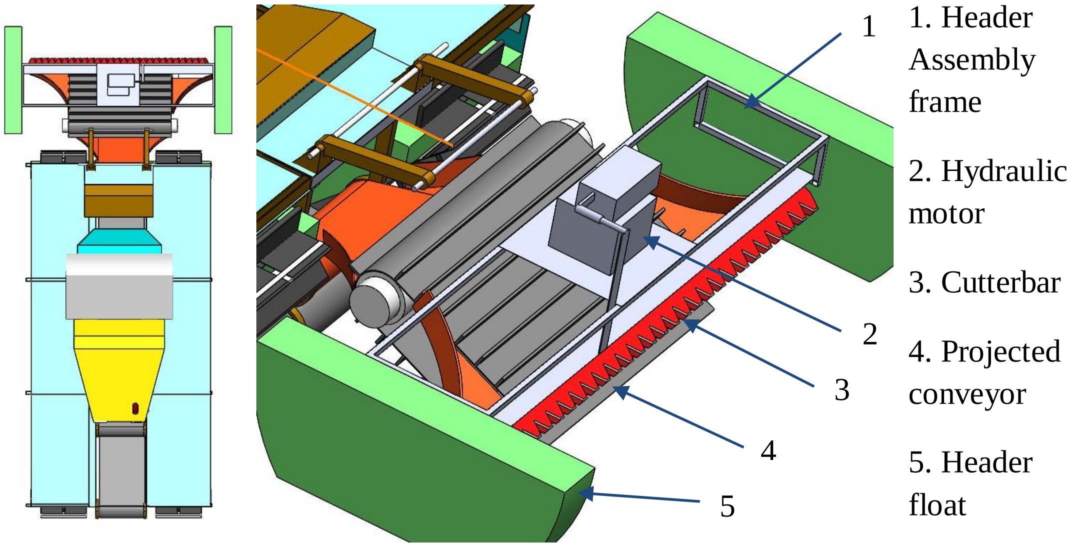


Fig. 4.12 (a) Top view (b) Floating type cutter header Assembly

Table No. 4.11 Specifications of float of cutter header assembly

S. No	Mass of the header assembly (kg)	Length of float (m)	Volume of float (m^3)	Reserve Buoyancy (n)
1.	50	0.50	0.185	3.700
2.	100	1.00	0.245	2.450
3.	150	1.75	0.335	2.240
4.	200	2.50	0.425	2.125

*n – Required reserve buoyancy

4.3.5 Conveyor assembly

The cutter header assembly of different models were designed with the conceptual conveying system. Crop conveyor assembly consists of front conveyor, mounted on the rear of the cutter header platform, collects the harvested crop and conveys it to the central conveyor. Central conveyor was extends till the rear end of the machine passes between two air barges, stores the crop mass. At the rear end, discharging conveyor was fixed to unload the harvested crop materials loaded on the central conveyor, when machine reaches the bunds.

4.3.6 Energy inputs in pokkali harvesting

In total manual harvesting energy input expended was 585 MJ compared to 4770 MJ of total energy for existing weed harvesting attachment with Truxor DM 5045. Direct and indirect energy consumption was 4410 MJ and 360 MJ respectively. Also the field efficiency was observed to be 25%, but the proposed designs will have a higher efficiency than existing one, due to the presence of conveyor system and storage facility, the energy input for the newly proposed design will be less than 4770 MJ.

4.4 Selection of best model

The best design model of cutter header assembly was selected by QFD technique as per the steps discussed in the section 3.4. The AHP method gives the weightage to the different minor criteria under three major criteria. The weightage obtained are given in Table No. 4.12. Each major criterion has weightage of unity which is shared by minor criteria on the basis of AHP result. The minor criterion gathering performance in harvesting performance (major criterion) and minor criterion stability in machine performance (major criterion) were found to have maximum weights. The minor criterion collection performance in harvesting performance (major criteria) and minor criterion transportability in major criterion machine performance were found to have least weights. Kumar *et al.* (2019) discussed that ease of operation and ease of transportation was the main factors considered while rating the coconut palm climbing aid, but in this research transportability has not received a higher ranking comparing other factors. This is because of the fact that, coconut palm climbing aids are manual tool with intermittent operation but harvesting machine is self propelled one with linear motion.

Table No. 4.12 Weightage for minor criteria through AHP

S. No	Major Criteria		Minor Criteria	Weights
1.	Harvesting Performance	i.	Cutting performance	0.15
		ii.	Gathering Performance	0.39
		iii.	Collecting & Conveying	0.05
		iv.	Cut stalk losses	0.10
		v.	Uncut stalk losses	0.31
2.	Machine Performance	vi.	Manuevarability	0.21
		vii.	Transportability	0.06
		viii.	Stability	0.63
		ix.	Field capacity	0.10
3.	Component evaluation	x.	Importance of components	1

Table No. 4.13 Relationship matrix for QFD

	Reel speed index	Material of construction	Cutter bar type	Mass of the assembly	Reel type	Position & degree of freedom
Cutting Performance	35	**79**	**75**		38	**85**
Gathering Performance	60				56	67
Collection Performance	51	18	18		45	
Cut stalk losses	51	67	67		51	68
Uncut Stalk losses	44	58	58		44	**72**
Manuevarability		21		70	44	47
Transportability		64				59
Stability		**74**		**84**		**83**
Field capacity	58		**77**		**77**	45
Importance of components	62	**81**	**88**		55	**94**

1 to 30 – Less relationship   31 to 50 – Moderate relationship
51 to 70 – High relationship   **71 to 90** – Extreme relationship

The relationship matrix was given in Table No. 4.13, explains the relationship between ten minor criteria upon the six technical requirements. Weighted relationship matrix (Appendix X) is formed as per the section 3.4 step 5, ranking of technical requirements as given in the Table No. 4.14.

Table No. 4.14 Ranking of technical requirements of cutter header assembly

	Reel speed index	Material of construction	Cutter bar type	Mass of the assembly	Reel type	Position & degree of freedom of assembly
Rank	5	2	3	6	4	1
Weighted percentage	13.9 %	20.5 %	15.7 %	8.0 %	14.2 %	27.5 %

Position and degree of freedom was observed to be most important among the technical requirements and mass density of the assembly found to be least important. According to ranking, the importance should be given for the technical requirements in the ascending order of ranks during the design and development. The various suggestions from the experts opinion through questionnaire and interview process observed that solutions for the technical requirements are discussed as follows in subsequent section according to the order of importance of their ranks.

Position and degree of freedom: The cutter header assembly position and its movement was given importance as one of the important technical requirements for the pokkali harvester when it works above the water surface as 45% and below the water surface as 55% from the analysis. From Table No. 4.13, it can be observed that, importance of component and position and degrees of freedom of assembly having highest score (94) was observed. The least score (44) was observed between field capacity and position and degrees of freedom. The cutting performance and position and degrees of freedom were having the second highest score. The other customer requirements gathering performance, collection performances and losses had scores ranging from 47 to 67. Position and degrees of freedom of cutter header assembly with stability of the harvester under customer requirements has a score of 83 which signifies the importance of position and degree of movement of the cutter header assembly with the vessel. Position and degrees of freedom ranked first in the technical requirements as discussed earlier and this result is comparable with the results of Kumar *et al.* (2015) which shows that out of various design requirements of a agricultural machinery, 'Adjustments' ranked first. Hence it is inferred that adjustments and control over the positions of any component is important while designing an agricultural machine.

Material of construction: Material of cutter header assembly ranked second as observed from Table No. 4.14. Cutterbar knife material type was discussed as one of the main technical requirements for the knife blades. The knife material suggested in the QFD analysis by the majority of the experts was high carbon steel with or without coatings followed by spring steel and stainless steel. Majority of the experts opined that knife blade should be corrosion resistant with nano coatings. The material of knife blade suggested by the experts were in agreement with research result reported by Hamid *et al.* (2021) recommended that co-deposition of TiO_2 (Titanium dioxide) nanoparticles within the Ni (Nickel) matrix on harvester knives which improved the corrosion resistance and mechanical properties. Similarly Hematian *et al.* (2013) reported the application of nano-coated knifes which reduced specific shearing energy by 34%. The importance of materials of construction with respect to the cutting was 79 score and also importance of components score 81. Overall the experts evaluated the material of construction of cutter header assembly has significant effect on stability of the all system. Both the cut stalk losses and uncut stalk losses also reflected the material of construction of knife blades since the score related between two factors in relationship matrix was 67 and 58 respectively.

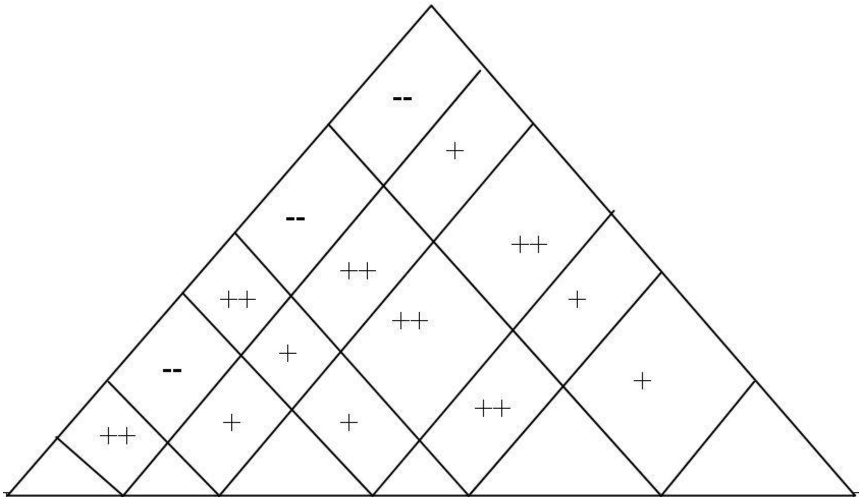
Cutterbar type: Among the technical requirements, the cutterbar type was ranked third, which indicated its importance in cutter header assembly. The relationship between cutterbar type and the customer requirements as shown in Table No. 4.13 indicated that cutting performance, field capacity and importance of components had extreme relationships since the score ranged from 71 to 90. The cut stalk losses and uncut stalk losses were having high relationship with cutterbar type since the scores were 67 and 58 respectively. Cutterbar knife blade type experts suggested that the reciprocating double shear knife bar with serrated blades for the cutterbar among the scissor type and double shear reciprocating cutter blades.

Reel type: The importance of reel as a technical requirement for cutter header assembly ranked fourth from the experts opinion from the Table No. 4.14. The maximum score of 77 was observed for the customer requirement field capacity in relation to the reel type was observed and for all other minor criteria the importance of reel type for the customer requirement was below score of 51. 63% of the respondents suggest the need of reel in cutter header assembly while 36% suggested no reel or other gathering mechanism for pokkali harvesting in flooded condition is significant.

Reel index: The technical requirement reel speed index ranked lowest as observed from the Table No 4.14. The reel index with minor criteria given in Table No. 4.13. Gathering performance, field capacity and importance of components as a cutomer requirement weighted scores above 57 indicating high relationship. In addition to this, the collection and cut stalk losses had weighted score of 51 indicating the relationship of reel index on cutter header perfomance. Suggested values of the reel index by the experts ranged from 1.2 to 1.7. Kepner *et al.* (1978) suggested 1.25 to 1.5 reel index for normal cereal crop harvesting, where the upper limit is less than the expert's suggestion.

