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Technical note

# Development of grain threshers based on ergonomic design criteria

Adarsh Kumar[a], Dinesh Mohan[b,*], Rajesh Patel[b], Mathew Varghese[c]

[a] *Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi-110012, India*

[b] *Transportation Research & Injury Prevention Programme, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi-110016, India*

[c] *Department of Orthopaedics, St. Stephen's Hospital, Delhi, India*

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**Abstract**

Threshers are used extensively on Indian farms for threshing grains, but are involved in a significant proportion of limb crush injuries. International safety standards are somewhat difficult to enforce because manufacture of machines is done at widely dispersed local workshops. Locally made machines are used for crop production and post-harvesting operations, with a great deal of manual work. This technical note reports the results of a study to develop a cost effective, improved design for safe operation of threshers based on ergonomic principles. © 2002 Elsevier Science Ltd. All rights reserved.

*Keywords:* Threshers; Agricultural injuries; Safety

## 1. Introduction

The mechanisation of agricultural practices has resulted in increased agricultural productivity in India but at the same time the incidence of traumatic injuries among agricultural workers seems to have increased also. It is estimated that every year in Haryana, Punjab and Uttar Pradesh (three states of northern India) alone there may be 5000–10,000 deaths, 15,000–20,000 amputations and 150,000–200,000 serious injuries due to agricultural related activities (Mohan and Patel, 1992). Among these, threshing machines are responsible for a significant number of serious injuries (Mohan and Patel, 1992). Threshers are power driven machines designed for threshing wheat and rice during the harvesting season. These machines use auxiliary power from tractor power take off or electric motors/diesel engines. The typical thresher is fitted with a feeding chute at a slope of 10–15° at the mouth of the threshing drum (Fig. 1).

Thresher injuries have not been reported by any high-income countries (HICs) after 1969 (Kumar et al., 2000). However, the number of powered threshers has increased from 0.2 million in 1971–72 to 3 million in 1995–96 on Indian farms (Singh, 1997). Mohan and Patel (1992) recorded that this machine caused 2% of total agricultural injuries though they are used only for a few days in the whole year. A study from Pakistan says that threshers were associated with 16% of injuries (Mufti et al., 1989). They reported that belt entanglement, electric shock and feeding crop without safety were main reasons attributed to thresher injuries; the mechanical failures responsible for injuries were 17%. Singh and Sinha (1980) reported 30 thresher injuries out of 50 in a survey from India, but the study did not give any details of type of injury or mechanism of injury. In another study from Punjab, India, the human factors were associated with thresher injuries in 73% of the cases. These included inattentiveness, wearing of loose garments, overwork and physical incapability, etc. (Rawal, 1988). However, these observations were not based on any detailed investigations. No study has evaluated improvements in design or any safety mechanisms.

## 2. Methodology

This study was done in villages of District Sonipat of Haryana State and District Baraut of Uttar Pardesh, northern states of India. These villages were selected for high agricultural activities and use of modern technology on farms; crops are predominantly wheat, sugarcane and rice. Visits were made to households where

*Corresponding author. Tel.: +91-11-659-1147; fax: +91-11-685-1169.

*E-mail addresses:* adarsh_iari@rediffmail.com (A. Kumar), dmohan@cbme.iitd.ernet.in (D. Mohan), ssh@vsnl.com (M. Varghese).


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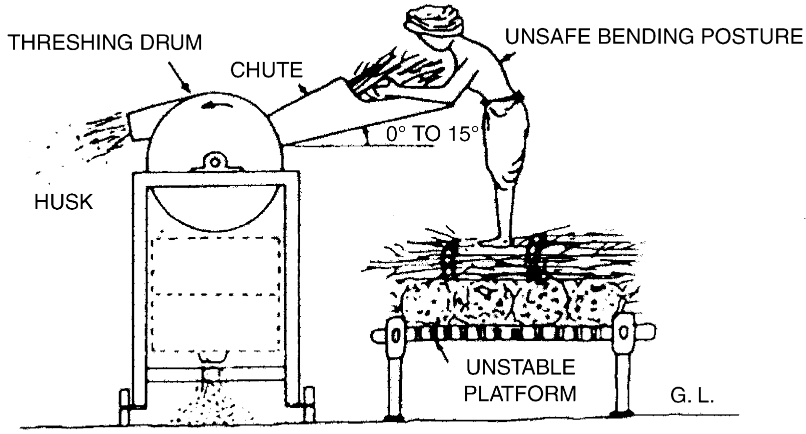

Fig. 1. Existing threshing operation.

threshers were involved in injury. A total of 65 thresher injuries were investigated in detail. The details regarding the event, injuries, causation factors and thresher dimensions were obtained.

