Design analysis of pokkali paddy harvester using quality function deployment (QFD) technique and analytical hierarchy process (AHP)

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Abstract: Pokkali ecosystem found prevalent in the regions of Central Kerala in India, had a unique cultivation methods and saline tolerant varieties of paddy. Mechanizing harvest operation is a great demand in this sector, especially reaping (grain earheads) and transportation (transfer from field to bunds).Hence to analyze the criteria for designing a harvesting machine, quality function deployment (QFD) technique is followed along with analytical hierarchy process (AHP) in this study. Under 2 major criteria (harvesting performance and machine performance), 9 minor criteria (cutting performance, gathering performance, collection performance, cut stalk losses, uncut stalk losses, stability, field capacity, maneuverability and transportability of the machine) were considered. Six different technical requirements (reel index, reel type, Position and degrees of freedom, mass density of the assembly, cutter bar type and material of construction) for satisfying the customer requirements were considered. The result shows that gathering operation under harvesting performance criterion, stability factor under machine performance criterion were observed to be important criteria. Out of 6 different technical requirements 'Position and degrees of freedom' ranked first. And these selection parameters were suggested for initiation of optimized design of pokkali paddy harvester.

Keywords: Pokkali ecosystem; Quality function deployment; Paddy harvester; Design analysis.

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1 Introduction

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. Ranjith et al. (2019) using Garrett's ranking technique; analyzed the problems of pokkali farmers. 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.

Earlier research works involved in development and experimentation of amphibian machines (works in both land and water) with float chambers, to suit the pokkali paddy harvest operation done in stagnated water condition (Reddy, 2018; Rathinavelet al., 2022). But those machines has limitations on field capacity,

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manuevarability issues etc. Since the machine must be amphibious, there are several limitations on design, hence preliminary analyses were required, which is studied and discussed in this chapter throughquality function deployment (QFD) and analytical hierarchy process(AHP).

Zariniet 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 Slamet (2016) used the AHP to select a best post harvesting method for Citrus fruits in Japan out of several postharvest methods such as modified atmosphere packaging, controlled atmosphere storage, hot water treatment, coatings and etc.

Kumar et al. (2019) studied the QFD methodology and applied it for their performance evaluation on coconut palm climbing aid along with AHP. 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 discussed by Shahin (2005).

Hence with the objective of analysing the design considerations of the pokkali paddy harvest with an amphibian machine using the QFD and AHP techniques was undertaken.

2 Materials and methods

QFD was selected for analyzing the design criteria 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 Figure 1. The voice of customers (customer requirement) from farmers and expert opinion were collected through the survey by direct interview with questionnaire. Requirements and four designs made which is further evaluated by expert committee through second questionnaire along with rating chart. Expert committee includes 19 members from the farmers community, 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.

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 (Ernakulam and Alapuzha districts). The customer requirements were classified into major and minor criteria. Under two major criteria (Harvesting performance and Machine performance), nine minor criteria are placed.

Under harvesting performance, five minor criteria (cutting performance, gathering performance, collection and conveying, cut stalk losses, uncut stalk losses) were considered**.** Under machine performance, four minor criteria (maneuverability, transportability, stability and field capacity) were considered. For determining weightages on minor criteria, AHP was used. The AHP method was carried out by plotting the same minor criterion both row and column in a table (pair wise comparison). These matrixes indicate a preference or priority for each decision alternative in terms of how a criterion contributes to each other criterion.When the parameters (minor criteria) have equal importance upon each other, the rating provided is 1. Hence the diagonal values tend to be unity. When the row parameter important than column parameter in a cell, value between 2 to 9 is preferred depending on level of importance. This is done individually for both the set of minor criteria. In the next step is to divide each column value of a cell with its corresponding column total (sum of column values), hence normalized pair wise comparison matrix is formed. The average value 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.