Mass of the assembly: The least ranked technical requirement was cutter header assembly as given in Table No. 4.14. The mass of the assembly dependent on the material of construction and the design of the components. Since the harvester is operating moslty under flooded condition it is desired to keep the mass of the machine as low as possible. The material for the cuter header and the vessel was mainly marine aluminium to reduce the weight. The transmission and other components were hydraulic motors and pipings substituting the traditional components used. The relationship between the technical requirement and cutomer requirement indicated that the minor criteria manueavrability and stability were having extreme high relationship with the mass of the cutter header assembly.

Correlation between the technical requirements: The roof of HoQ is build with correlations between technical requirments as expalined in the step 5 in Section 3.4 and represented in the Fig. 4.13. Reel speed index since affecting the crop conveying operation signifies the performance of the cutterbar assembly, reel speed index is highly correlated with the cutterbar type.



Reel speed index	Cutterbar type	Mass density of the assembly	Reel type	Position and degree of freedom	Material of construction

Fig. 4.13 Roof of the House of Quality (HoQ)

Reel index varies according to the number of bats, i.e if number of revolutions increases, the reel speed index also increases. Hence the reel speed index is highly correlated with the reel type. Cutterbar type determines the mass of the assembly, hence they were correlated. Cutterbar type and reel type has to be selected so as to optimize the performance, hence the cutter bar type and reel type are correlated factors. Based on the reel type, position of asssembly has to be adjusted and reel type has inlfuence on mass density and material of construction. Hence these factors were correlated. Material of construction influences mass density highly, indicating the strong correlation. Aluminium is less in density whereas steel desnity is higher comparitively. Position of the assembly is affected by the mass density of the assembly due to the strong correlation. Other than reel type and cutterbar type, reel speed index has no other factors in correlation. These are the observation and inferences of the relationship between the technical requirements in the roof of the HoQ of the cutter header assembly design models.

Customer Rating: As per the procedure in Section 3.4 step 7 and 8, customer rating matrix and weighted customer rating matrix were formed (Appnedix XI). The rating ditribution and ranking of the design models discussed as follows.

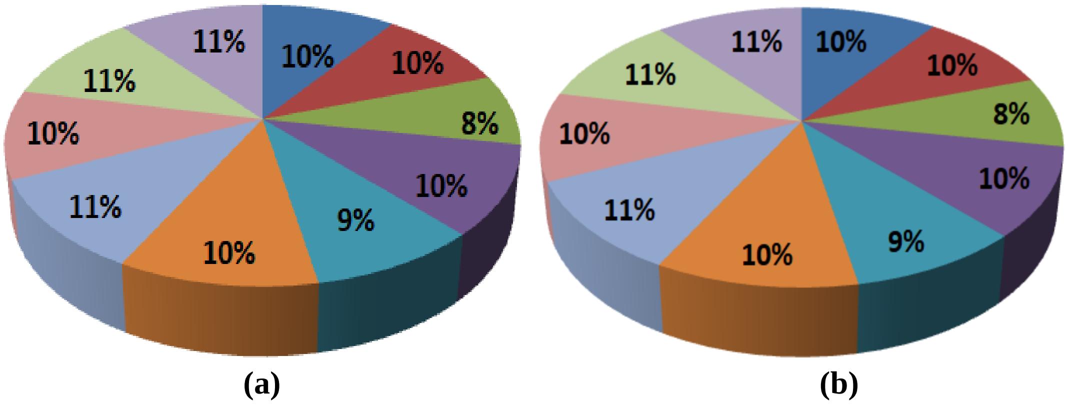


Fig. 4.14 Rating distribution on various criteria for (a) design I (Multiple bat reel system) and (b) design II (Single bat reel system)

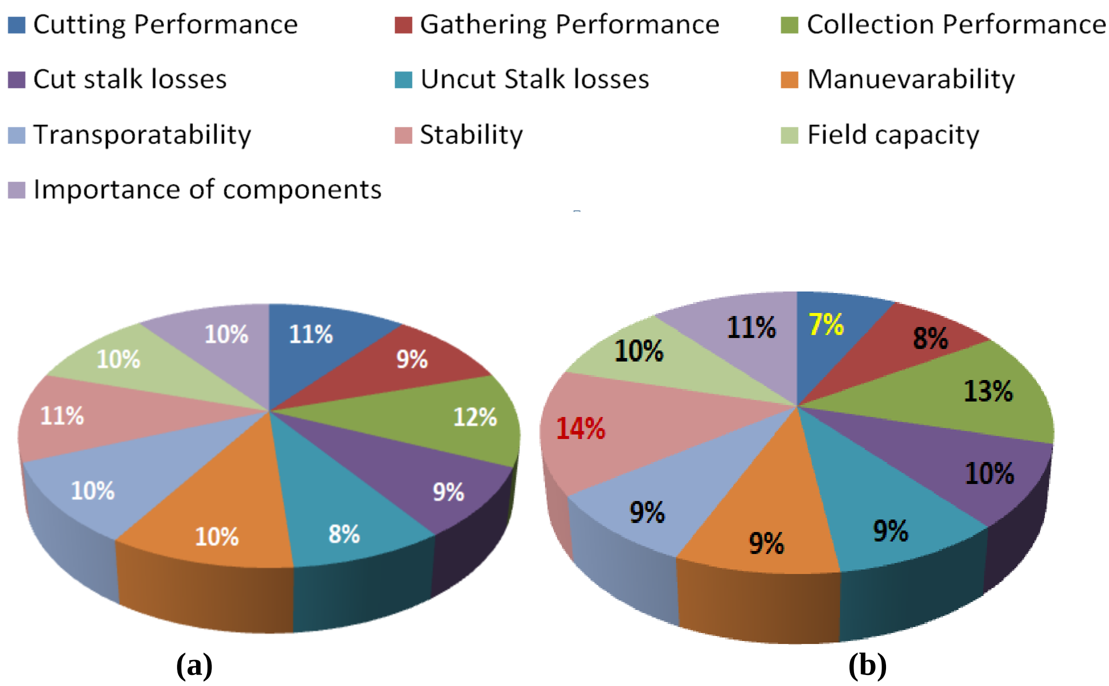


Fig. 4.15 Rating distribution on various criteria for (a) design III (Vertical axis bat reel system) (b) design IV (Floating type projected conveyor system)

Rating distribution among criteria: The rating distributions for each criterion under different design models are given as a pie chart in the Fig. 4.14 and 4.15.

The design models I and II as in Fig. 4.14 (a) and (b) showed that the criteria having more or less equal importance on the customer ratings. Collection performance with 8% tends to be slight lesser in importance. This indicated that collection performance has to be improved comparing other criteria in case of design I and II. In Fig. 4.15 (a), uncut stalk losses with 8% has least effect on ratings, indicating that the design III is less capable of handling uncut stalk losses. Fig. 4.15 (b) showed that stability (13%) and collection performance (14%) has highest importance on ratings inferred that, stability and collection performance were expected to be optimum in design IV. But the cutting (7%) and gathering performance (8%) has least importance and need improvements. The ranking of the different models based on customer ratings were given as Table No. 4.15 and Fig. 4.15.

Table No. 4.15 Customer rating based ranking of different design models

Model	Design I	Design II	Design III	Design IV
Total	126.72	180.74	105.10	129.40
Rank	2	1	4	3

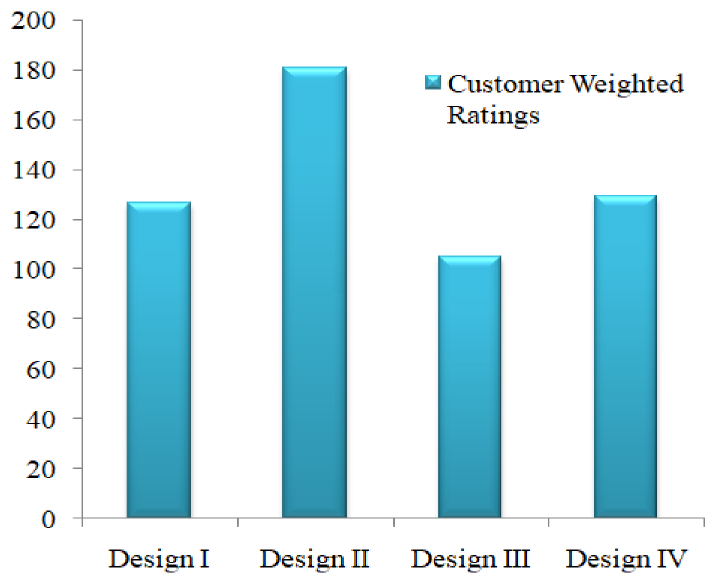


Fig. 4.16 Customer weighted ratings of different design models

QFD technique results presented in Table No. 4.15, based on customer ratings. The average value of minor criteria on customer ratings were multiplied with weights is given in the table in appendix XI. Design II followed by design I ranked highest.

4.4.1 Statistical Analysis

The statistical analysis of minor criteria results on different designed models were discussed as follows.

Table No. 4.16 ANOVA result of ratings on criteria with design models

S. No	Criteria	*p*	Significance
1.	Cutting Performance	0.0069	Significant
2.	Gathering Performance	0.0048	Significant
3.	Collection Performance	0.2530	Insignificant
4.	Cut stalk losses	0.0003	Significant
5.	Uncut Stalk losses	0.0097	Significant
6.	Manuevarability	0.0001	Significant
7.	Transportability	0.0001	Significant
8.	Stability	0.0016	Significant
9.	Field capacity	0.0003	Significant
10.	Importance of components	0.0015	Significant

From the Table No. 4.16, among 10 different minor criteria under 3 major criteria, Collection performance is the only criterion is insignificant in rating observations. This shows that the collection system has no major differences in performance among 4 different models to make a significant impact on the design of Pokkali paddy harvesting machine. On the other hand, in rating distribution chart (Fig. 4.15) says that collection performance of design IV (floating type with projected conveyor type system) is better comparing other criteria within the same design. Other criteria had significant differences on rating due to their design nature which is further analysed on Post Hoc – Tukey HSD (Honest Significant Difference) Test results (Table No. 4.17), which expresses the significance of each criterion on other criteria, individually for 4 models. Same as in ANOVA test result, post hoc test also shows that collection performance is insignificant with each and other criteria. But the other criteria show significant differences between the designs which are expressed in the Table No. 4.17. Design II (Single bat reel system is shows higher significant difference with design III and IV. But design I and design II has 40% of significant difference.

