REDESIGNING AND DEVELOPMENT OF INDIGENOUS BEATER WHEAT THRESHER

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ABSTRACT

Mechanical wheat threshing has gained a spectacular popularity in Pakistan over a short span of time and so is the population of beater-wheat threshers that are being manufactured and marketed by the roadside vendors with little scientific and engineering experience. In fact, the major problems on conventional threshers have been identified as bulky weight, poor machine performance, human accidents and a high fuel consumption rate. Therefore, the present study has been planned for investigation and improvements in the prevalent design of the indigenous beater-wheat thresher to bring about durability, reduction in weight of machine and grain losses in addition to an accident free and cost effective thresher. A review of the indigenous thresher suggests presence of three heavy flywheels with little scientific argument and similarly poorly designed beaters/spikes and five rings on the beater-drum appear injudicious and unscientific. A horizontal throw of straw from the exhaust-blower takes away a noticeable amount of grains with it. Indigenous threshers have witnessed terrifying accidents for the persons feeding the material. The local manufacturers least care about the fabrication drawings of the conventional machines and therefore their knowledge of manufacturing is restricted to the whims and wishes of "ustad-shagird" (seniors, juniors).In view of above mentioned problems, the present study hypothesizes engineering oriented solutions for the ill-designs of the conventional threshers. Modified designs and fabrication drawings of various components such as flywheel, beater, beater drum, blower and feeding conveyer were prepared. Both machines were operated during the wheat threshing seasons for two consecutive years at farmer's field. Total weight of redesigned wheat thresher was reduced from 1600 kg to 1300 kg by improving beaters in thresher drum and the grain damage in redesigned thresher reduced four times. The mean threshing efficiency is increased from 98% to 99%.The replacement of the three flywheels by one wheel of required size saved 24.37kN-m energy. The fluctuation in speed was reduced to 2.055 times and coefficient of energy two times than that of conventional thresher. By redesigning and redeveloping the direction of fan

blower exhaust, the mean grain cleaning efficiency improved from 97.44 to 98.18% causing elimination of grain loss through straw blowing process. In improving the crop feeding system by designing, developing and fabricating a new conveyor, not only smooth uniform feed rate was improved yet intake was also doubled than the conventional feed rate The economic return of the redesigned thresher was found to be 26% higher and saving of 1.3 L/hr (15 kW) was assured.

Keywords: *beater wheat thresher, agricultural machinery, total weight*

INTRODUCTION

In Pakistan, there are about 250 units manufacturing agricultural machinery and implements, with a capacity of 1.38 million per annum such as wheat threshers, sugar cane crushers, chaff cutters, sprayers, rice hullers, rice husking machines, rice polishing machines, ploughs, drills, cultivators, plant protection equipment etc Qidwai, A. 1990.

The traditional methods of seed separation from the stalks are uneconomical, time consuming and laborious. The development of mechanical threshers for the purpose has clearly an edge over conventional methods and has reduced the drudgery of work to a great extent. The use of these stationery threshing machines is based on the quick process, level of performance and economy. It is need of the hour to mechanize wheat threshing operation in order to recover better yield completing the operation timely. Chaudhry (1979) found the total loss of wheat from bullock threshing, mechanical threshing; tractor threshing and combine harvester amounted to 3.11, 2.68, 2.01, and 1.2% respectively. The maximum losses were of bullock threshing and minimum for combine harvester. It was estimated that about 2.65% of the potential production of wheat was lost during harvesting, threshing and winnowing operation for all modes of wheat threshing.

At present, about 1, 36,614 wheat threshers are being used in Punjab alone (Anonymous 2011). Considering an average use of nearly 150 hours per year with consumption of diesel oil as 7.50 l/h/tractor @ Rs.105/l, the total cost of fuel consumed annually on wheat threshing in the Punjab is estimated at 16 billion (PAK) rupees. This is a substantial amount of money for an oil importing country like Pakistan.

At rated speed of tractor engine, the PTO operates at 540 RPM. Through belts, pulleys transmission system, power from PTO is transferred to crop feeding, threshing, separation and cleaning units. Crop is manually fed in the indigenous machines where wheat is threshed by fast revolving spike toothed beaters of the threshing drum through impact and rubbing action in the clearance between beaters and concave.

Both the separated grains and chopped straw pass through the concave grates and fall onto the sieves. The tossing action of oscillating sieves separates grain from larger straw chaff and allows them to fall onto small hole-mesh sieve underneath. The straw chaff is sucked vertically upward by centrifugal fan blower and thrown out of the thresher through the exit outlet installed at the rear side of thresher. The grains are further cleaned from small straw pieces and debris by air coming horizontally from small blower across the bouncing mixture of grain and material other than grains (MOG).This has provided bases for the present study that would surface some problems of locally manufactured wheat threshers along with field tested remedies.

Unfortunately little scientific argument is available for either the sizes or the weights of the flywheels and the beaters except the market norms. Similarly, the centrifugal fan blower causes grain loss through its exhaust outlet Khoshtaghaza and Mehdizadeh (2006). Manual feeding of the crop into threshing drum in conventional machines is also a main cause of human accidents Singh et al., (2005) in addition to erratic vibrations. In view of heavy flywheels and cylinder beaters, unsafe crop feeding mechanism and poor blower design, present study has been designed with following objectives in two phases.

Phase 1: Designing and fabricating flywheel, cylinder beater, fan blower and material feeding conveyor on indigenous spike toothed wheat thresher.

In the first phase a beater wheat thresher was selected and procured for the purpose. The problems identified in the thresher were; labour injury, heavy weight, grain breakage, and grain loss during air cleaning. Efforts were made to address all the problems of machine simultaneously. Noorani Industries were engaged for improving the beater thresher and the machine was disassembled for further investigation and redesigning.

Phase 2: Testing and analyzing the new designs for energy efficiency, economics of operation and human safety.

In the second phase, the machinery components were redesigned including modification in the high efficiency CAD/CAM Laboratory of University of Agriculture, Faisalabad applying Solid Works package. Total weight was reduced from 1600 kg to 1300 kg by improving beaters in threshing drum and the grain damage after redevelopment reduced four times, as well as the mean threshing efficiency increased from 98 to 99%. The replacement of three flywheels by one flywheel of required size saved 24.38 kN-m energy. The fluctuation in speed reduced to 2.055 time with two times less coefficient of energy than that of conventional thresher. By redesigning and modifying the direction of fan blower exhaust, the mean grain cleaning efficiency improved from 97.44 to 98.18% causing elimination of grain loss through straw blowing process. In improving the crop feeding system by designing, developing, and fabricating a new conveyer which was non-existent in conventional thresher, improvement in feed rate with uniformity resulted in 2770 kg/hr intake of whole crop. After compiling the overall efficiency of the redesigned beater wheat thresher, the economic return was found to be 26% higher and saving of 1.3 L/hr diesel fuel energy power.