A random survey of 100 threshers was also carried out to obtain control data for dimensional and operator work details in the study area. These data were compared with the dimensions of threshers involved in injuries to identify the factors associated with injuries.

Based on the information regarding factors associated with injuries, a safer design of thresher was prepared using anthropometric data of the Indian population (Patel et al., 2000). Indian stature was used to generate other body part dimensions (Roebuck et al., 1975) for safer thresher design.

## 3. Results

We interviewed all thresher injury victims ($N = 65$) with serious cuts or amputations taking treatment in nearby hospitals. Table 1 gives the details of the victims, body part injured and machine part involved in injury; 4% of victims were under 16 years, 82% 16–45 years and 14% over 45 years. The right hand was involved in 80% cases, left hand was involved in 15% and other body parts 5%. Thirty-five cases involved amputations of the right hand fingers (5), right hand (9), right forearm (18), left hand fingers (1) and left hand (2).

The analysis of machine parts associated with injuries revealed that the threshing drum and the feeding system were involved in 52 cases, belt and pulley in 6 cases and rest by any other machine part. The thresher chute dimensions are given in Table 2.

This sample of injured users was compared with a control group of 100 users by visiting sites where threshing was in operation and obtaining thresher and working details. The threshing drum-feeding details are given in Table 3.

Injury victims were feeding the chute from the left in 27 cases, from the right in 9, and from the front in 2 cases. In our control survey 54% workers had elbow height above the chute, 18% at the chute and 28% operators had elbow height below the chute. Also, 72% persons operated the machine while bending over the chute and 47% of the operators stood on unstable platforms; 44% injury victims used a stable platform for feeding the crop while the rest used bullock carts, tractor trolleys, cots or stood on crop bundles.

The factors reported by the victims included unstable platform, improper work posture, small chute dimensions, feeding of small crop pieces, jerks due to high moisture content in the crop bundles and entanglement of body parts into the auxiliary power transmission system.

## 4. Discussion

Fig. 2 shows the chute-opening height distribution in injury-associated threshers and the control sample threshers; chute-opening height is smaller (mean 15 cm) in injury-associated threshers as compared to control threshers (mean 18 cm). Because of the smaller chute-opening height the operator has to use greater force to push the crop in with his hands, which can take the hands close to the fast moving threshing drum (600–700 rpm) which results in an injury.

Mean chute cover length of injury-associated threshers was 27 cm compared to 36 cm for the control group of threshers. Also, amputation of the forearm showed a decreasing trend with increased chute cover length (Fig. 3). This trend has a direct relationship with anthropometric dimensions of forearm, in that higher chute cover length prevents the forearm to come into