Table No. 4.17 Post Hoc – Tukey HSD Test result

S. No	Criterion	Design I	Design II	Design III	Design IV	Significance
1.	Cutting Performance	2.47^{ab}	3.47^{a}	2.18^{b}	1.76^{b}	Significant
2.	Gathering Performance	2.24^{ab}	3.35^{a}	1.94^{b}	2.00^{b}	Significant
3.	Collection Performance	2.47^{a}	2.82^{a}	2.35^{a}	3.12^{a}	Insignificant
4.	Cut stalk losses	2.12^{b}	3.53^{a}	1.76^{b}	2.24^{b}	Significant
5.	Uncut Stalk losses	2.29^{ab}	3.12^{a}	1.71^{b}	2.12^{ab}	Significant
6.	Manuevarability	2.59^{b}	3.65^{a}	2.06^{b}	2.06^{b}	Significant
7.	Transportability	2.59^{b}	3.65^{a}	2.06^{b}	2.00^{b}	Significant
8.	Stability	2.35^{cb}	3.53^{a}	2.24^{b}	3.35^{ac}	Significant
9.	Field capacity	2.82^{ab}	3.71^{a}	2.00^{b}	2.24^{b}	Significant
10.	Importance of components	2.71^{ab}	3.76^{a}	2.12^{b}	2.53^{b}	Significant

**Note: Presence of same alphabets in exponential of mean - Differences is insignificant,* *Presence of different alphabet in exponential of mean - Significant difference exists*

For example, the cutting performance in design II has exponential of ‘a’, design I has ‘ab’. Since the exponential terms in design I and II have same alphabet ‘a’ the difference between them are insignificant. But the design III and IV has exponential term ‘b’ which represent that significant difference exists between deign II, but design I has ‘ab’ containing alphabet ‘b’ also shows design and III and IV are insignificant with design I. In the same way other criteria can be observed for significance.

From the QFD analysis and statistical analysis, design I (Single bat reel system can be selected among other designs based on its ranking. Also design II (Multiple bat reel system) shows no significant difference much as per statistical analysis. Hence design II followed by design I are found to be feasible

4.4.2 Inferences

Design II was the selection from the QFD results and statistical analysis, and also experts suggested the same because of the lesser weight than any other model, simple actuation mechanism and compactness. Design II may have the problem of uneven rotational speed and vibration problems to maintain the reel index and the bat has to convey comparatively more number of plants than the design I. If the design II encounters such problems, alternatively design I can be considered. Hence the design I was the second option in selection. Design III is least preferred, may be because of the reason that the reel may gather and convey the crop mass into a bunch at a section of cutterbar which may create a clogging tension at the particular section of cutterbar. Also maintaining the stability is complicated, as the reel bats are supported from single end and rotate vertically. Design IV is preferred over the design III because of the higher performance in stability, but it is least preferred than design II and design I because adjustment of float position by the operator needs complex mechanism and also the model is not compact.

4.4.3 Finite Element Model (FEM) Analysis

FEM analysis was carried out on component of reel bat and tyne of design II (single bat reel type system) and reel bat of design I models' reel bat assembly as per the assumptions explained in section 3.4.1. The outer diameter was assumed 2 cm and different inner diameters of bat (hollow shaft) were tested for safe loading. The inner diameters tested were 10 mm, 15 mm, 14 mm. All three different diameters were found to be safe under the applied load. Hence a minimum thickness (3 mm) yielding diameter 14 mm to reduce the weight is selected. Materials out of aluminium and structural steel, aluminium has less weight density and more or less equal safety on loads. Hence aluminium hollow shaft with outer diameter 20 mm and inner diameter 14 mm can be selected. Fig. 4.17 and 4.18 gives the finite element analysis result observed with total deformation and equivalent (von-Mises) stress of the design II respectively. Fig. 4.19 and 4.20 gives the results of design model I.

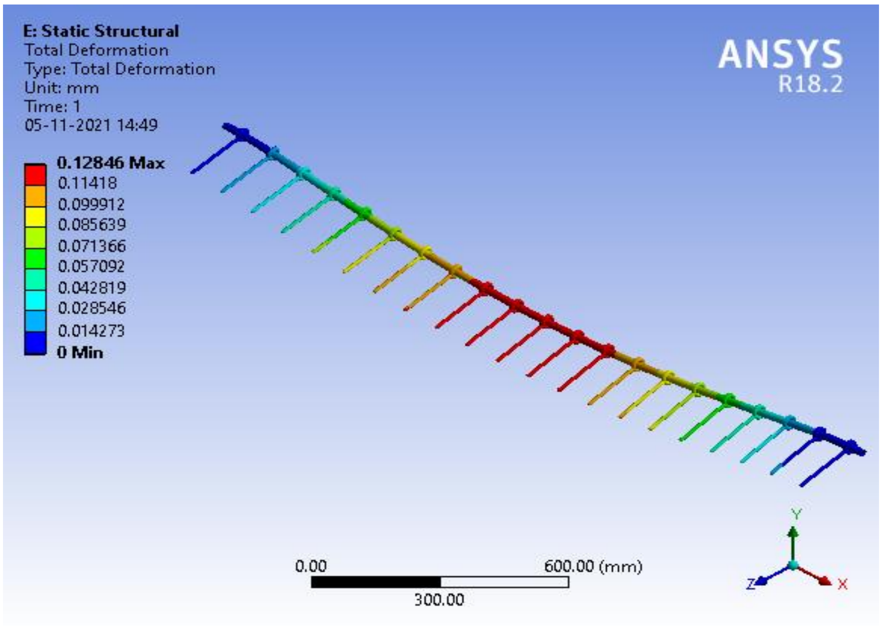


Fig. 4.17 FEM result window showing total deformation of bat and tyne of single bat reel assembly under applied parameters

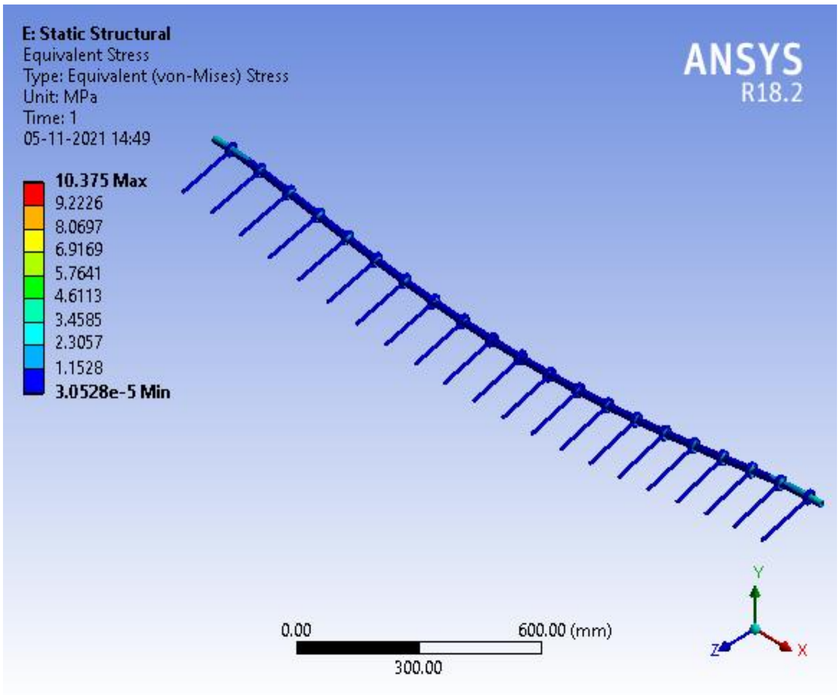


Fig. 4.18 FEM result window showing equivalent (von-Mises) stress of bat and tyne of single bat reel assembly under applied parameters

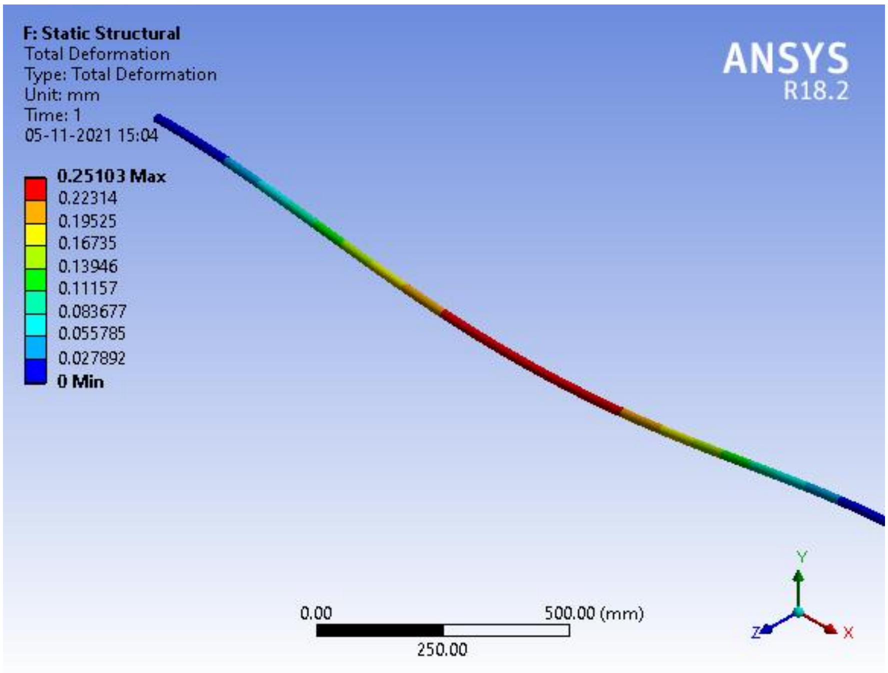


Fig. 4.19 FEM result window showing total deformation of bat of multiple bat reel assembly under applied parameters

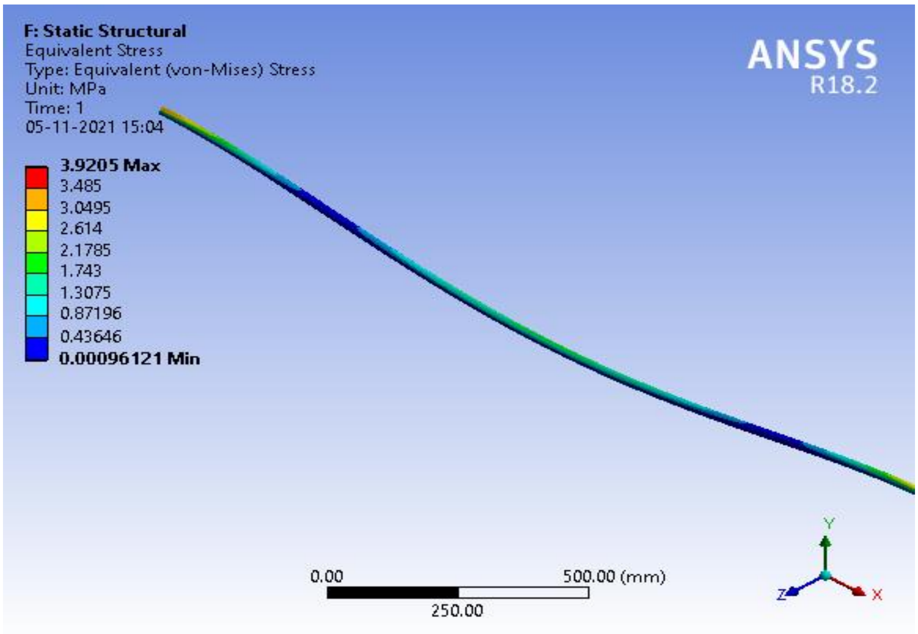


Fig. 4.20 FEM result window showing total deformation of bat of multiple bat reel assembly under applied parameters

From the QFD, statistical and finite element analysis, design II single bat reel system or alternatively the design I multiple bat reel system attached with Truxor DM 5045 were suggested. The Fig. 4.21 shows the suggested models of single bat reel system and specifications are provided in Table No. 4.18. The cutter bar of reciprocating type standard serrated with double shear operation and made of high carbon steel with nano coatings for corrosion resistance. The cutterbar has to work below the water surface. Reel is single bat type with elongated tyne made up of aluminium is suggested. The assembly has to be provided with provision for lifting and lowering in field.