MATERIALS AND METHODS

Phase 1: Redesigning of flywheel.

A thresher manufactured by Noorani Industries Sumandri Road, Faisalabad Model 2010 was procured and coupled with Millat MF-375 Massey Ferguson for the present study in PARS research area University of Agriculture, Faisalabad Pakistan during threshing season 2010 & 2011. The indigenous thresher has three flywheels for controlling the vibrational fluctuations. The two flywheels, each of dia. 0.736 m and weight 80 kg are attached at either ends of the main shaft of threshing cylinder to absorb vibrational impacts resulting from variation in manual uneven feeding. The third flywheel (0.493 m dia. and 60 kg weight) is placed with the pulley at the attachment of tractor PTO shaft with the thresher for minimizing the vibrational effects from the tractor. The available flywheels are considered too heavy and demand redesigning. In order to reduce their weights as well as number, available literature relating mechanical design provides elaborative information for

determining energy stored in flywheel, mass and dimensions of flywheel (Khurmi R.S and J.K. Gupta, 2008; Shigley and Mische, 2007; and Kepner, et. al., 2005.
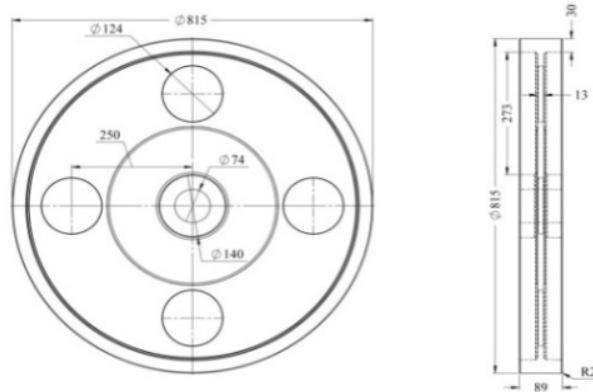

Figure 1: Drawing of Redesigned Flywheel

Design calculations of redesigned flywheel

As it has been reviewed and decided to redesign a single flywheel that can replace the two bulky *heavy weight* flywheels, gray cast iron material of density 7200 kg/m³ was chosen. Main objective was to design a single flywheel saving extra weight of two flywheels. The design calculations are as follows.

Dia of the redesigned flywheel was assumed as 0.815 m
Radius, R = 0.4075 m.
The mass of the thin disc and hub is neglected while selecting the mass of flywheel. Thresher flywheel energy, kN-m at minimum PTO speed of 500 = 758 rpm Table 1.
= Emin= 51.96 kN-m
From table 1 Redesigned thresher flywheel energy at 939 rpm = Emax= 79.90 kN-m.

Maximum fluctuation of energy

$$\Delta E = E_{max} - E_{min} = 79.90 - 51.96 = 27.94 kN - m$$

Also we know that from the equation

$$\Delta E = mR^2 . \omega^2 . C_s$$ (R.S. Khurmi)

Where

R = 0.815/2= 0.4075 m

$$\omega = \frac{\omega_{max} + \omega_{min}}{2}$$

$$\omega_{max} = \frac{2\pi N_{max}}{60}$$

$$\omega_{min} = \frac{2\pi N_{min}}{60}$$

$$\omega = \frac{1}{2\left[\frac{2 \times 3.141 \times 939}{60} + \frac{2 \times 3.141 \times 758}{60}\right]} = 88.81 \frac{rad}{s}$$

Cs= coefficient of fluctuation of speed

= $(N_1 - N_2)/N$

The only unknown is mass of the flywheel

$$27.94 \times 10^3 = m \times (0.4075)^2 \times (88.806)^2 \times 0.21$$

Mass m of flywheel = 98.2 kg

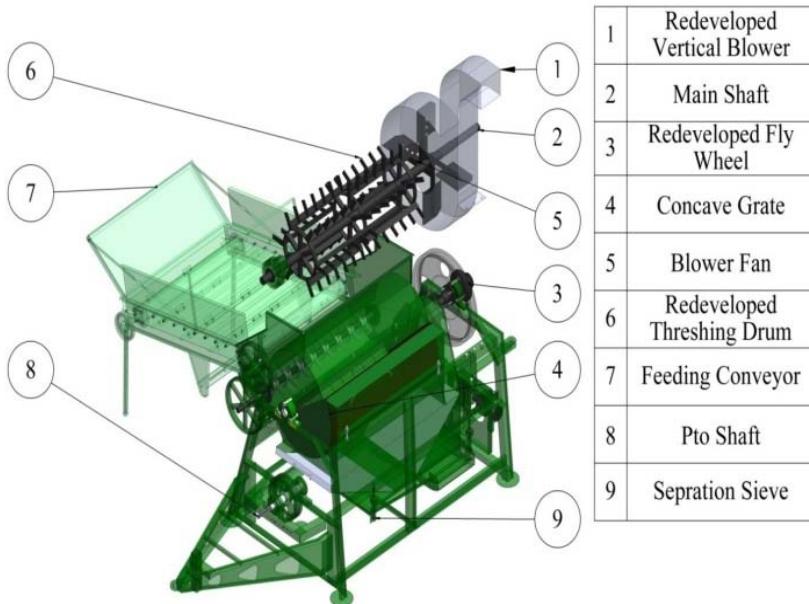|	
1	Redeveloped Vertical Blower
2	Main Shaft
3	Redeveloped Fly Wheel
4	Concave Grate
5	Blower Fan
6	Redeveloped Threshing Drum
7	Feeding Conveyor
8	Pto Shaft
9	Sepration Sieve