Table 1
Details of injured victims

| Case no. | Age (years) | Sex | Body part | Machine part | Power source |
|---|---|---|---|---|---|
| 1 | 20 | Male | Right hand elbow | Any other | Tractor PTO |
| 2 | 35 | Male | Left hand fingers | Belt and pulley | Tractor PTO |
| 3 | 35 | Male | Right hand index finger | Threshing drum | Tractor PTO |
| 4 | 15 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 5 | 21 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 6 | 24 | Male | Right hand | Threshing drum | Tractor PTO |
| 7 | 14 | Male | Right hand | Threshing drum | Tractor PTO |
| 8 | 22 | Female | Right hand fore arm | Threshing drum | Tractor PTO |
| 9 | 50 | Male | Right hand | Threshing drum | Tractor PTO |
| 10 | 17 | Male | Right hand | Threshing drum | Tractor PTO |
| 11 | 29 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 12 | 30 | Female | Death case | Belt and pulley | Electric motor |
| 13 | 30 | Male | Left hand finger | Threshing drum | Tractor PTO |
| 14 | 13 | Male | Right hand fingers | Belt and pulley | Tractor PTO |
| 15 | 21 | Male | Right hand | Threshing drum | Tractor PTO |
| 16 | 40 | Male | Left hand | Threshing drum | Tractor PTO |
| 17 | 22 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 18 | 30 | Male | Right hand | Belt and pulley | Tractor PTO |
| 19 | 60 | Male | Right hand fingers | Threshing drum | Tractor PTO |
| 20 | 25 | Male | Right hand | Threshing drum | Tractor PTO |
| 21 | 16 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 22 | 22 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 23 | 16 | Male | Right hand | Any other | Unknown |
| 24 | 17 | Male | Right hand | Any other | Unknown |
| 25 | 21 | Male | Left/right hand | Any other | Unknown |
| 26 | 45 | Male | Right hand fingers | Threshing drum | Electric motor |
| 27 | 36 | Male | Right hand | Threshing drum | Tractor PTO |
| 28 | 14 | Female | Right hand thumb | Threshing drum | Electric motor |
| 29 | 19 | Male | Back bone | Threshing drum | Electric motor |
| 30 | 38 | Male | Left hand fingers | Any other | Unknown |
| 31 | 46 | Male | Right hand | Threshing drum | Tractor PTO |
| 32 | 58 | Female | Right hand fingers | Belt and pulley | Tractor PTO |
| 33 | 50 | Male | Right hand | Threshing drum | Tractor PTO |
| 34 | 35 | Male | Right hand fingers | Threshing drum | Tractor PTO |
| 35 | 18 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 36 | 19 | Male | Right hand finger | Threshing drum | Tractor PTO |
| 37 | 0 | Female | Death case | Belt and pulley | Unknown |
| 38 | 22 | Male | Left hand | Threshing drum | Electric motor |
| 39 | 23 | Male | Right hand finger | Threshing drum | Tractor PTO |
| 40 | 27 | Male | Right fore arm, Left hand finger | Threshing drum | Electric motor |
| 41 | 27 | Male | Right fore arm | Threshing drum | Tractor PTO |
| 42 | 25 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 43 | 18 | Male | Left hand fingers, Thumb | Any other | Unknown |
| 44 | 25 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 45 | 60 | Male | Right hand fore arm | Threshing drum | Diesel engine |
| 46 | 25 | Male | Right hand | Threshing drum | Tractor PTO |
| 47 | 21 | Male | Right hand | Threshing drum | Electric motor |
| 48 | 20 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 49 | 30 | Male | Right hand | Threshing drum | Tractor PTO |
| 50 | 18 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 51 | 30 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 52 | 40 | Male | Right hand | Threshing drum | Tractor PTO |
| 53 | 26 | Male | Right hand fore arm | Threshing drum | Tractor PTO |
| 54 | 35 | Female | Left hand | Threshing drum | Tractor PTO |
| 55 | 42 | Female | Left hand | Threshing drum | Tractor PTO |
| 56 | 16 | Male | Left hand | Threshing drum | Tractor PTO |
| 57 | 32 | Female | Right hand fore arm | Threshing drum | Tractor PTO |
| 58 | 32 | Female | Right hand finger | Any other | Unknown |
| 59 | 0 | Male | Right hand fore arm | Threshing drum | Electric motor |
| 60 | 27 | Male | Left hand fingers | Threshing drum | Tractor PTO |
| 61 | 43 | Male | Right hand | Threshing drum | Tractor PTO |
| 62 | 22 | Male | Right hand fore arm | Threshing drum | Diesel engine |
| 63 | 30 | Male | Right hand fingers | Threshing drum | Electric motor |
| 64 | 18 | Male | Right hand fore arm | Threshing drum | Diesel engine |
| 65 | 42 | Male | Right hand fore arm | Threshing drum | Tractor PTO |

Table 2
Thresher feeding system dimensions

| Thresher part dimensions (cm) | Percentage of threshers | |
|---|---|---|
| | Associated with injuries | In the control sample |
| *Chute length* | | |
| <50 | 0 | 2 |
| 50–60 | 2 | 2 |
| 60–70 | 18 | 7 |
| 70–80 | 23 | 10 |
| 80–90 | 36 | 60 |
| >90 | 21 | 19 |
| *Chute cover length* | | |
| <25 | 23 | 7 |
| 25–30 | 18 | 12 |
| 30–35 | 18 | 17 |
| 35–40 | 11 | 20 |
| 40–45 | 21 | 32 |
| >45 | 9 | 12 |
| *Chute height* | | |
| <15 | 11 | 8 |
| 15–16 | 35 | 17 |
| 17–18 | 14 | 34 |
| 19–20 | 21 | 19 |
| 21–22 | 14 | 14 |
| >23 | 5 | 8 |