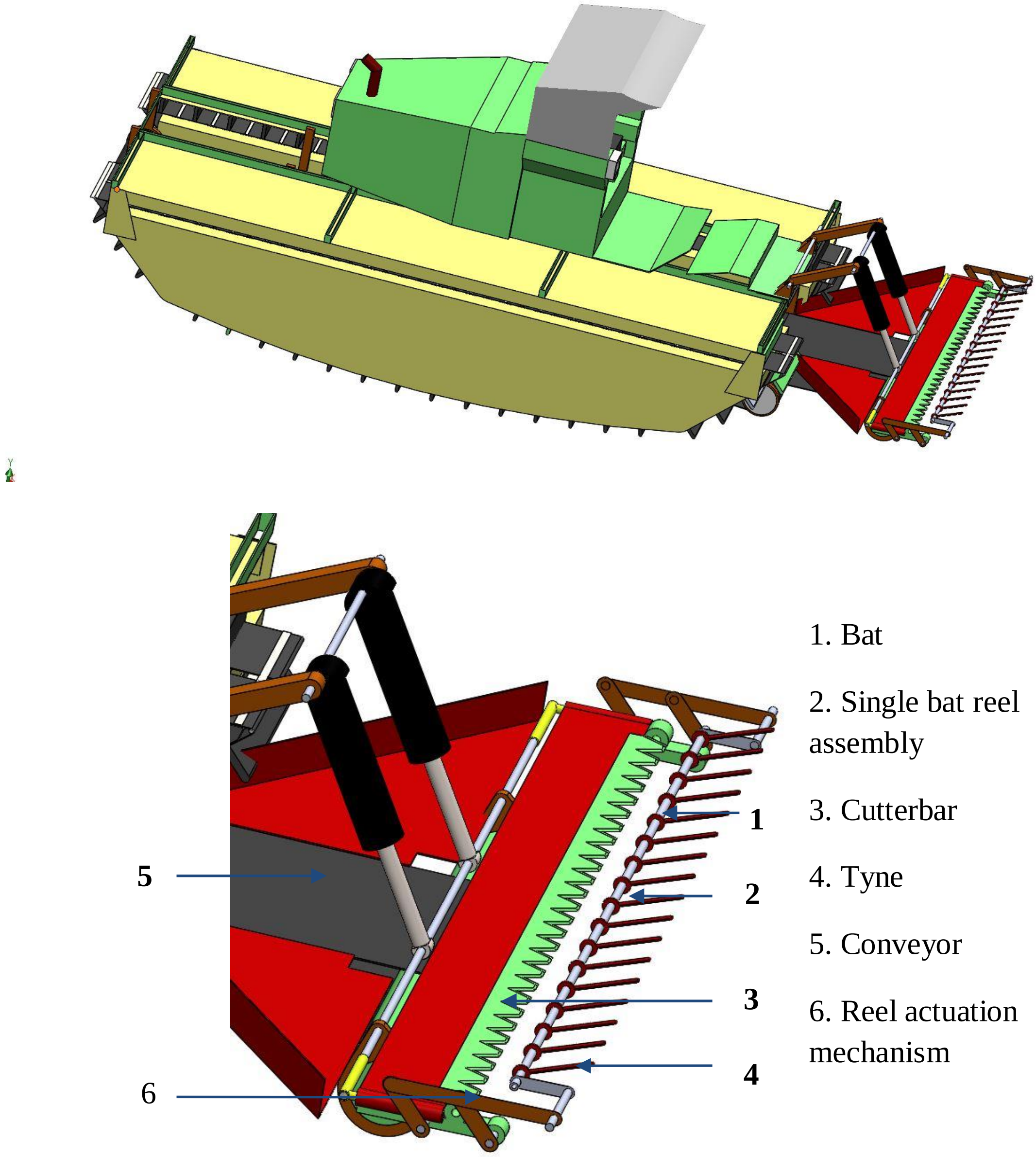


Fig. 4.21 Single bat reel model (Design II) – Selected from result analysis

Table No. 4.18 Specifications of suggested design model

S. No	Parameter	Range
1.	Approximate Dimensions of the machine	5.6 m Length 2.1 m Width 2.0 m Height
2.	Gathering System	Single bat type reel or Multiple bat reel
3.	Cutterbar	2.1 m width Serrated Standard type
4.	Stroke length	76.2 mm
5.	Cutterbar knife material	High Carbon Steel Nano coated corrosive resistance Double shear type
6.	Power for cutter header assembly	Hydraulic motor from hydraulic system
7.	Approximate mass of the machine	1.6 tonnes
8.	Approximate float capacity	1.6 m^3 each float

4.4.4 Future scope

In order to operate the machine in the smaller fields and cross the bunds without damage, this smaller sized machine will be more suitable than the existing machines. The smaller size machine with the corresponding sized cutter header assembly which was selected as per the previous discussion is suggested for further design, development and evaluation. Also the other features and components of the Truxor DM 5045 favouring the operation in marshy, water logged and dry fields has to be incorporated in the reduced size machine.

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CHAPTER V

SUMMARY AND CONCLUSION

Pokkali system of rice cultivation is a unique practice in central Kerala under a special natural ecosystem. The mechanization in the system was in emerging stage. Among the major cultivation operation in pokkali paddy farming system, harvesting is the drudgery involving and mechanization demanded operation with major problems such as labour shortage. Since it is in water stagnated condition throughout the year (one to five feet variation in water level), conventional combines cannot work and also threshing to be done after drying (two days). Amphibian natured machine was found suitable, further KAU Pokkali Paddy Harvester (Kelachandra Harvester) was designed and developed in Kerala Agricultural University. Another amphibian machine which is multipurpose utilization was imported from Sweden and suitably tried in the pokkali fields. Both the machines having their own drawbacks, new machine is expected. And this research was undertaken to carry out a design analysis on suitable cutter header assembly for the machine to be designed and developed.

The existing machines, KAU Pokkali Paddy Harvester and amphibian multipurpose machine (Truxor DM 5045) with weed harvester attachment were studied. The former one has more weight and large dimensions made the machine to be difficult in operations such as transportation and manuevarability in the pokkali fields having small area, small and weaker bunds. Later one has better stability and manuevarability, but the field capacity was found to be less and cutting performance were affecting the quality of the cut stalks in turn affects the collection and threshing operation. Hence to overcome the drawbacks of the machine, new modifications and designs are demanded. A computerized diagram of Truxor DM 5045 was made with Solidworks 2018.

A survey was conducted with the help of a questionnaire on farmers at Ernakulam and Alapuzha districts to collect information about the socio economic status, cultivation practices, mechanization demands, cost economics requirements in mechanical harvesting and technical aspects etc. The survey was conducted at respective farmer's fields, so as to observe the field conditions. A fishbone diagram or affinity diagram was prepared by brainstorming methods with the available data observed from the questionnaire results. The crop parameters such as yield, seed rate, cutting height, crop height, lodging conditions were observed. Indigenous varieties (*Chootu pokkali* and *Virippu*) and Vytilla varieties (*Vytilla 1* and *Vytilla 10)* seed samples were collected and plant density was calculated through 1000 seed weight and seed rate. Plant densities were calculated as 261, 218, 268 and 281 for *Chootu pokkali*, *Virippu, Vytilla 1* and *Vytilla 10* respectively. Field conditions were analysed with water level, harvesting water level and other engineering aspects. Soil and water properties important for the design of harvester are collected from the Rice Research Station, Vytilla. With this available data further design process was carried out for the cutter header assembly.

Using the softwares Solidworks 2018 and Microsoft Excel, four different designs were made and attached with the model of Truxor replacing the weed harvesting attachment. Design I was a multiple bat reel system, consisting of 4 bats with 0.25 m diameter. The cutterbar was reciprocating type standard knife section serrated and width of 2.1 m. The conveyor was assumed and conceptualized for taking and storing the cut crops. In design II, it was the single bat reel system, has a single bat type reel with longer tynes. The radius of gyration is 0.125 m actuated through double crank mechanism. The cutter bar was same as in design I for all the 4 designs. Conveyor conceptualization is same for the first three designs. Hydraulic motor operated from the hydraulic port in prime mover. Design III named vertical axis type reel system has vertically places two sets of bars (sets) on each sides of the assembly having 4 no. of bats on each bar. The bats have to be optimized with angles for better performance. The reel is powered by crank and pitman from the hydraulic motor. Design IV is a floating type projected conveyor type system is provided with two floats on each side to maintain the stability perfectly. Conveyor has projection on its surface and extends just below the cutterbar to few centimetres. There is no gathering system is added. All the designs were operated by the hydraulic system with different actuation mechanisms. Other specifications on each design were discussed individually. A power flow diagram is made to understand the flow of power from fuel to end component.

Energy input was calculated for the manual harvesting operation and mechanical harvesting with Truxor DM 5045 with newly designed cutter header assembly. Manual harvesting involves 585 MJ as input and mechanical harvesting involves 2460 MJ of input energy (direct energy of 2100 MJ and indirect energy of 360 MJ).

Selection of best model out of 4 different models was done by industrial engineering techniques. Out of various techniques, Quality Function Deployment (QFD) was selected suitably. The method involves 4 major phases. House of Quality (HoQ) building, Analytical Hierarchy Process (AHP), Questionnaire and survey, Result analysis. The procedure on QFD was studied in a detailed manner.

HoQ diagram consisted of Voice of Customers (VoC) which is customer requirement, technical requirements which satisfies VoC, relationship matrix which formed out of VoC and technical requirements, establishes the relationship level between them by values. Weightage of the different customer requirements are also founds a place in HoQ. Correlation matrix which is the roof the matrix gives the correlation between each and other technical requirements. Customer importance rating matrix is formed with VoC and different designs to have rating for designs based on different VoC. VoC is found from the questionnaire and survey already conducted giving fishbone diagram. Weightage on the VoC were found by a process called AHP. Technical requirements and its correlation matrix were given by the research team. Relationship matrix and customer importance rating was filled by questionnaire (English and Malayalam) and survey process as expert evaluation, conducted on expert individuals having experience and knowledge in pokkali system. This includes 19 different experts from farmers, ICAR institutes, KVKs, Rice Research Stations, Kerala Agricultural University and industries. The QFD results were analysed with weightage obtained out of AHP and questionnaire results.

Statistical tests were carried out on ratings received in customer importance rating from number of respondents in QFD process. Analysis of Variance (ANOVA) was carried out to know the significance existence on different ratings for various four designs with respect to ten customer requirements. Significance of each design on other is given by Post hoc Tukey HSD test. The results from QFD and statistical analysis were compared and inferred.