Figure 2: Redesigned Thresher

Figure 3: Indigenous Thresher in Operation

Table 1: Energy in the Flywheels of Conventional and Redesigned Threshers

PTO speed, N_{pto} (rpm)	Threshing drum, N_{cyl} (rpm)	Thresher flywheel energy, kN-m				Redesigned Thresher TH2	Excess Energy (kN-m)
		Conventional thresher TH1					
		(a)	(b)	(c)	(d)	(e)	(d-e)
		E_1 at N_{cyl} (main shaft front flywheel) (kN-m)	E_2 at N_{cyl} (main shaft rear flywheel) (kN-m)	E_3, at N_{pto} PTO shaft flywheel (kN-m)	E_{conv} = sum of (a)+(b)+(c) (kN-m)	$E_{redesigned}$ (kN-m)	Excess Energy = E_{conv}-E_{red} (kN-m)
500	758	34.14	34.14	4.16	72.45	51.96	20.48
510	773	35.52	35.52	4.33	75.37	54.06	21.31
520	788	36.93	36.93	4.50	78.36	56.20	22.15
530	803	38.36	38.36	4.68	81.40	58.39	23.01
540	818	39.82	39.82	4.86	84.50	60.61	23.89
550	833	41.31	41.31	5.04	87.66	62.88	24.78
560	849	42.83	42.83	5.22	90.88	65.18	25.69
570	864	44.37	44.37	5.41	94.15	67.53	26.62
580	879	45.94	45.94	5.60	97.48	69.92	27.56
590	894	47.54	47.54	5.80	100.87	72.35	28.52
600	909	49.16	49.16	5.99	104.32	74.83	29.50
610	924	50.82	50.82	6.20	107.83	77.34	30.49
620	939	52.50	52.50	6.40	111.39	79.90	31.49

$$For\ conventional\ thrasher\ C_N = \frac{N_{max} - N_{min}}{N_{mean}} = \frac{560 - 500}{530} = 0.113$$

$$For\ redeveloped\ thrasher\ C_N = \frac{N_{max} - N_{min}}{N_{mean}} = \frac{560 - 500}{530} = 0.11$$

$$For\ conventional\ thrasher\ C_E = \frac{E_{max} - E_{min}}{E_{mean}} = \frac{90.88 - 72.45}{81.40} = 0.23$$

$$For\ conventional\ thrasher\ C_E = \frac{E_{max} - E_{min}}{E_{mean}} = \frac{65.18 - 58.39}{61.78} = 0.11$$

Above calculations depicted that coefficient of fluctuation of speed C_N under redesigned thresher and conventional thresher was 0.05 and 0.113 respectively indicating 2.055 times less fluctuation in redesigned thresher. Similarly, coefficient of fluctuation of flywheel energy C_E under conventional thresher and redesigned thresher was 0.23 and 0.11 respectively. This indicated that C_E under redesigned thresher (TH2) was two time less than that under conventional thresher (TH1). The low fluctuation in C_E under thresher TH2 definitely would have been due to uniform feeding crop employing a newly designed conveyor which has reduced overloading of tractor engine and ultimately reduced fluctuations in engine speed.
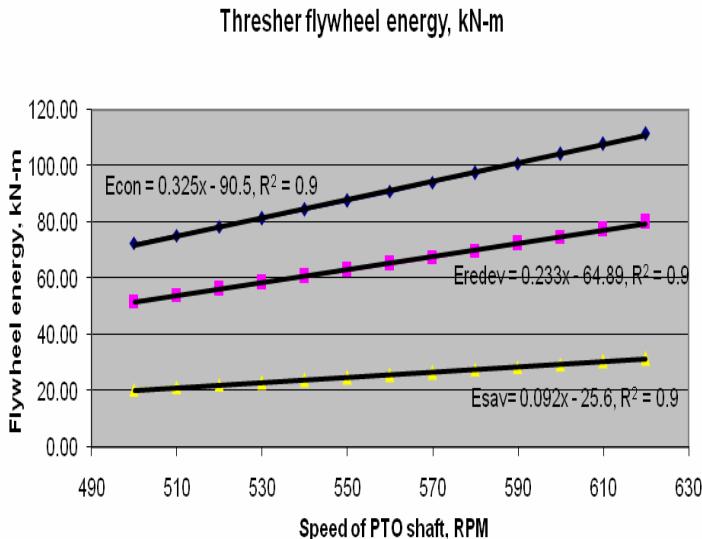

Figure 4: The Effects of PTO Speed of Tractor on Energy of Flywheels

The effects of PTO speed of tractor on energy of flywheels of both the conventional and redesigned threshers have been plotted in figure 4. The

figure 4 depicted that there was a consistent saving in energy at the flywheel of newly developed thresher from 490 to 630 RPM speed of PTO of tractor. This saving in energy definitely needed less tractor fuel energy under redesigned thresher.

Sizing the flywheel

It is now to be determined how large a single flywheel is needed instead of two heavy flywheels installed on conventional wheat thresher to absorb same amount of energy with an acceptable change in speed. The change in shaft speed during a cycle is called its fluctuation and is equalto:

$$Fluctuation = \omega_{max} - \omega_{min}$$

It can be normalized to a dimensionless ratio by dividing it by the average shaft speed.

C_s= coefficient of fluctuation of speed = $(N_1-N_2)/N$

The coefficient of fluctuation is a design parameter and it typically is chosen between 0.01 and 0.05 which corresponds to a 1 to 5% fluctuation in shaft speed Robert L. Norton. The smaller this chosen value the larger the flywheel will have to be. This presents a design trade-off. A larger flywheel will add more cost and weight to the system, which factors have to be weighed against the smoothness of operation desired.

The most efficient flywheel design in terms of maximizing moment of inertia for minimum material used is one in which the mass is concentrated in its rim and its hub is supported on spokes like a carriage wheel. This puts the majority of the mass at the largest radius possible and minimizes the weight for a given moment of inertia. Even if a flat, solid circular disc flywheel design is chosen, either for simplicity of manufacture or to obtain a flat surface for other functions. Since in general, $I = MR^2$,a thin disc of large diameter will need given moment of inertia than will a thicker disc of smaller diameter. Dense materials such as cost iron and steel are the obvious choices for the flywheel. Aluminium is seldom used.

A fly wheel is generally attached at the end of the shaft in order to have uniform torque throughout the rotation of the shaft. It smoothens the back and forth of energy through the mechanical circuit. Therefore, a flywheel is considered as an energy reservoir which will absorb and to deliver energy for the purpose it has been designed for. In any power transmission circuit two elements must exist viz; the power source (electrical or mechanical) and the user (a machine to convert power into useful work). The flywheel is a third element which is placed between the source and the user and serves the important purpose preventing the serious short time energy disturbance in either direction. In the conventional wheat thresher there were three flywheels viz one (0.493 m dia kg weight) on the input PTO shaft from the PTO of tractor, the second and the third (0.7366 m dia 60 kg weight) on the front rear end of main shaft of the threshing cylinder of thresher.