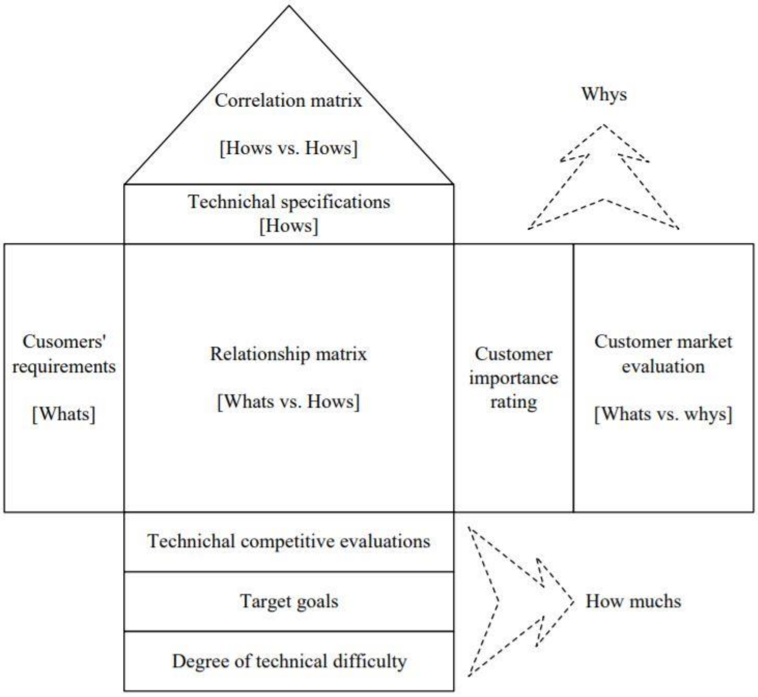

Figure 1 House of quality (HoQ) (Menkset al., 2000)

Table 1 Pairwise comparison matrix for AHP (Major criterion 1)

	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

Table 2 Pairwise comparison matrix for AHP (Major criterion 2)

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

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 Equation 1, the consistency index ('*CI*') is determined.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (1)$$

Further the random number was selected from the random index table (Table 3). 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 found to be inconsistent, the process should be repeated for different weightage. If the result is consistent, the priority values are considered as weights for the minor criteria.

As per the HoQ, requirements (engineering parameters) for the cutter header assembly of pokkali paddy harvesting machine has been found and listed (Reel type, cutter bar type, reel speed index, position of operation of cutter header assembly, material of construction and mass density of the assembly).

The relationship between VoC and engineering parameters is dealt in the relationship matrix. The relationship matrix (Table 4) is to be completed by the expert committee through questionnaire and survey process. The relationship is stated by 0 to 9 rating (0 - nil, 3 - less, 5 - moderate, 7 - higher and 9 – extreme level of relationship).

Table 3 Random index table

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

Table 4 Relationship matrix (Relation between Engineering parameters and VoC)

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

The weightage (found using AHP) is incorporated to relationship matrix to give a weighted relationship matrix (product of weightage and corresponding criterion's row values). The column total gives the total score of each technical requirement and its ranking is done to prioritize the parameters assisting in design process.

Triangular part of HoQ describes the supports and conflicts in between the engineering parameters. Done by correlating (++ strong positive, - weak, -- no correlation) the technical specifications within themselves, by the research group of technical people based on past experience and test data available.

3 Results and discussion

The relationship matrix was given in table, gives the weights of different criteria and also explains the relationship between 9 minor criteria upon the 6 technical requirements. 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 5 Relationship matrix with weightages

S. No	Weightage	Criteria	Reel index	Material of construction	Cutter bar type	Mass of the assembly	Reel type	Position & degree offreedom
1	0.15	Cutting Performance	5.10	11.51	10.93	0.00	5.54	12.39
2	0.39	Gathering Performance	23.56	0.00	0.00	0.00	21.99	26.31
3	0.05	Collection Performance	2.31	0.81	0.81	0.00	2.04	0.00
4	0.10	Cut stalk losses	5.27	6.92	6.92	0.00	5.27	7.02
5	0.31	Uncut Stalk losses	13.78	18.17	18.17	0.00	13.78	22.55
6	0.21	Manuevarability	0.00	4.41	0.00	14.71	9.24	9.87
7	0.06	Transportability	0.00	3.68	0.00	0.00	0.00	3.39
8	0.63	Stability	0.00	46.64	0.00	52.94	0.00	52.31
9	0.10	Field capacity	5.87	0.00	7.80	0.00	7.80	4.56
		Total	55.9	92.15	44.63	67.65	65.6	138.41
		Rank	5	2	6	3	4	1
		Weighted percentage	12.03%	19.80%	9.61%	14.56%	14.12%	29.80%

'Position and degree of freedom'was observed to be most important among the technical requirements and 'cutter bar type' found to be least important. According to ranking, technical requirements are prioritized in the ascending order of ranks for design and development.