From QFD, design II has the first ranking followed by design I, design IV and lastly design III. From statistical analysis, design II and I doesn’t have significant difference on ratings, but design II has significant difference over design III and IV. Hence the design I and design II are found to be better in the view of statistical analysis, is comparable with QFD result showing design II and design I with first and second ranking respectively. The relationship matrix was formed and calculated to give rankings for technical requirements. Rating distribution on each design model with respect to customer requirements was studied to know the best and poor feature in each design. Correlation matrix formed and inferred for the correlation between each and other technical requirements. And important suggestions were observed from the experts on technical requirements such position of operation of assembly, material for cutterbar, cutterbar type etc.

It was concluded that design II and design I can be suggested for further testing and evaluation with Truxor DM 5045 with cutter header assembly of design II is suggested. FEM analyses were carried out on bat and tynes of design II and bat of design I for safe loading and determined the suitable diameters. The cutterbar material high carbon steel with anticorrosive coatings, other construction material on marine aluminium, optimized tyne dimensions on reel, cutterbar working below the water are the major suggestions for the new developing machine. Other parameters such as reel speed index, position of reel has to be field experimented and finalized. Since the efficiency is expected to be higher for the newly designed system for Truxor DM 5045 comparing existing attachment, the energy input for the new design is less than the existing design. A reduced size machine with same features as in Truxor DM 5045 is suggested for design, development and evaluation. Further development of the selected design models with design of conveying system can be carried out as an extension of this research to fulfil the demand of pokkali farmers and elimination of drudgery on pokkali paddy harvesting.

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Appendix I

Questionnaire for identifying the harvesting requirements and constraints

Kerala Agricultural University

Design Analysis of Cutter Header Assembly of Pokkali Paddy Harvester

<u>Questionnaire for Pokkali farmers</u>

Block: Village:
Date :

1. Socio-economic details of the farmer:

A. Name of the respondent :
B. Age :
C. Gender :
D. Address :

E. Contact number :
F. Educational qualification

a. Below SSLC ☐
b. SSLC ☐
c. Plus Two ☐
d. Diploma ☐
e. Degree ☐
f. Post graduation ☐

Specify (If any other)………………

G. Experience in Pokkali farming (Years) :
H. Is Pokkali Cultivation is continued from ancestors? :
I. Area under Pokkali out of total land holding :

<1 acre	**1-2 acres**	**2-5 acres**	**2-5 acres**	**Nil**
☐	☐	☐	☐	☐

2. Cropping pattern followed

____

3. Is your Pokkali field size reduced in last 5 years, if so area of reduction?

____

4. If reduced, the reduced land is now presently utilized for?

____

5. Crop details:

S. No.	**Variety**	**Area (acres)**	**Quantity produced (Kg)**	**Price realized Rs /Kg**	
				Current year	**Previous year**
1					
2					
3					
4					

Other crops/farming in the same field:

a) Fish ☐ b) Other ☐

6. Method of Seed bed preparation:

a) Continuous Mounds ☐ b) Hill mounds ☐ c) Ridges ☐

d) Simple Broadcasting ☐

7. Method of Sowing:

a) Direct broadcast ☐ b) Hill dropping + Transplanting ☐ c) Mound sowing + Transplanting ☐

8. Input requirement details:

A. Purchase of seed:

a) Self produced ☐
b) Research Stations ☐
c) Dept. of Agriculture ☐
d) Private agencies ☐

B. Whether you are getting any technical support?

Yes ☐ / No ☐

If yes, details of support:

S. No.	**Name of the institution**	**Kind of support**
1	Farmers association	
2	Dept. of Agriculture	
3	Government Institutions	
4	Farmer Producer Companies	
5	Others	

9. Production details:

A. Availability of labor:

a) Adequate ☐ b) Less than adequate ☐ c) Very less than adequate ☐

B. Skilled labor problem: Yes ☐ / No ☐

C. Did you experienced any kind of loss due to:

a) Climate ☐

b) Pest and diseases ☐

c) Government policy on pricing ☐

d) Labor shortage ☐

e) Lack of Mechanization ☐

f) Others ☐

D. Rank the constraints faced in Pokkali paddy cultivation (1 to 7):

S. No.	**Problems**	**Ranks**
1	Low yield	
2	High labour charge	
3	Scarcity of labour	
4	Climate change	
5	Unavailability of harvesting machine	
6	Unavailability of other machines	
7	Inadequate price	
8	Crop protection	
9	Decreasing demand	

E. In case of pest and disease, specify the kind and cause of attack:

____

F. In case of Lack of mechanization, specify the major operations requires urgent mechanization:

____

10. Harvesting Details:

A. Water level while harvesting?

<1 foot	**1-3 feet**	**3-5 feet**	**5-6 feet**	**1-6 feet**
☐	☐	☐	☐	☐

B. Mode of Harvest: Manual ☐ Boat ☐ Both ☐

C. In case of manual harvest, what is the level of submergence of human body in water?

Ankle	**Knee**	**Hip**	**Chest**	**Neck**
☐	☐	☐	☐	☐

D. In case of manual harvest, what is the level of sinkage in slurry?

Ankle	**Knee**	**Hip**
☐	☐	☐

E. Cutting Height of crop :

F. Cut crops to be carried in what mode?

Gunny bags	**Tied bundles**	**Tractor trailer**	**Other modes**
☐	☐	☐	☐

G. What was age category of majority of the harvest laborers?

18 - 30	**30 – 40**	**40 - 50**	**50 – 60**	**60 <**
☐	☐	☐	☐	☐

H. If harvesting machines on Pokkali Paddy is observed earlier, give details of the machine and opinion on the trial.

____

____

I. What is the expected storage required in harvester in a single pass in terms of acres?

0.25 acres	**0.5 acres**	**1 acre**	**>1 acre**
☐	☐	☐	☐

J. What range of rent is feasible for harvesting one acre with machine in rupees?

<1000	**1000 - 2500**	**2500 – 5000**	**>5000**
☐	☐	☐	☐

K. What is the acceptable loss on grains in mechanized harvest comparing manual harvest?

>50% ☐ **> 35** ☐ **>25%** ☐ **>10%** ☐

L. Is threshing to be done after drying? : Yes ☐ / No ☐

If yes, how many days after harvesting threshing to be done? :

M. Ranking of problems associated with harvesting operation in priority base?

Moving ☐ **Cutting** ☐ **Carrying** ☐ **Post work** ☐ **Atmosphere** ☐

11. Investment Details:

A. Did you avail any Loan /Subsidy? Yes ☐ / No ☐

B. If yes, source:

S. No	Particulars	Amount	Percentage on total cost	Interest rate (%)
1	Financial institutions (Banks)			
2	Cooperatives			
3	SHG			
4	Money lenders			
5	Government			
6	Others			

12. Labour and/or Machine charges

S. No.	Activities	Labour hours		Cost of labor/ day	Machine charges per hour
		Manual	Machine		
1	Land preparation				
2	Sowing				
3	Transplanting				
4	Intercultural operations (weeding)				
5	Harvesting				
6	Threshing				
7	Transportation				

13. Income details:

A. Source of income:

a. Pokkali Paddy alone
b. Pokkali Paddy + Prawn Farming
c. Prawn Farming alone
d. Pokkali System + Self employment/ Business/ Government job

Specify if any other: ___________________________

B. Annual income from Pokkali Paddy alone

<50,000	**50000-1 lakhs**	**1 lakhs - 1.5 lakhs**	**1.5 lakhs- 2 lakhs**	**>2 lakhs**
☐	☐	☐	☐	☐

C. Whether the entire produce produced during the season is marketed?

Yes ☐ / No ☐

D. What level you are getting prices for Pokkali Rice?

a) High ☐ b) Average ☐ c) Low ☐ d) No profit ☐ e) Loss ☐

14. Opinion about Pokkali Cultivation:

A. What is the reason to sustain in Pokkali Paddy cultivation?

a) Tradition ☐
b) Field situation (no other crop possible) ☐
c) To maintain Pokkali system ☐
d) Passionate about Pokkali ☐
e) Profit ☐

B. What are three major supports needed in priority for extending the cultivation area?

a) Harvest mechanization ☐
b) Crop protection aids ☐
c) Land preparation aids ☐
d) Transplanting mechanization ☐
e) Increased subsidy ☐
f) Hike in selling price ☐
g) High Yielding varieties ☐

Appendix II

Observations of 1000 Seed Weight and Number of seeds in 10 gm of Indigenous and Vytilla varieties of paddy in pokkali system

S. No	Trial	***Chootu pokkali***		***Chettivirippu***		***Vytilla 1***		***Vytilla 10***	
		1000 Seed Weight	**No. of seeds in 10 gm**	**1000 Seed Weight**	**No. of seeds in 10 gm**	**1000 Seed Weight**	**No. of seeds in 10 gm**	**1000 Seed Weight**	**No. of seeds in 10 gm**
1	Trial 1	28.10	351	32.50	280	27.98	353	25.95	370
2	Trial 2	29.30	346	34.00	296	28.16	357	25.98	380
3	Trial 3	27.10	339	36.20	299	28.01	355	25.99	378
4	Trial 4	28.90	352	35.30	289	27.96	357	26.15	379
5	Trial 5	29.50	341	34.95	281	28.16	361	26.09	366
6	Trial 6	29.35	349	35.60	279	27.85	349	26.04	374
7	Trial 7	29.90	350	33.10	290	28.02	365	26.18	379
8	Trial 8	28.95	340	34.00	301	28.11	355	26.05	372
9	Trial 9	29.95	356	36.10	297	28.01	360	26.05	372
10	Trial 10	27.95	352	33.00	285	27.94	354	25.98	373
Average		**28.80**	**348**	**34.50**	**290**	**28.02**	**357**	**26.05**	**375**

Appendix III

Reel Design Calculations

*Reel design calculation for Reel assembly of KAU Pokkali Paddy Harvester

S. No	Reel Index	Dia meter (m)	No. of Bats	Reel tip speed	Angular velocity (rad s^{-1})	RPM	Time per revolution (s)	Distance per revolution (m)	Area per revolution (m^2)	Staggered pitch (m)
1.	1.00	0.50	5	0.42	1.66	15.90	3.77	1.57	3.30	0.31
2.	1.25	0.50	5	0.52	2.08	19.87	3.02	1.26	2.64	0.25
3.	1.50	0.50	5	0.62	2.50	23.85	2.52	1.05	2.20	0.21
4.	1.70	0.50	5	0.71	2.83	27.03	2.22	0.92	1.94	0.18
5.	1.75	0.50	5	0.73	2.91	27.82	2.16	0.90	1.88	0.18
6.	2.00	0.50	5	0.83	3.33	31.80	1.89	0.79	1.65	0.16
7.	1.70	0.84*	5	0.71	1.68	16.09	3.73	1.55	3.26	0.31
8.	1.00	0.50	6	0.42	1.66	15.90	3.77	1.57	3.30	0.26
9.	1.25	0.50	6	0.52	2.08	19.87	3.02	1.26	2.64	0.21
10.	1.50	0.50	6	0.62	2.50	23.85	2.52	1.05	2.20	0.17
11.	1.75	0.50	6	0.73	2.91	27.82	2.16	0.90	1.88	0.15
12.	2.00	0.50	6	0.83	3.33	31.80	1.89	0.79	1.65	0.13
13.	1.00	0.25	4	0.42	3.33	31.80	1.89	0.79	1.65	0.20
14.	1.25	0.25	4	0.52	4.16	39.75	1.51	0.63	1.32	0.16
15.	1.50	0.25	4	0.62	4.99	47.69	1.26	0.52	1.10	0.13
16.	1.75	0.25	4	0.73	5.82	55.64	1.08	0.45	0.94	0.11
17.	2.00	0.25	4	0.83	6.66	63.59	0.94	0.39	0.82	0.10
18.	1.00	0.50	4	0.42	1.66	15.90	3.77	1.57	3.30	0.39
19.	1.50	0.50	4	0.62	2.50	23.85	2.52	1.05	2.20	0.26
20.	2.00	0.50	4	0.83	3.33	31.80	1.89	0.79	1.65	0.20
21.	1.00	0.25	1	0.42	3.33	31.80	1.89	0.79	1.65	0.79
22.	1.20	0.25	1	0.50	3.99	38.16	1.57	0.65	1.37	0.65
23.	1.50	0.25	1	0.62	4.99	47.69	1.26	0.52	1.10	0.52
24.	2.00	0.25	1	0.83	6.66	63.59	0.94	0.39	0.82	0.39