Stresses in a flywheel Rim

A flywheel consists of a rim at which the major portion of the mass or weight of the flywheel is concentrated. Tensile stress at due to centrifugal force is produced in the flywheel

$$\sigma t = p.R^2. \omega^2 = p.v^2$$

Where

σt is tensile stress in N/m^2 or Pa,ω is angular speed in rad/s
p is density in kg/m^3 and R is radius of the flywheel in meters
$$\sigma t = 7200 \times (0.4075)^2 \times (88.81)^2$$
$$\sigma t = \text{Tensile Stress} = 9.429 \text{ MPa}$$

Development of feed conveyor

Keeping in view the human safety, tractor overloading, thresher performance factors, a 1.65 m long and 1.3 m wide replaceable conveyor has been designed, developed, fabricated, and field tested for its performance during the wheat threshing season of the year 2011 (Figure 5). A 14-gauge MS sheet was used to develop 20 cm wide u-channel (5 cm x 20 cm x 5 cm). The frame was made from locally available materials. These U-frames were made into a frame in which two 15-cm dia MS pipes (3-mm wall thickness) were adjusted as rollers over which a canvas belt had to roll over for conveying crop from lower end to upper end of conveyor. Each roller pipe had a central 50 mm dia shaft as an axle which

had ball bearings at each end in u-frame. Flat wooden bars (50 mm wide x 10 mm thick) were bolted on the conveyer belt at an interval of about 40 cm throughout the conveyor. Three MS angle iron pieces (25 mm x 25 mm x 3 mm) were also bolted at equal interval on the wooden bars for holding crop positively to avoid crop slippage during conveying. A 33 cm high 16 gauge MS sheet was bolted vertically along the conveyor length on both the u-channels (right and left channel) to avoid the crop fall down during conveying. A 40 cm high 16 gauge MS sheet had been bolted at an oblique angle of 45^0 for holding the crop at feeding end. Folding square end (5 cm x 5 cm) MS angle iron legs (2 legs 71 cm long each) have been employed to raise the lower end of conveyer 71 cm above ground. From upper side the conveyer U-channels were bolted on the hopper of feeder end of thresher 30-cm above the star feeder shaft. The crop can be conveyed without slippage at 29^0 slope with horizontal. A belt (B-type) has been employed to transfer power from thresher feeder pulley to a pulley installed at the axle shaft of lower roller of conveyor. The other end of lower axle of conveyer has chain and sprocket to convey power to the sprocket on the centre axle of upper roller. The belt moves at a linear velocity of 0.57 m/s for optimum feeding and best crop threshing. A horizontally laying adjustable height control frame has been mounted to control the crop feed rate if desired.
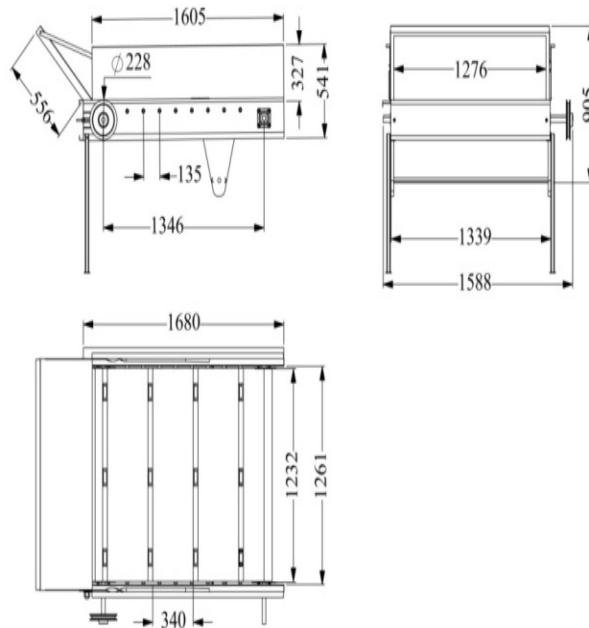

Figure 5: Orthographic Views of Redesigned Feeding Conveyor

The output capacity of conveyor

$$L_c.\,W_c.\,s.\,V_c.\,\in.\,\gamma m\frac{kg}{s} = 2370.970\frac{kg}{h}$$

Sharma D.N. (2008)
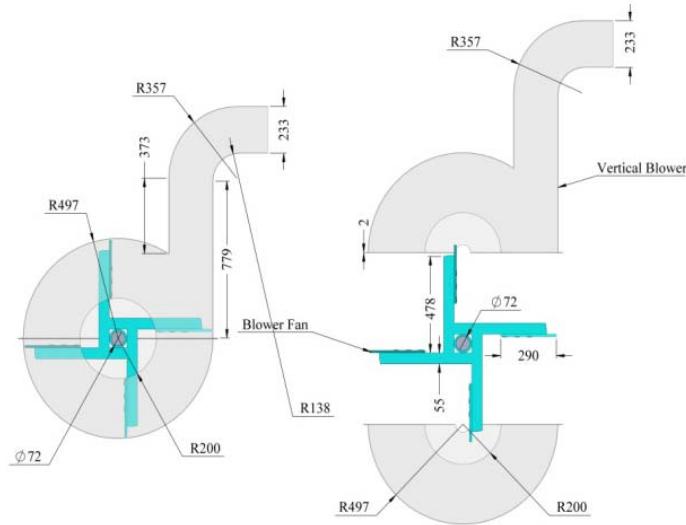
Blower design calculations at inlet of blower

Figure 6: Dimensions of Redesigned Vertical Blower

The linear velocity of blower as well as wheat straw chaff

$V_{(at\ inlet\ with\ eye)}$ $= r\ \omega = 0.2 \times 85.30$
          $= 17.06$ m/sec
$V_{(at\ blade\ tip)}$ $= r\ \omega = 0.494 \times 85.30$
          $= 42.138$ m/sec

Area of blower at the inlet for air and wheat straw chaff

Area at the eye of redeveloped blower,
$A_{(inlet)}$ $= 2 \times \pi \times r \times L$
        $= 2 \times 3.14 \times 200mm \times 127mm$
$A_{(inlet)}$ $= 0.1595$ m^2

Area at the exit for air and wheat straw chaff

Area at the exit end of redeveloped blower,
A out $= 250mm \times 250mm = 62500$ mm^2

= 0.0625 m2

It was found that at feed rate 2430 kg/hour there was 1318 kg/h wheat chaff.