Table 3
Anthropometric dimensions (mm) of Indian male used for safer thresher design features

| Percentile | Stature | Forearm | Arm length | Elbow height |
|---|---|---|---|---|
| 95th | 1745 | 443 | 768 | 925 |
| 50th | 1645 | 418 | 724 | 872 |
| 5th | 1555 | 395 | 784 | 824 |

contact with the threshing drum. The mean chute length of injury-associated threshers was 69 cm whereas control thresher chute length was 80 cm.

The analysis of thresher chute parameters shows that chute cover length and chute-opening height are critical dimensions which influence the outcome of whether an operator sustains injuries or not. Chute-opening height should be such that it ensures smooth feeding without excessive force application. Some operators stand on unstable/high platforms causing a bending work posture. As a result their torsos are high with respect to the chute. While feeding the crops into the chute they bend over it and in the event of a jerk or loss of balance the torso weight helps push the hands into the drum, resulting in injury.

The above analysis shows that the injury-associated threshers as compared to the control sample had shorter chutes, shorter chute covers and narrow chute openings.

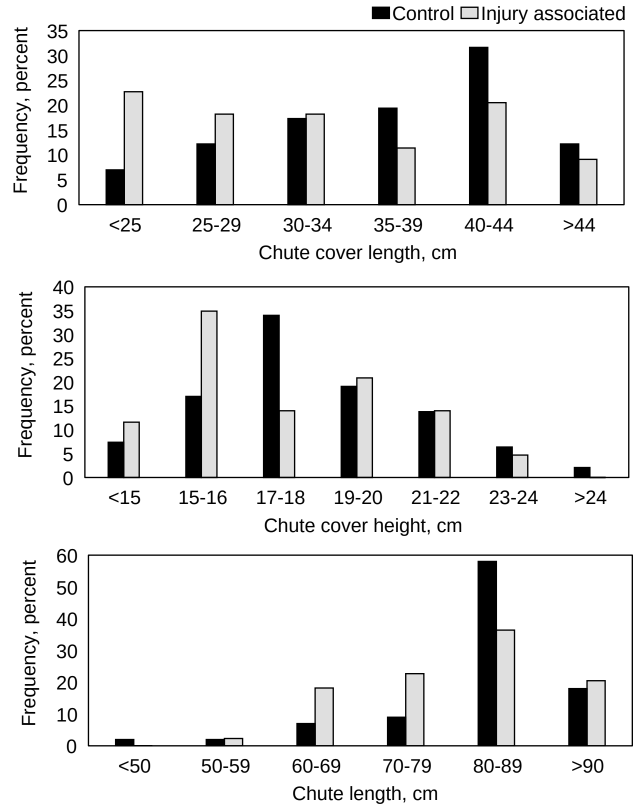


Fig. 2. Thresher feeding chute dimensions in injury-associated and control threshers.

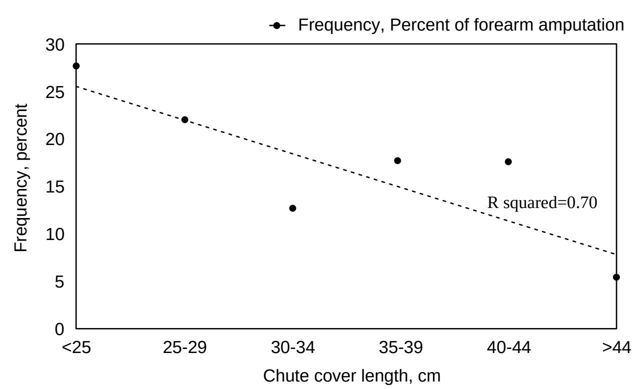


Fig. 3. Effect of chute covers on operator injury.

According to the Bureau of Indian standard BIS: 11691-1986, threshers should have chute covers with lengths of 45 cm and chute lengths of 90 cm, considering the average forearm length of Indian men. But, as Fig. 4 shows, the whole hand gets pulled in into the threshing drum in the case of an accident, which indicates that 45-cm chute cover length is inadequate to prevent such injuries.