Torque and Power Calculation

For a 4 bat and single bat reel, the power requirement is calculated as follows

S. No	Mass of the reel (kg)	RPM	Angular Velocity (rad s^{-1})	Radius of gyration (m)	Torque (N m)	Power (W)
1.	25	15	1.57	0.125	0.5	0.8
2.	25	25	2.62	0.125	1.3	3.5
3.	25	35	3.66	0.125	2.6	9.6
4.	25	45	4.71	0.125	4.3	20.4
5.	25	55	5.76	0.125	6.5	37.3
6.	25	65	6.80	0.125	9.0	61.5
7.	50	15	1.57	0.125	1.0	1.5
8.	50	25	2.62	0.125	2.7	7.0
9.	50	35	3.66	0.125	5.2	19.2
10.	50	45	4.71	0.125	8.7	40.8
11.	50	55	5.76	0.125	12.9	74.5
12.	50	65	6.80	0.125	18.1	123.0
13.	75	15	1.57	0.125	1.4	2.3
14.	75	25	2.62	0.125	4.0	10.5
15.	75	35	3.66	0.125	7.9	28.8
16.	75	45	4.71	0.125	13.0	61.2
17.	75	55	5.76	0.125	19.4	111.8
18.	75	65	6.80	0.125	27.1	184.5
19.	100	15	1.57	0.125	1.9	3.0
20.	100	25	2.62	0.125	5.3	14.0
21.	100	35	3.66	0.125	10.5	38.4
22.	100	45	4.71	0.125	17.3	81.6
23.	100	55	5.76	0.125	25.9	149.0
24.	100	65	6.80	0.125	36.2	246.0

Appendix IV

Analytical Hierarchy Process

AHP Pair wise comparison matrix on harvesting performance

	Cutting Performance	Gathering Performance	Collection & Conveying	Cut Stalk losses	Uncut stalk losses
Cutting Performance	1				
Gathering Performance		1			
Collection & Conveying			1		
Cut Stalk losses				1	
Uncut stalk losses					1

AHP Pair wise comparison matrix on Machine Performance

	Manuevarability	Transportability	Stability	Field capacity
Manuevarability	1			
Transportability		1		
Stability			1	
Field capacity				1

Random index Table for AHP

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Appendix V

Relationship matrix for QFD

S. No	Factors	Reel index	Material of Construction	Cutter bar type	Mass of the assembly	Reel type	Position & degrees of freedom
1	Cutting Performance						
2	Gathering Performance						
3	Collection Performance						
4	Cut stalk losses						
5	Uncut stalk losses						
6	Manuevarability						
7	Transportability						
8	Stability						
9	Field Capacity						
10	Importance of components						

Appendix VI

Customer Rating on Different designs

S. No	**Customer requirement**	**Factors**	**Multiple bat model, Design I**	**Single bat model, Design II**	**Vertical axis gathering, Design III**	**Floating type with projected conveyor Design IV**
1	Harvesting Performance	Cutting Performance				
2		Gathering Performance				
3		Collection Performance				
4		Cut stalk losses				
5		Uncut stalk losses				
6	Machine Performance	Manuevarability				
7		Transportability				
8		Stability				
9		Field capacity				
10	Component Evaluation	Importance of Components				

Appendix VII

Questionnaire for Quality Function Deployment Method – Expert Committee Evaluation

Kerala Agricultural University

Design Analysis of Pokkali Paddy Harvester – Cutter Header Assembly

1. General Details

A. Name of the respondent :

B. Profession :

C. Age :

D. Gender :

E. Contact number :

F. Address :

2. Relative Weightage determination - Analytical Hierarchy Process

A. Harvesting Performance

	Cutting	Gathering	Collection & Conveying	Cut Stalk losses	Uncut stalk losses
Cutting	1				
Gathering		1			
Collection & Conveying			1		
Cut Stalk losses				1	
Uncut stalk losses					1

B. Machine Performance

	Manuevarability	Transportability	Stability	Field Capacity
Manuevarability	1			
Transportability		1		
Stability			1	
Field Capacity				1

3. Give the Yes/No questions. If so 'Yes', what is the relationship ranking (0/1/3/5/7/9)

Cutting

1. Whether cutting is influenced by reel speed? Yes ☐ / No ☐ _______

2. Whether cutter bar knife material influences cutting? Yes ☐ / No ☐ _______

3. What is the influence level of cutterbar type on cutting? _________

4. Does reel type influences cutting? Yes ☐ / No ☐ _________

5. What is the influence of position of cutter bar on cutting? __________

Gathering

1. What is the influence level of reel speed on gathering? _______

2. Whether pick up tynes influences gathering? Yes ☐ / No ☐ _______

3. What is the influence level of reel type on gathering? _________

4. What is the influence of position of reel in gathering? __________

Conveying & Collection

1. What is the influence level of reel speed on collection and conveying? _______

2. Whether cutterbar type and material influences gathering? Yes ☐ / No ☐ _______

3. What is the influence level of reel type on collection & conveying? _________

Cut stalk losses

1. Whether reel properties influence cut stalk losses? Yes ☐ / No ☐ _______

2. Whether cutter bar properties influences cut stalk losses? Yes ☐ / No ☐ _______

3. Whether position influences cut stalk losses? Yes ☐ / No ☐ _______

Uncut stalk losses

1. Whether reel properties influence uncut stalk losses? Yes ☐ / No ☐ _______

2. Whether cutter bar properties influences uncut stalk losses? Yes ☐ / No ☐ _______

3. Whether position influences uncut stalk losses? Yes ☐ / No ☐ _______

Manuevarability

1. Whether reel type influences manuevarability? Yes ☐ / No ☐ _______
2. Whether position influences manuevarability? Yes ☐ / No ☐ _______
3. Whether material of construction influences manuevarability? Yes ☐ / No ☐ _______
4. Whether mass of the assembly influences the manuevarability? Yes ☐ / No ☐ _______

Transportability

1. Whether position influences transportability? Yes ☐ / No ☐ _______
2. What is level of influence in material of construction in transportability? _______

Stability

1. What is level of influence in material of construction in stability? _______
2. Whether position influences stability? Yes ☐ / No ☐ _______
3. What is level of influence in mass of the assembly in stability? _______

Field capacity

1. What is the level of influence of reel and cutterbar type in field capacity? ________
2. Whether reel index influences field capacity? Yes ☐ / No ☐ _______
3. Whether positions influence field capacity? Yes ☐ / No ☐ _______

Component Evaluation

1. Whether reel is important on gathering? Yes ☐ / No ☐ _______
2. If not reel, can any other gathering mechanism is required? Yes ☐ / No ☐ _______
3. What type of cutter bar to be used? What is the level of importance on type of cutterbar type? Reciprocating ☐ / Scissor ☐ _______
4. What material for knife can be suggested and what level of impact it have on the machine? ______ _______
5. Where the position of assembly to be applied?

   Above the water ☐ At the level of water ☐ Below the water surface ☐

   Importance level of maintaining position? __________
6. What will be the reel index for best performance? __________

   Importance level of maintaining reel index? ________

4. Rating from 1 to 5

S. No	Customer requirement	Factors	Multiple bat model, Design I	Single bat model, Design II	Vertical axis gathering, Design III	Floating type model, Design IV
1	Harvesting Performance	Cutting Performance				
2		Gathering Performance				
3		Collection Performance				
4		Cut stalk losses				
5		Uncut stalk losses				
6	Machine Performance	Manuevarability				
7		Transportability				
8		Stability				
9		Field capacity				
10	Component Evaluation	Importance of Components				

Appendix VIII

Malayalam Version of Questionnaire in Appendix VII

കേരള കാർഷിക സർവകലാശാല
കേളപ്പജി കോളേജ് ഓഫ് അഗ്രികൾച്ചറൽ എഞ്ചിനീയറിംഗ്
ആൻഡ് ടെക്നോളജി, തവനൂർ, മലപ്പുറം

പൊക്കാളി പാഡി ഹാർവെസ്റ്ററിന്റെ ഡിസൈൻ വിശകലനം - കട്ടർ ഹെഡർ അസംബ്ലി

ചോദ്യാവലി

1. പേര് :
2. തൊഴിൽ :
3. പ്രായം :
4. ലിംഗഭേദം :
5. മൊബൈൽ നമ്പർ :
6. വിലാസം :

വിളവെടുപ്പ് പ്രകടനം

	കട്ടിംഗ്	ഒത്തുചേരൽ	ശേഖരണവും കൈമാറ്റവും	മുറിക്കുക തണ്ട് നഷ്ടം	മുറിക്കാത്ത തണ്ടിന്റെ നഷ്ടം
കട്ടിംഗ്	1				
ഒത്തുചേരൽ		1			
ശേഖരണവും കൈമാറ്റവും			1		
മുറിച്ച തണ്ടുകളുടെ നഷ്ടം				1	
മുറിക്കാത്ത തണ്ടിന്റെ നഷ്ടം					1

മെഷീൻ പ്രകടനം				
	കൈകാര്യം ചെയ്യൽ	ഗതാഗതക്ഷമത	സ്ഥിരത	ഫീൽഡ് ശേഷി
കൈകാര്യം ചെയ്യൽ	1			
ഗതാഗതക്ഷമത		1		
സ്ഥിരത			1	
ഫീൽഡ് ശേഷി				1

3. അതെ/ഇല്ല ചോദ്യങ്ങൾ നൽകുക. അങ്ങനെയാണെങ്കിൽ 'അതെ', ബന്ധങ്ങളുടെ റാങ്കിംഗ് എന്താണ് (0/1/3/5/7/9)

കട്ടിംഗ്

1. മുറിക്കുന്നത് റീൽ വേഗതയെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ ഇല്ല _______
2. കട്ടർ ബാർ കത്തി മെറ്റീരിയൽ കട്ടിംഗിനെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ ഇല്ല _______
3. മുറിക്കുന്നതിൽ കട്ടർബാർ തരത്തിന്റെ സ്വാധീന നില എന്താണ്?
____
4. റീൽ തരം കട്ടിംഗിനെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല _________
5. മുറിക്കുന്നതിൽ കട്ടർ ബാറിന്റെ സ്ഥാനത്തിന്റെ സ്വാധീനം എന്താണ്? _________

ഒത്തുചേരൽ

1. ശേഖരിക്കുന്നതിൽ റീൽ വേഗതയുടെ സ്വാധീന നില എത്രയാണ്?
____
2. പിക്കപ്പ് ടെയിനുകൾ ശേഖരിക്കുന്നതിനെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല _______
3. ശേഖരിക്കുന്നതിൽ റീൽ തരത്തിന്റെ സ്വാധീന നില എന്താണ്?
____
4. ശേഖരിക്കുന്നതിൽ റീലിന്റെ സ്ഥാനത്തിന്റെ സ്വാധീനം എന്താണ്?
____

കൈമാറലും ശേഖരണവും

1. ശേഖരണത്തിലും കൈമാറ്റത്തിലും റീൽ വേഗതയുടെ സ്വാധീന നില എത്രയാണ്?
____

2. കട്ടർബാർ തരവും മെറ്റീരിയലും ശേഖരിക്കുന്നതിനെ സ്വാധീനിക്കുന്നുണ്ടോ? അതെ അല്ല

____

3. ശേഖരണത്തിലും കൈമാറ്റത്തിലും റീൽ തരത്തിന്റെ സ്വാധീന നില എന്താണ്?