Straw grain ratio = 1318/1112 = 1.1852

The centrifugal force of fan blower paddle to throw the chaff

$Fc = mr\omega^2 = 0.36 kg/sec \times 0.4945 m \times (85.33 rad/sec)^2 = 1296 N$

Figure 7: Schematic Diagram of Redesigned Flywheel,
Blower Fan and Spike Toothed Drum Beater

Table 2: Parameters and their levels

Parameters	Levels
Year	2011,2012
Machine (Thresher)	Conventional TH_1 Redesigned TH_2
Crop variety (V)	V_1 = Sehar 2006 V_2= Faisalabad 2008 V_3= Lasani 2008
Moisture contents (M_C)	M_{C1}= Later harvesting (3rd week of Harvesting) M_{C2} = Mid harvesting (2nd week of Harvesting) M_{C3}= Early harvesting (1st week of Harvesting)
Feed rate (F_R)	F_{R1}, F_{R2}, F_{R3}
Replications (R)	R_1, R_2, R_3

Statistical analysis:

A 2x3x3x3 factor factorial was employed in CRD statistical design to evaluate the effect of two threshers ,conventional and redesigned, three different wheat varieties (Seher 2006, Faisalabad 2008, Lasani 2008), three different crop moisture contents (MC1, MC2 & MC3), at three different feed rates, (F_{R1}, F_{R2} & F_{R3}) on the machine efficiency and crop recovery. Statistical analysis done using PROC GLM (General Linear Model) procedures of SAS institute (SAS, 2002-03).

RESULTS AND DISCUSSION

Effect of wheat varieties (V) on threshing performance of conventional (TH1) and redesigned threshers (TH2)

The effects of crop and machine parameters on wheat threshing showed highly significant effects of threshers (TH), crop varieties (V) and interaction of thresher and variety (TH*V) for grain damage. Table A5 showed highly significant effects of threshers (TH) and crop varieties (V) on grain cleaning efficiency. All the other interactions related to threshers and crop varieties showed insignificant effects on grain damage, threshing efficiency, and material other than grain or grain cleaning efficiency.

Table 3 depicted that mean grain damage (GD) over varieties was significantly lower under redeveloped thresher, TH2 (0.48%) than that under conventional thresher, TH1 (1.98%). The variety Lasani 2008 (V3) had significantly lowest susceptibility to grain damage than that observed under both other two varieties Seher 2006 (V1) and Faisalabad 2008 (V2). A keen look into Table T4 clearly reflected that thresher TH1 had more grain damage than those observed under thresher TH2 for all the varieties selected for this study. It could safely be concluded that thresher TH1 had more aggressive threshing action than thresher TH2 and variety V3 had been strong enough to resist the threshing aggressiveness than the other two varieties V1 and V2. Varieties V1, V2 & V3 had 2.06%. 2.02% & 1.86% grain damage (GD) under thresher TH1 & 0.48%, 0.49% & 0.46% under thresher TH2 respectively. Mean grain damage produced by redeveloped thresher (TH2) was 24 times less than that of conventional thresher (TH1).

Table 3: Effect of Conventional and Redesigned Wheat Threshers on Grain Damage (GD) for three varieties of Wheat.

Variety	Mean Grain Damage (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	$2.06^a{}_a$	$0.48^a{}_b$	1.27_a	0.1029
V2	$2.02^b{}_a$	$0.49^a{}_b$	1.26_a	0.1051
V3	$1.86^c{}_a$	$0.46^a{}_b$	1.16_b	0.071
Mean	1.98_a	0.48_b	1.23	0.0532
LSD (0.05)	0.0136	0.1311	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively. Same alphabets a, b, c etc indicate non-significant difference (α=0.05) V1, V2, and V3 show Seher 2006, Faisalabad 2008, Lasani 2008 wheat varieties respectively .Table 4 presented the effects of conventional (TH1) and modified (TH2) wheat threshers on grain threshing efficiency (THE) for three varieties of wheat. Threshing efficiencies of both the threshers Th1 and Th2 were significantly highest for variety V1 than the other two varieties. Thresher TH1 had 98.26%, 98.21%, and 98.22% and thresher TH2 had 98.92%, 98.88%, and 98.87% threshing efficiencies for varieties V1, V2, and V3, respectively.

Table 4:Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Grain Threshing Efficiency (THE) for three varieties of Wheat

Variety	Mean Threshing Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	$98.26^a{}_b$	$98.92^a{}_a$	98.59_a	0.0759
V2	$98.21^b{}_b$	$98.88^a{}_a$	98.55_a	0.1285
V3	$98.22^b{}_b$	$98.87^a{}_a$	98.55_a	0.1026
Mean	98.23_b	98.89_a	98.56	0.059
LSD (0.05)	0.0152	0.1454	0.072	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc indicate non-significant difference (α=0.05)

V1, V2, and V3 show wheat varieties Seher 2006, Faisalabad 2008, Lasani 2008 respectively

The newly redeveloped thresher TH2 excelled in threshing efficiency than thresher TH1 under all the selected varieties. This indicated that newly modified/designed beaters installed on the threshing drum had more capability of rubbing crop ears against concave bars and detaching grains smoothly without damaging grain than the old beaters having high carbon steel tips welded at the top of each beater.

The effects of conventional (TH1) and modified (TH2) wheat threshers on grain cleaning efficiency for three varieties of wheat had been presented in Table 5. The mean cleaning efficiency over varieties was significantly greater under thresher TH2 (98.18%) than that under thresher TH1 (97.44%). This could be concluded that better the thresh-ability (Table 4) better would be the cleaning efficiency (Table 5). Thresher TH2 might had threshed the crop uniformly and therefore, chopped the wheat straw uniformly which would have been easy for the fan blower to separate the straw from grain. Mean cleaning efficiencies under thresher TH1 for varieties V1, V2, & V3 were 97.22%, 97.88%, & 97.22% and under thresher TH2 for the same varieties were 97.87%, 98.41% & 97.75% respectively. This indicated that under both threshers TH1 and TH2, variety V2 had the greatest and V1 had the lowest cleaning efficiency.