The cutter header assembly position and its movement was an important technical requirements for the pokkali harvester. And this result is comparable with the results of Kumar et al.(2015) which shows that out of various design requirements of an agricultural machinery, 'Adjustments' ranked first. Hence it is inferred that adjustments and control over the positions of any component is first priority while designing an agricultural machine. The 45% expert response suggest cutter header assembly of pokkali harvester to work above the water surface and 55% to work under water.

As stated by Smith (2020), the material of construction for a farm machine is very important. Relatively, Material of construction ranked two in the QFD analysis. The material for machine construction is suggested as marine aluminium and high carbon steel. The knife material suggested by the majority of the experts was high carbon steel with or without coatings followed by spring steel and stainless steel. Also, experts opined that knife blade should be corrosion resistant, hence blade can be coated with nano materials. The research result reported by Abdel 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 mass of the assembly, ranked third and it is mostly dependent on the material of construction and the design of the components. Since the harvester is operating mostly under flooded condition it is desired to keep the mass of the machine as low as possible.

The importance of reel as a technical requirement for cutter header assembly ranked fourth from the experts opinion, but the 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 which fifth ranked, is suggested in the range of 1.2 to 1.7 which is considered in previous studies (Bawatharani et al.,2013; Reddy, 2018). Kepner et al. (1978) and Behrouzi-Lar et al. (1995) suggested 1.25 to 1.5 reel index for normal cereal crop harvesting, where the upper limit is less than the expert's suggestion for pokkali paddy.

Though the cutterbar knife blade type is influencing the harvest operation (Tabatabaee Koloor and Borgheie, 2006), cutterbar type is least ranked.Experts suggested reciprocating double shear knife bar with serrated blades among the scissor type and double shear reciprocating cutter blades.

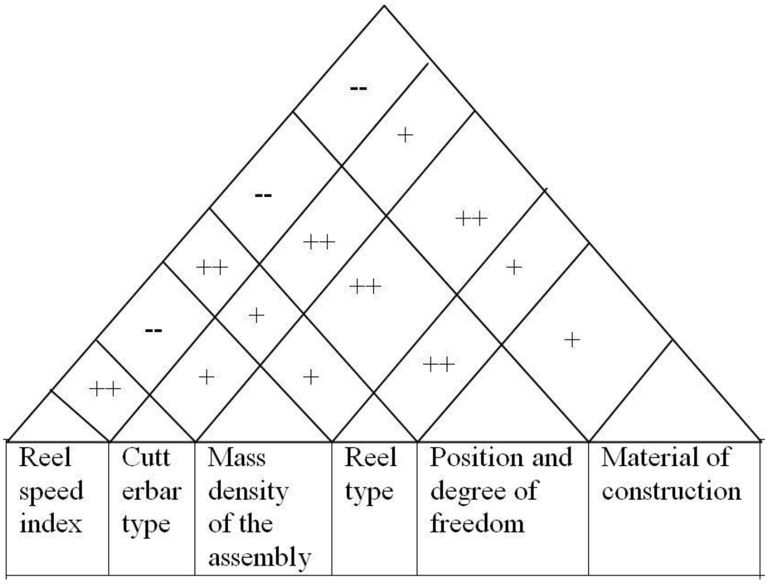

Figure 2 Roof of HoQ for Pokkali Paddy Harvester Design

The roof of HoQ is build with correlations between technical requirements is represented in the Figure 2. This part explains the inter relationship between the various technical requirements for analyzing the design and proceed with betterment.

With these design suggestions the several pokkali paddy harvesters design can be initiated and they can be rated with customers on experimental basis, which may be further extension of the work.

4 Conclusion

Using QFD and AHP methods, pokkali paddy harvester design analysis was carried out. From the analysis, it is found that out of various aspects of the pokkali paddy harvester, cutter header assembly's gathering operation and machine stability has to be prioritized serves the basis for design over other aspects such as cutting, collection, maneuverability, losses and transportability which can be subsequently considered. Position and degrees of freedom must be the preceding design criteria followed by material of construction, mass of the assembly, reel type, reel index and cutterbar. Based on this priority, the harvester must be designed along with the suggested technical specifications. Further, several designs to be arrived with this criteria followed by development to select the better one through experimentation.

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