____

മുറിച്ച തണ്ടുകളുടെ നഷ്ടം

1. റീൽ പ്രോപ്പർട്ടികൾ തണ്ടിന്റെ നഷ്ടം കുറയ്ക്കുമോ?
അതെ/ഇല്ല ______

2. കട്ടർ ബാർ പ്രോപ്പർട്ടികൾ തണ്ടുകളുടെ നഷ്ടം കുറയ്ക്കുന്നുണ്ടോ? അതെ അല്ല

____

3. സ്ഥാന സ്വാധീനങ്ങൾ തണ്ടിന്റെ നഷ്ടം കുറയ്ക്കുമോ? അതെ/ഇല്ല

____

മുറിച്ച തണ്ടുകളുടെ നഷ്ടം

1. റീൽ പ്രോപ്പർട്ടികൾ വെട്ടാത്ത തണ്ടിന്റെ നഷ്ടത്തെ സ്വാധീനിക്കുമോ? അതെ/ഇല്ല ______

2. കട്ടർ ബാർ പ്രോപ്പർട്ടികൾ വെട്ടാത്ത തണ്ടിന്റെ നഷ്ടത്തെ സ്വാധീനിക്കുന്നുണ്ടോ? അതെ/ഇല്ല ______

3. സ്ഥാനം വെട്ടാത്ത തണ്ടിന്റെ നഷ്ടത്തെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

കൈകാര്യം ചെയ്യൽ

1. റീൽ തരം മാനുവറബിലിറ്റിയെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

2. സ്ഥാനം മാനുവറബിലിറ്റിയെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

3. നിർമ്മാണ സാമഗ്രികൾ മാനുവറബിലിറ്റിയെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

4. ബഹുജന സാന്ദ്രത മാനുവറബിലിറ്റിയെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

ഗതാഗതക്ഷമത

1. സ്ഥാനം ഗതാഗതത്തെ സ്വാധീനിക്കുന്നുണ്ടോ?
അതെ/ഇല്ല ______

2. ഗതാഗതയോഗ്യതയിലെ നിർമ്മാണ സാമഗ്രികളുടെ സ്വാധീന നില എന്താണ്?

____

സ്ഥിരത

1. സ്ഥിരതയുടെ നിർമ്മാണ സാമഗ്രികളിൽ സ്വാധീനത്തിന്റെ അളവ് എന്താണ്? _______

2. സ്ഥാനം സ്ഥിരതയെ സ്വാധീനിക്കുന്നുണ്ടോ? അതെ/ഇല്ല _______

3. സ്ഥിരതയിലെ ബഹുജന സാന്ദ്രതയിലെ സ്വാധീന നില എന്താണ്? _______

ഫീൽഡ് ശേഷി

1. ഫീൽഡ് കപ്പാസിറ്റിയിൽ റീൽ, കട്ടർബാർ തരം എന്നിവയുടെ സ്വാധീന നില എത്രയാണ്? _______

2. റീൽ സ്പീഡ് ഇൻഡക്സ് ഫീൽഡ് കപ്പാസിറ്റിയെ സ്വാധീനിക്കുന്നുണ്ടോ? അതെ/ഇല്ല _______

3. സ്ഥാനങ്ങൾ ഫീൽഡ് ശേഷിയെ സ്വാധീനിക്കുന്നുണ്ടോ? അതെ/ഇല്ല _______

ഘടകം വിലയിരുത്തൽ:

1. ശേഖരിക്കുന്നതിൽ റീൽ പ്രധാനമാണോ? അതെ/ഇല്ല _______

2. റീൽ ഇല്ലെങ്കിൽ, മറ്റേതെങ്കിലും ശേഖരണ സംവിധാനം ആവശ്യമുണ്ടോ? അതെ/ഇല്ല _______

3. ഏതുതരം കട്ടർ ബാർ ഉപയോഗിക്കണം? കട്ടർബാർ തരത്തിന്റെ പ്രാധാന്യത്തിന്റെ അളവ് എന്താണ്? പരസ്പരം / കത്രിക _______

4. കത്തിക്ക് എന്ത് മെറ്റീരിയൽ നിർദ്ദേശിക്കാനാകും, അത് മെഷീനിൽ എത്രത്തോളം സ്വാധീനം ചെലുത്തുന്നു? _______

5. അസംബ്ലി സ്ഥാനം എവിടെയാണ് പ്രയോഗിക്കേണ്ടത്?
ജലത്തിന് മുകളിൽ ജലനിരപ്പിൽ ജലത്തിന്റെ ഉപരിതലത്തിന് താഴെ സ്ഥാനം നിലനിർത്തുന്നതിന്റെ പ്രാധാന്യം? _______

6. മികച്ച പ്രകടനത്തിന് റീൽ സ്പീഡ് ഇൻഡക്സ് എന്തായിരിക്കും?_______
റീൽ സ്പീഡ് സൂചിക നിലനിർത്തുന്നതിന്റെ പ്രാധാന്യം? _______

(1 മുതൽ 5 വരെ റേറ്റിംഗ്)

S. No	ആവശ്യകതകൾ	ഘടകങ്ങൾ	വെയിറ്റേജ് (1 to 10)	4 ബാർ	ഒറ്റ ബാർ	ലംബ അക്ഷ തരം	ഫ്ലോട്ടിംഗ് തരം
1	വിളവെടുപ്പ് പ്രകടനം	കട്ടിംഗ് പ്രകടനം					
2		ഒത്തുചേരൽ					
3		ശേഖരണവും കൈമാറ്റവും					
4		മുറിച്ച തണ്ടുകളുടെ നഷ്ടം					
5		മുറിക്കാത്ത തണ്ടിന്റെ നഷ്ടം					
6	മെഷീൻ പ്രകടനം	കൈകാര്യം ചെയ്യൽ					
7		ഗതാഗതക്ഷമത					
8		സ്ഥിരത					
9		ഫീൽഡ് ശേഷി					
10	ഘടകം വിലയിരുത്തൽ	ഘടകങ്ങളുടെ പ്രാധാന്യം					

Appendix IX

List of Core Committee Experts

S.No	Name	Designation
		Farmers
1.	**V N Rajendran**	Manimandiram, Ezhikkara, **+919961169780**
2.	**M S Ratheesh**	Meppillil (H), Kedamangalam, Ezhikkara, **+919895833900**
3.	**K M Vincent**	Kodiyanthara, Ezhikkara, **+919947844584**
4.	**Justin Thomas**	Chiriya Pattaparambil, Moolampally, Kochi, **+918086081791**
5.	**E D Xavier**	Earathara house, Pizhala, Kochi, **+919495467813**
6.	**E R David**	Edathil house, Pizhala, Kochi 27, **+919447576204**
7.	**Raju V**	Chaukri kandam home, Ezhupunna,Alapuzha, +**916380489282**
8.	**Sajeevan S**	Thekkemudi, Ezhupunna, Alapuzha, **+919500586988**
		Scientists
9.	**Dr Jayan P R**	Professor & Head, Department of Farm Machinery & Power Engineering, KCAET, KAU, Tavanur. **+919447301928**
10.	**Dr Manoj Mathew**	Professor (Farm Machinery & Power Engineering), Rice Research Station, KAU, Moncompu. **+919447939705**
11.	**Er Sindhu Bhaskar**	Assistant Professor, Department of Farm Machinery & Power Engineering, KCAET, KAU, Tavanur. **+919475382218**
12.	**Dr T Senthil kumar**	Principal Scientist (Farm Power & Machinery), ICAR Central Institute of Agricultural Engineering, Regional centre, Coimbatore. **+919842955606**
13.	**Dr Deepa Thomas**	Assistant Professor, Rice Research Station, KAU, Vytilla. **+919446605795**
14.	**Dr Shinoj Subramaniam**	Senior Scientist & Head, KVK, Narakkal, Ernakulam , **+919496303457**
15.	**Er Sanju Sukumaran**	Assistant Professor, Department of Farm Machinery & Power Engineering, KCAET, KAU, Tavanur, **+919809339875**

Experts from related field		
16.	**Ms Saritha Mohan J**	Agricultural Officer, Krishi bhavan, Ezhikkara – 683513, **+919447895501**
17.	**Er Shareesh P**	Design Engineer, Rennaissance Power Products Pvt Ltd (Bheem), Coimbatore, **+919003900445**
18.	**Dr Edwin**	Teaching Assistant, Department of Farm Machinery & Power Engineering, KCAET, KAU, Tavanur. **+918907780447**
19.	**Dr Rajesh**	Teaching Assistants, Department of Farm Machinery & Power Engineering, KCAET, KAU, Tavanur. **+919995223553**

Appendix X

Weighted Relationship matrix for QFD

S. No	Criteria	Reel index	Material of construction	Cutter bar type	Mass of the assembly	Reel type	Position & degree of freedom
1	Cutting Performance	5.10	11.51	10.93	0.00	5.54	12.39
2	Gathering Performance	23.56	0.00	0.00	0.00	21.99	26.31
3	Collection Performance	2.31	0.81	0.81	0.00	2.04	0.00
4	Cut stalk losses	5.27	6.92	6.92	0.00	5.27	7.02
5	Uncut Stalk losses	13.78	18.17	18.17	0.00	13.78	22.55
6	Manuevarability	0.00	4.41	0.00	14.71	9.24	9.87
7	Transportability	0.00	3.68	0.00	0.00	0.00	3.39
8	Stability	0.00	46.64	0.00	52.94	0.00	52.31
9	Field capacity	5.87	0.00	7.80	0.00	7.80	4.56
10	Importance of components	62.00	81.00	88.00	0.00	55.00	94.00
	Total	**117.9**	**173.15**	**132.63**	**67.65**	**120.6**	**232.41**
	Rank	5	2	3	6	4	1
	Weighted Percentage	13.9 %	20.5 %	15.7 %	8.0 %	14.2 %	27.5 %