Table 5: Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Cleaning Efficiency (CLE) for three varieties of Wheat

Variety	Grain Cleaning Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	97.22^b_b	97.87^a_a	97.54_b	0.6207
V2	97.88^a_a	98.41^a_a	98.15_a	0.5242
V3	97.22^b_a	98.28^a_a	97.75_b	0.4248
Mean	97.44_b	98.18_a	97.81	0.2987
LSD (0.05)	0.4537	0.5846	0.3658	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05)

V1, V2, and V3 show wheat varieties Seher 2006, Faisalabad 2008, Lasani 2008 respectively.

Effect of wheat moisture content (MC) on threshing performance of conventional (TH1) and redesigned threshers (TH2)

The statistical analysis presented in ANOVA Tables A2, A3, A4, & A5 showed significant effects of thresher (TH) and moisture content (MC) but showed insignificant effects of interaction TH*MC for grain damage, threshing efficiency, and cleaning efficiency. The effects of conventional (TH1) and modified (TH2) wheat threshers on wheat grain damage (GD) at three moisture contents had been presented in Table 6. The Table 6 depicted that the mean grain damage at moisture content MC1 was significantly greatest (1.31%) than those at MC2 (1.21%) and MC3 (1.18%). Moisture contents MC1, MC2, & MC3 were 11.2%, 13%, and 14.5% (wb) respectively.

Table 6: Effect of Conventional (TH1) and Redesigned (TH2) Wheat Threshers on Wheat Grain Damage (GD) at three Moisture Contents

Moisture Content	Grain Damage (%)		Mean	LSD (0.05)
	TH1	TH2		
MC1	2.07^a_a	0.55^a_b	1.31_a	0.087
MC2	1.97^b_a	0.45^a_b	1.21_b	0.096
MC3	1.91^c_a	0.44^a_b	1.18_b	0.099
Mean	1.98_a	0.48_b	1.23	0.0532
LSD (0.05)	0.0131	0.1311	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05).

MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat respectively.

This indicated that less was the moisture content more was the grain damage. The findings are in line with the findings of Arnold (1964), Bainer & Borthwick (1934), Bunnelle et al (1954), and Kanafojski and Karwowski (1972) reported that seed damage increases as the seed

moisture content is reduced from 14%. The best moisture content for harvesting and threshing wheat had been found 18 to 14% (OAEC, 1969-70).It could safely be concluded that the decrease in moisture content makes the grain more brittle to withstand against the high impact forces of dynamic beaters installed on rotating drum. Thresher TH2 excelled in low grain damage performance than thresher TH2 at all the three moisture levels. Therefore, TH2 had 0.55%, 0.45% & 0.44% and thresher TH1 had 2.07%, 1.97% & 1.91% grain damage (GD) at moisture content MC1, MC2 & MC3 respectively. This strengthened the previous conclusion of uniform and smooth thresh-ability for grain detachment from ears and chopping straw. Therefore, it could be safely concluded that what else the moisture content would be, the beaters without high carbon steel tips but with simple welded tops would result in better performance regarding low grain damage, high thresh-ability and high grain cleaning efficiency.

The Table 7 showed the effect of conventional (TH1) and modified (TH2) wheat threshers on threshing efficiency (THE) at three moisture contents. The increase in moisture content from MC1 (11.2%) to MC3 (14.5%) resulted in increased threshing efficiency. The greatest efficiency of threshing was observed at MC3 moisture content both under thresher TH1 and thresher TH2. Moreover, threshing efficiency was significantly greater under thresher TH2 (98.89%) than that observed under thresher TH1 (98.23%).

Table 7: Effect of Conventional (TH1) and Redesigned (TH2) Wheat Threshers on Threshing Efficiency (THE) at three Moisture Contents

Moisture Content	Threshing Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
MC1	98.18^b_a	98.80^b_a	98.49_b	0.1068
MC2	98.25^a_b	98.93^{ab}_a	98.59_a	0.1138
MC3	98.27^a_b	98.95^a_a	98.61_a	0.092
Mean	98.23_b	$98.89.$	98.56	0.059
LSD (0.05)	0.0152	0.1454	0.0723	

Superscripts and subscripts show column wise and row wise comparison respectively. Same alphabets a, b, c etc. indicate non-significant difference (α=0.05) MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat respectively.

Mean threshing efficiency at MC1, MC2, and MC3 was 98.49%, 98.59%, and 98.61% respectively. Even-though there was no significant difference between the mean threshing efficiency at MC2 and MC3 yet MC3 produced 0.02% greater value of threshing efficiency. It could be concluded from above discussion that the moisture content MC3 (14.5%) being within the best moisture content range for threshing (14-18%) was the best moisture content for greatest grain threshing and separation from straw.

Effect of conventional (TH1) and modified (TH2) wheat threshers on grain cleaning efficiency (CLE) at three moisture contents had been presented in Table 8. Table 8 depicted that overall mean CLE was significantly greatest (98.29%) at moisture content (MC3=14.5%) and lowest (97.62%) at moisture content (MC1=11.2%). It could be safely expected that at MC1 (11.2%) the light chopped straw and broken brittle grain might had more volume to be separated from clean grain than that at MC3 (14.5%) and, therefore, could not be separated easily from threshed grain by the air sucked by the impeller blower, hence resulted in lower cleaning efficiency. So far as the significantly greater value of CLE value under TH2 (98.19%) than that under TH1 (97.71%) is concerned, it strengthened the previous discussion of uniform and smooth threshing capability of redeveloped beaters without high carbon steel. Thresher TH2 had 0.43%, 0.4%, & 0.57% more values of CLE than those under thresher TH1 at moisture content MC1, MC2, & MC3 respectively. The CLE values at MC1, MC2, & MC3 under TH1 were 97.41%, 97.74%, & 98% respectively and under thresher TH2 were 97.84%, 98.14%, & 98.57% respectively.

Table 8: Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Grain Cleaning Efficiency (CLE) at three Moisture Contents

Moisture Content	Cleaning Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
MC1	97.41^{b}_{a}	97.84^{a}_{b}	97.62_{b}	0.6008
MC2	97.74^{ab}_{a}	98.14^{ab}_{a}	97.94^{a}_{b}	0.5452
MC3	98.00^{a}_{b}	98.57^{a}_{a}	98.29_{a}	0.4270
Mean	97.71_{b}	98.19_{a}	97.95	0.2587
LSD (0.05)	0.4537		0.3658	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05).

MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat respectively.