To evolve safer chute parameters, dimensions of forearm, arm length and waist height were used for

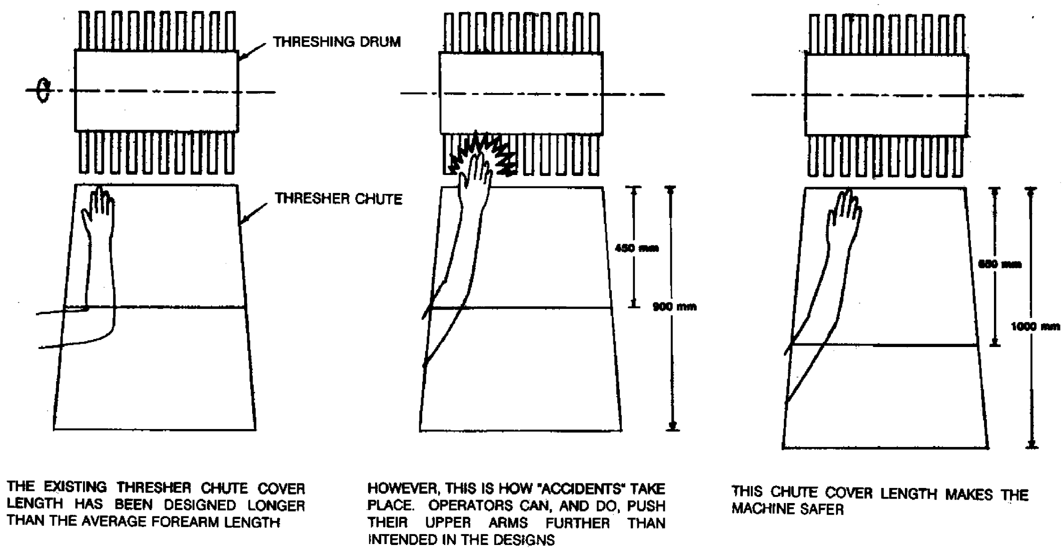


Fig. 4. Top view of thresher indicating injury mechanism.

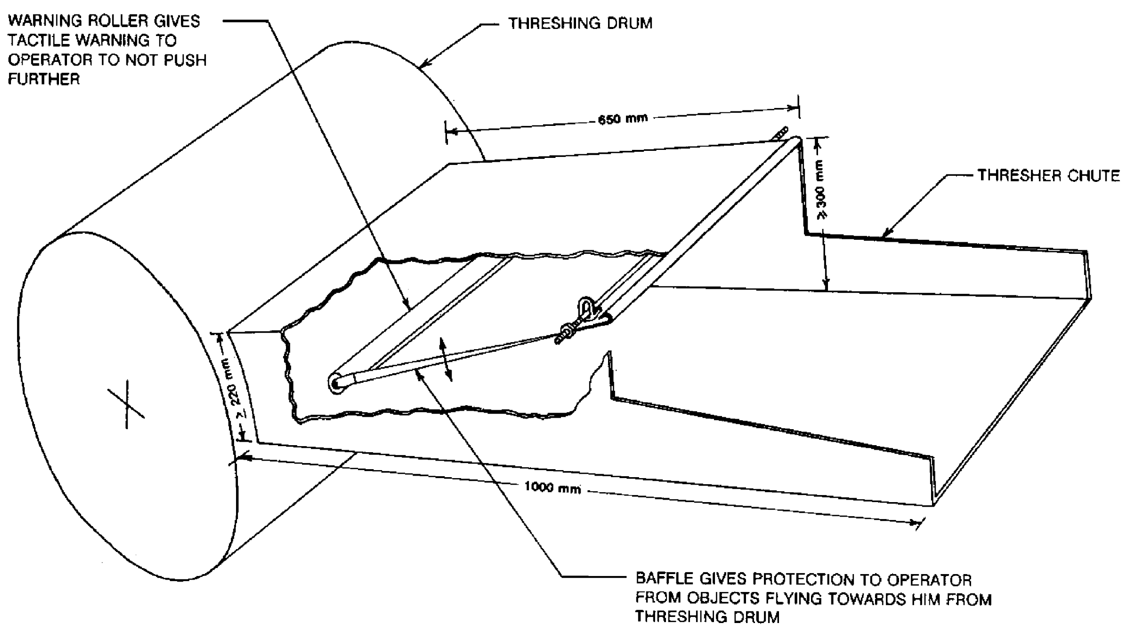


Fig. 5. Proposed safer chute for threshers.