Appendix XI

Weighted Rating matrix for QFD

S. No	Criteria	Design I	Design II	Design III	Design IV
1	Cutting Performance	6.12	8.60	5.39	4.37
2	Gathering Performance	14.92	22.38	12.96	13.35
3	Collection Performance	1.90	2.17	1.81	2.40
4	Cut stalk losses	3.72	6.20	3.10	3.93
5	Uncut Stalk losses	12.21	16.60	9.08	11.27
6	Manuevarability	9.24	13.03	7.35	7.35
7	Transportability	2.53	3.57	2.01	1.96
8	Stability	25.21	37.82	23.95	35.93
9	Field capacity	4.86	6.38	3.44	3.85
10	Importance of components	46.00	64.00	36.00	45.00
	Total	**126.72**	**180.74**	**105.10**	**129.40**
	Rank	**2**	**1**	**4**	**3**

DESIGN ANALYSIS OF SUITABLE CUTTER HEADER ASSEMBLY FOR POKKALI PADDY HARVESTER

By

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ABSTRACT

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2021

DESIGN ANALYSIS OF SUITABLE CUTTER HEADER ASSEMBLY FOR POKKALI PADDY HARVESTER

ABSTRACT

Pokkali system of rice cultivation is a unique farming under pokkali ecosystem prevalent exclusively in central Kerala. Harvesting of paddy in pokkali is to be carried out under stagnated water level which may raise upto five feet. Hence a research was undertaken to design a suitable cutter header assembly for the harvester, as other existing harvesting machines can't be used in pokkali fields. Existing machines were studied and their drawbacks were identified. Four different designs of cutter header assembly models were made suiting an existing amphibian weed harvester (Truxor DM 5045). The four design models were design I (multiple bat reel system), design II (single bat reel system), design III (vertical axis reel system) and design IV (floating assembly with projected conveyor system). Selection of the best model out of these four was carried out by Quality Function Deployment (QFD) Technique along with Analytical Hierarchy Process (AHP) as a sub process, statistical analysis with expert ratings on models and Finite Element Analysis (FEM) on components suspected to failure of the selected models. All the results were collectively analysed and design II (single bat reel system) was selected. Also the design I (multiple bat reel system) can be an alternative as per statistical analysis. The single bat reel type system consists of single bat reel with elongated tynes. The corrosion resistant standard type cutterbar is finalized. Other specifications such as position of assembly, material of construction, dimensions etc were discussed in detail. Further the design, development and evaluation are suggested on the selected models with reduced size machine with same features and components as in Truxor DM 5045 (Amphibian weed harvesting machine).

Keywords: *Pokkali system of paddy cultivation; pokkali paddy harvester; Harvest mechanization; Cutter header assembly; Reel.*

പൊക്കാളി വിളവെടുപ്പിന് യോഗ്യമായ കൊയ്ത്തുയന്ത്രത്തിന്റെ കട്ടർ-ഹെഡ്ഡർ അസ്സംബ്ളിയുടെ രൂപകല്പനാ വിശകലനം

എഴുതിയത്

രത്തിനവേൽ, എസ്

രത്നച്ചുരുക്കം

ബിരുദലഭ്യതയുടെ ഭാഗിക ആവശ്യത്തിനായി സമർപ്പിയ്ക്കുന്നു

മാസ്റ്റർ ഓഫ് ടെക്നോളോജി
അഗ്രിക്കൾച്ചുറൽ എഞ്ചിനീയറിംഗ് (ഫാം മെഷീനറി ആൻഡ് പവർ എഞ്ചീനീയറിംഗ്)
ഫാക്കൽട്ടീ ഓഫ് അഗ്രിക്കൾച്ചുറൽ എഞ്ചിനീയറിംഗ് ആൻഡ് ടെക്നോളജി
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കേളപ്പജി കോളേജ് ഓഫ് അഗ്രിക്കൾച്ചുറൽ എഞ്ചിനീയറിംഗ് ആൻഡ് ടെക്നോളോജി, തവനൂർ, കേരളം, ഇൻഡ്യ

2021

പൊക്കാളി വിളവെടുപ്പിന് യോഗ്യമായ കൊയ്ത്തുയന്ത്രത്തിന്റെ കട്ടർ-ഹെഡ്ഡർ അസ്സംബ്ളിയുടെ രൂപകല്പനാ വിശകലനം

മധ്യകേരളത്തിൽ സമുദ്രനിരപ്പിനുതാഴെയുള്ള പ്രത്യേക ആവാസവ്യവസ്ഥയിൽ അവലംബിച്ചുവരുന്ന കൃഷിരീതിയാണ് പൊക്കാളി. വളരെയധികം പ്രതിരോധശേഷിയുള്ള, ലവണാംശം ഉള്ള മണ്ണിൽ നന്നായി വളരാനും വിളയാനും കഴിയുന്ന, നല്ല പൊക്കത്തിൽ വളരുന്നതുമായ നെല്ലിനങ്ങളാണ് ഈ പ്രദേശങ്ങളിൽ കൃഷി ചെയ്തു വരുന്നത്. പൊക്കത്തിൽ ആളി നിൽക്കുന്നതുകൊണ്ടാണ് ഇതിന് ആ പേര് വരാൻ കാരണം. ഇത്തരം കൃഷിരീതിയേയും പൊക്കാളി എന്നു തന്നെ വിളിയ്ക്കുന്നു.

ഈ പ്രദേശങ്ങളിൽ കൊയ്ത്ത് സമയത്ത് ജലനിരപ്പ് അഞ്ചടിവരെ ഉയരാൻ സാധ്യതയുണ്ട്.ആയതിനാൽ പൊക്കാളി പാടങ്ങളിൽ നിലവിലുള്ള കൊയ്ത്ത് യന്ത്രങ്ങൾ ഉപയോഗിയ്ക്കാൻ സാധ്യമല്ല. നിലവിലുള്ള ആംഫിബിയൻ കള നിവാരണ യന്ത്രത്തിന്റെ (ട്രക്സോർ ഡി എം 5045) ജലഗതാഗത സവിശേഷതകളും ലളിതമായ നിയന്ത്രണ രീതികളും ഈ യന്ത്രത്തിൽ കൊയ്ത്ത് യന്ത്രഭാഗങ്ങളിൽ അനുയോജ്യമായ മാറ്റം വരുത്തിയാൽ ഒരു നല്ല പൊക്കാളി കൊയ്ത്ത് യന്ത്രമാക്കി മാറ്റിയെടുക്കാൻ കഴിയും എന്ന തീരുമാനത്തിൽ എത്തിച്ചേരാൻ കാരണമായി. അതിനായി കൊയ്ത്ത് യന്ത്രത്തിന്റെ കട്ടർ-ഹെഡ്ഡർ അസ്സംബ്ളി രൂപകല്പന ചെയ്യുന്നതിനായി ഗവേഷണം നടത്തി. നിലവിലുള്ള പൊക്കാളി കൊയ്ത്ത് യന്ത്രങ്ങൾ പഠിയ്ക്കുകയും അതിന്റെ പോരായ്മകൾ കണ്ടെത്തുകയും ചെയ്തു. നിലവിലുള്ള ആംഫിബിയൻ കള നിവാരണ യന്ത്രത്തിന് (ട്രക്സോർ ഡി എം 5045) അനുയോജ്യമായ രീതിയിലുള്ള നാലു കട്ടർ-ഹെഡ്ഡർ അസ്സംബ്ളികൾ രൂപകല്പന ചെയ്ത് അതിന്റെ സാധ്യതകൾ പരിശോധിച്ചു. മൾട്ടിപ്പിൾ ബാറ്

റീൽ സിസ്റ്റം, സിങ്കിൾ ബാറ്റ് റീൽ സിസ്റ്റം, വെർട്ടിക്കൽ ബാറ്റ് റീൽ സിസ്റ്റം ഫ്ളോട്ടിംഗ് അസ്സംബ്ലി വിത്ത് പ്രൊജക്ടഡ് കൺവെയർ സിസ്റ്റം എന്നിവയാണ് അവ. ഈ നാലു മോഡലുകളിൽ നിന്ന് ഏറ്റവും ഫലപ്രദമായത് തിരഞ്ഞെടുക്കുന്നതിന് ക്വാളിറ്റി ഫംഗ്ഷൻ ഡിപ്ലോയ്മെന്റ്, അനലിറ്റിക്കൽ ഹയറാർക്കി എന്നീ ഇൻഡസ്ട്രിയൽ എഞ്ചിനീറിംഗ് ടെക്നിക്കുകൾ സയോജിപ്പിച്ചാണ് ഉപയോഗിച്ചത്. ഈ നാലു മോഡലുകൾക്കും പൊക്കാളി കൃഷിരീതികളിലും കാർഷികയന്ത്ര രൂപകല്പനയിലും വിദഗ്ദ്ധരായവരുടെ അഭിപ്രായങ്ങളും അവർ കൊടുത്ത റേറ്റിംഗും വിശകലനം ചെയ്ത് സിംഗിൾ ബാറ്റ് റീൽ സിസ്റ്റമാണ് ഏറ്റവും ഫലപ്രദമായത് എന്ന് കണ്ടെത്തി. സ്ഥിതിവിവരക്കണക്കുകളുടെ സൂക്ഷ്മ നിരീക്ഷണത്തിൽ സിംഗിൾ ബാറ്റ് റീൽ സിസ്റ്റവും മൾട്ടിപ്പിൾ ബാറ്റ് റീൽ സിസ്റ്റവും തമ്മിൽ കാര്യമായ വ്യത്യാസം കണ്ടില്ല. ആയതിനാൽ ഒരു ബദൽ സംവിധാനമായി മൾട്ടിപ്പ്ൾ ബാറ്റ് റീൽ സിസ്റ്റം ഉപയോഗിയ്ക്കാം എന്നും നീരീക്ഷിച്ചു. അതുകൊണ്ട്തന്നെ തിരഞ്ഞെടുക്കപ്പെട്ട രണ്ടു രൂപകല്പനകളിലും ബലക്ഷയമുണ്ടാകാൻ സാധ്യതയുള്ള യന്ത്രഭാഗങ്ങളുടെ അളവുകൾ ഫൈനൈറ്റ് എലമെന്റ് അനാലിസിസ് ചെയ്ത് നിജപ്പെടുത്തി. കൊറോഷൻ റെസിസ്റ്റന്റ് സ്റ്റാന്റേർഡ് കട്ടർ ബാർ അസ്സംബ്ളിയുടെ സ്ഥാനം, നിർമ്മാണ സാമഗ്രികൾ, അളവുകൾ എന്നിവയും കൃത്യമായി ചർച്ചചെയ്തു. ട്രക്സോർ ഡി എം 5045 (ആംഫിബിയൻ കള നിവാരണ യന്ത്രം) ത്തിന്റെ അതേ സഞ്ചാര സവിശേഷതകളുള്ളതും വലുപ്പം കുറവുള്ളതും തിരഞ്ഞെടുത്ത മോഡലിലുള്ള കട്ടർ ഹെഡ്ഡർ അസ്സംബ്ളിയുള്ളതുമായ ഒരു ആധുനികയന്ത്രമായിരിയ്ക്കും പോക്കാളികൃഷിയ്ക്ക് അനുയോജ്യമാവുക എന്നാണ് ഈ പഠനത്തിൽ നിന്ന് മനസ്സിലാക്കുന്നത്.