Effect of crop feed rate (FR) on threshing performance of conventional (TH1) and redeveloped threshers (TH2)

The statistical analysis presented in ANOVA tables A2, A3, A4 & A5 showed that the effects of feed rate (FR) and the interaction of feed rate and thresher (FR*T) were significant for grain damage, threshing efficiency, and cleaning efficiency (α=0.1). The findings of the effect of conventional (TH1) and modified (TH2) wheat threshers on grain damage (GD) for three crop feed rates (FR) had been presented in Table 9. It can be depicted from Table 9 that thresher TH2 had significantly lower grain damage (GD) than those under thresher TH1 at the entire three selected crop feed rates (FR). The mean grain damage under TH2 (0.48%) was significantly lower than that under TH1 (1.98%). The excellent performance of thresher TH2 strengthened the above conclusions of best new design of beaters over the conventional design of beaters. The grain damage (GD) at feed rate FR1 was significantly greater than those at other two feed rates and GD at FR2 was significantly greater than that at FR3.

Table 9: Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Grain Damage (GD) for three Crop Feed Rates (FR)

Feed Rate	Grain Damage (%)		Mean	LSD (0.05)
	TH1	TH2		
FR1	2.33^a_a	0.66^a_b	1.496_a	0.0964
FR2	1.92^b_a	0.44^b_b	1.18_b	0.0578
FR3	1.70^c_a	0.33^b_b	1.02_c	0.1186
Mean	1.98_a	0.48_b	1.23	0.0532
LSD (0.05)	0.0136	0.131	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05).

FR1, FR2, and FR3 show 2560, 2720, and 2880 kg/hr crop feed rate respectively.

The results in line with the findings reported by Kanafojski and Karwowski (1972). At lower feed rate (FR1= 2560 kg/hr) there would have been more direct contact between grain and beaters than at higher feed rates FR2 (2720 kg/hr) and FR3 (2880) kg/hr. It could, therefore, be concluded that more the direct contact between grain and beaters more will be the grain damage. The results have been found in line with the findings of the OAEC (1970).

Table 10 presented the effect of conventional (TH1) and modified (TH2) wheat threshers on threshing efficiency (THE) for three crop feed rates (FR). The Table 9 showed that the increase in feed rate significantly decreased the mean threshing efficiency. The thresher TH2 had significantly greater THE than thresher TH1at all levels of feed rates. Thresher TH1 had 98.48%, 98.32% & 97.89% and thresher TH2 had 99.09%, 98.84% & 98.74% THE at feed rate FR1, FR2, and FR3 respectively. The mean "THE" of TH1 and TH2 was 98.23% and 98.89% respectively. As the threshing efficiency had decreased (Table 10) and grain damage had decreased with the increase in feed rate (Table 9), therefore, a compromise has to be made that which feed rate has to be selected from the quality of threshing and economics point of view. Thresher TH2 had lower grain damage and high efficiency values at all the three feed rates than those observed under thresher TH1. Since the damaged grain are more susceptible for the attack of insect and pest and there was only 0.48% decrease in mean THE at FR3 than that at FR1, therefore, it would be better to recommend FR3 for being on safe side, otherwise select the medium feed rate (FR2) of 2750 kg/hr.

Table 10: Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Threshing Efficiency (THE) for three Crop Feed Rates (FR)

Feed Rate	Threshing Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
FR1	98.48^a_b	99.09^a_a	98.79_a	0.0389
FR2	98.32^b_b	98.84^b_a	98.58_b	0.1036
FR3	97.89^c_b	98.74^b_a	98.31_c	0.1434
Mean	98.23_b	98.89_a	98.56	0.059
LSD (0.05)	0.0152	0.1454	0.0723	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05).

FR1, FR2, and FR3 show 2560, 2720, and 2880 kg/hr crop feed rate respectively.

Effect of conventional (TH1) and modified (TH2) wheat threshers on cleaning efficiency (CLE) for three crop feed rates (FR) had been presented in Table 11. The Table 11 depicted that the increase in feed rate from FR1 to FR3 significantly decreased mean cleaning efficiency. Even though there was no significant difference among CLE values at three different feed rates (FR1, FR2, & FR3) under thresher TH2, the CLE at FR1 was 0.52% & 0.57% greater than those at FR2 & FR3 respectively and the CLE at FR2 was 0.05% greater than that at FR3. Although there was no significant difference between CLE values observed at FR1 and FR2 but both were significantly greater that at FR3 under thresher TH1. The trend of efficiency was like the same as that of threshing efficiency discussed above. This would have been due to the reason that at less FR1, straw chopping was more; threshing efficiency was also more, so it was easy for fan blower to suck and throw straw easily than that at FR3.

Table 11: Effect of Conventional (TH1) and Modified (TH2) Wheat Threshers on Cleaning Efficiency (CLE) for three Crops Feed Rates (FR)

Feed Rate	Cleaning Efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
FR1	98.26^a_a	98.55^a_a	98.40_a	0.4315
FR2	97.88^a_a	98.03^a_a	97.96_b	0.4249
FR3	97.00^b_b	97.98^a_a	97.49_c	0.6883
Mean	97.71_b	98.19_a	97.95	0.2587
LSD (0.05)	0.4537	0.5846	0.3658	

Superscripts and subscripts show column wise and row wise comparison respectively.

Same alphabets a, b, c etc. indicate non-significant difference (α=0.05).

FR1, FR2, and FR3 show 2560, 2720, and 2880 kg/hr crop feed rate respectively.

The statistically analyzed results of fuel consumed (FC) by both the threshers at the selected feed rates had been presented in Table T14. The Table 12depicted that mean feed rate FR1 (2280 kg/hr) had significantly lowest fuel consumption (6.846 L/hr) and feed rate FR3 (2720 kg/hr) had greatest fuel consumption (6.852 L/hr). Same effect had been observed under each thresher at all the selected feed rates. This was obviously true; more the material had to be threshed more would have been the fuel consumption. Thresher TH1 had significantly greater fuel consumption values at all the three selected feed rates than those under the thresher TH2. This could be due to light thresher drum (35kg less weight than TH2) of redeveloped thresher and uniform feeding of crop due to was because the thresher TH2 and specifically its threshing drum were lighter in weight (300 kg less weight) than that of thresher TH1 and also feeding was uniform by the newly designed conveyor. On an average thresher TH2 consumed 1.3 L/hr less diesel fuel (15 kW, @ 1-liter diesel = (0.893 kg)*(46 MJ/kg)*(0.28 kWh/MJ) =11.5 kWh) than that consumed by thresher TH1.