Indian males (Table 3). It was observed that the 95th percentile male forearm dimension was 443 mm and this dimension takes care of the 95th percentile Indian woman also. To restrict hand contact with the threshing drum, the chute cover length has been increased to 650 and chute length to 1000 mm (Fig. 4). With these changes, the operator's hand to threshing drum contact has been made almost impossible in any working posture. It is recommended that the chute-opening height should be at least 220 mm to ensure smooth feeding of crop bundles. Fig. 5 shows the technical details of safer chute design.

Another preventive measure is proposed to reduce injury probability, by increasing the slope of feeding chute from 15° to 25°. Earlier, Thyagraj and Srivastava (1982) indicated that the appropriate tilt angle for the feeding chute was 6°. The coefficient of friction of wheat stems (straw) is high as compared to seeds and, moisture content in straw increases this (Buyanov and Voronyuk, 1985). The friction coefficient reported for wheat stems with steel sheet is in the vicinity of 0.35–0.50 and for seeds it is 0.25 at the time of threshing (Buyanov and Voronyuk, 1985). Considering this coefficient of friction of crops, an inclination of 15–25° is appropriate, so that

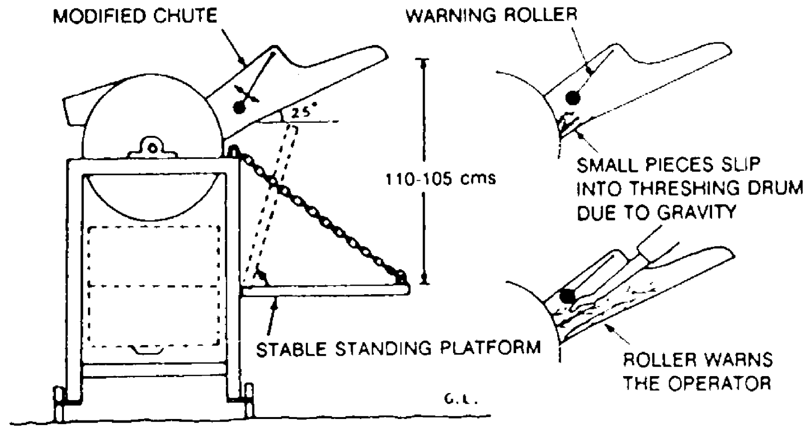


Fig. 6. Safe threshing operation.

small pieces of stocks fall into the drum on their own and the operator is not tempted to push them in.

A hand-warning roller has been placed at the end of a baffle plate in the mouth of the chute (Fig. 5). This gives a tactile warning to the operator to not push further. It also gives protection to the operator from objects flying towards him from the threshing drum.

It is also important that operators be instructed that the chute should always be at elbow level so that it is not possible to bend over it. As 72% operators work in bending postures, on the basis of the anthropometric dimension of elbow height of the 95th percentile Indian male population (Table 3) a new design of platform is suggested (Fig. 6). Minimum height difference between stand and chute should be more than 925 mm (100–105 cm) (Fig. 6).

The proposed design changes in thresher chutes will increase thresher cost by between Rs. 200 and 300 (4–7$) depending upon the size of the thresher. This is insignificant compared to the cost of the thresher. Another risk factor was entanglement in power transmission, which could be easily achieved by making threshers self-propelled but at increased cost.

Prototypes of the safe thresher chutes were successfully field tested in three wheat harvesting seasons in the study area. A total of 54 sets of safer feeding chutes were introduced for field trials. Local thresher manufacturers and technicians were involved in the fabrication. These chutes have received very favourable responses from the users. On follow up visits during threshing seasons, it was found that safer chutes had prevented injuries in at least two cases as reported by the farmers who have adopted them.

## 5. Concluding remarks

Thresher injuries result in crush/amputations of upper limbs. Chute design has an important bearing on injuries. Increased chute heights and chute cover lengths are recommended for safer operation. Height of platform and work posture were found to influence the injury outcome. Design modifications of the chute and a height difference of platform and chute can reduce the possibility of injury among thresher operators. The modifications are under consideration for changing the thresher design standards by Bureau of Indian Standards (BIS).

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