Table 12: Effect of Feed Rates on Fuel Consumption (L/hr) of Conventional (TH1) and Redesigned (TH2) Wheat Threshers

Feed Rate	Fuel Consumption (L/hr)		Mean	LSD (0.05)
	TH1	TH2		
FR1	7.496^c_a	6.196^c_b	6.846_c	0.0006
FR2	7.499^b_a	6.199^b_b	6.849_b	0.0006
FR3	7.502^a_a	6.202^a_b	6.852_a	0.0006
Mean	7.499_a	6.199_b	97.95	0.0003
LSD (0.05)	0.0005	0.0005	0.0004	

Regression models of wheat crop and wheat thresher machine parameters

Regression analyses were performed for the effect of grain moisture content (MC) on grain damage (GD) for threshing wheat by both the conventional (TH1) and redeveloped threshers (TH2). Figure 8 depicted that generally the decrease in moisture content from 14.5% to 11.2% increased the grain breakage. This confirmed the above conclusions that the decrease in wheat grain moisture content below 14% makes the grains brittle which then become more susceptible to the attack of insect and pests that lowers the grain quality. The quadratic models were well suited for feed rates FR1 and FR3 where as linear models well suited for feed rate FR2 (Equations T13-T18). The high values of coefficient of determination (R2) indicated the highest suitability of the models for predicting the behaviour of moisture content to grain damage. The Figure 59 clearly depicted that grain damage (GD) under redeveloped thresher (TH2) was significantly lower than that observed under thresher TH1 at all the selected feed rates.
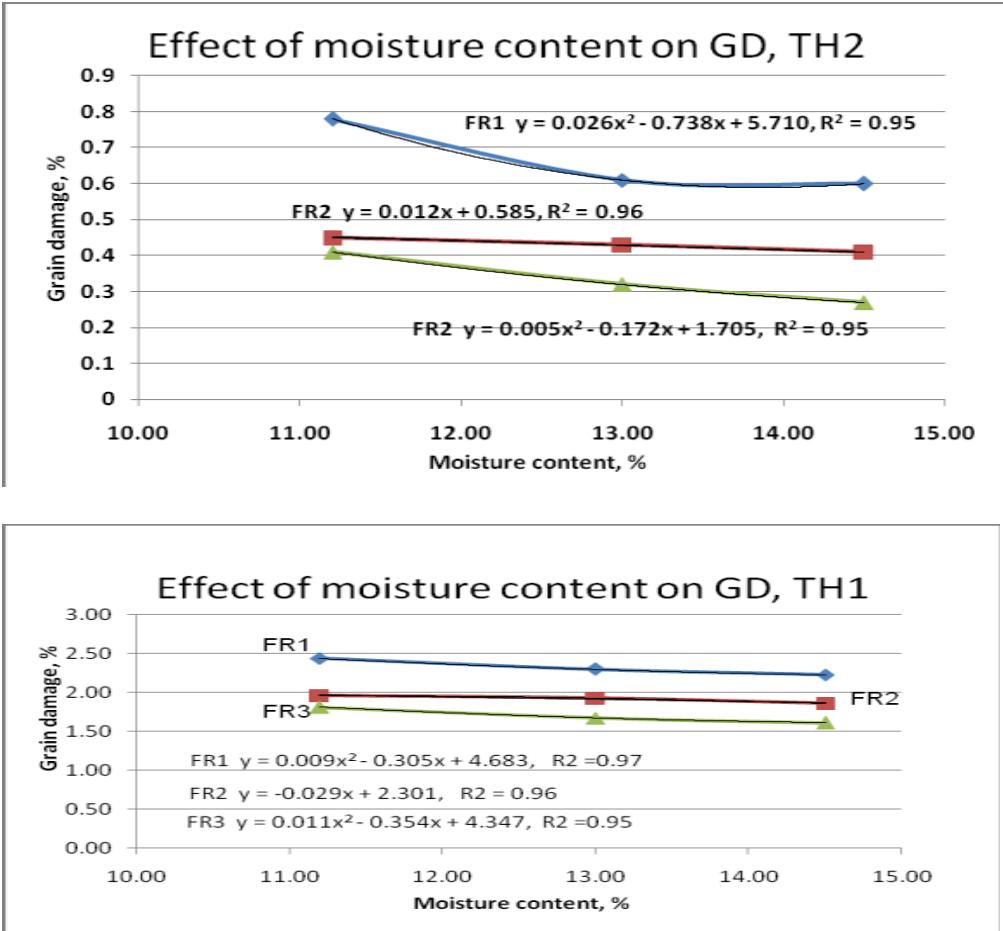
Figure 8: Effect of Moisture Content on Grain Damage with Threshers (TH1 & TH2)

TH1 FR1 GD% = 0.009MC2 - 0.305MC + 4.683, R2=0.97 T13
TH1 FR2 GD% = -0.029MC + 2.301, R2 = 0.96 T14
TH1 FR3 GD% = 0.011MC2 - 0.354MC + 4.347, R2 =0.95 T15
TH2 FR1 GD% = 0.026MC2 - 0.738MC + 5.710, R2 = 0.95 T16
TH2 FR2 GD% = 0.012MC + 0.585, R2 = 0.96 T17
TH2 FR3 GD% = 0.005MC2 - 0.172MC + 1.705, R2 = 0.95 T18

The data regarding the effect of moisture content on threshing efficiency with threshers (TH1 & TH2) was statistically analyzed for regression analysis. The quadratic models were well fitted for feed rate FR1 & FR3 under thresher TH1 and for feed rate FR2 & FR3 under thresher TH2, whereas linear models well fitted for feed rate FR2 and FR1 under TH1 & Th2 respectively (Figure 9). The high values of R2 of regression models

indicated highest suitability for the respective data set (Equation T19-T24). The Figure 9 depicted that the increase in moisture content from 11.2% to 14.5% had an increasing effect on threshing efficiency (THE). Feed rates FR1 and FR3 had significantly highest and lowest values of threshing efficiency respectively at all the moisture content levels (MC) under both the threshers (TH1 & TH2). The results have been found in line with the findings of Aga et al; (2004). Thresher TH2 had greater values of THE at all the feed rates than those observed under TH1 which indicated that the newly designed beaters of TH2 were more suitable than those of TH1. No doubt feed rate FR2 had increasing trend of THE but after 13% moisture content there was slow increase in THE under TH1 than that under TH2 for unknown reasons.
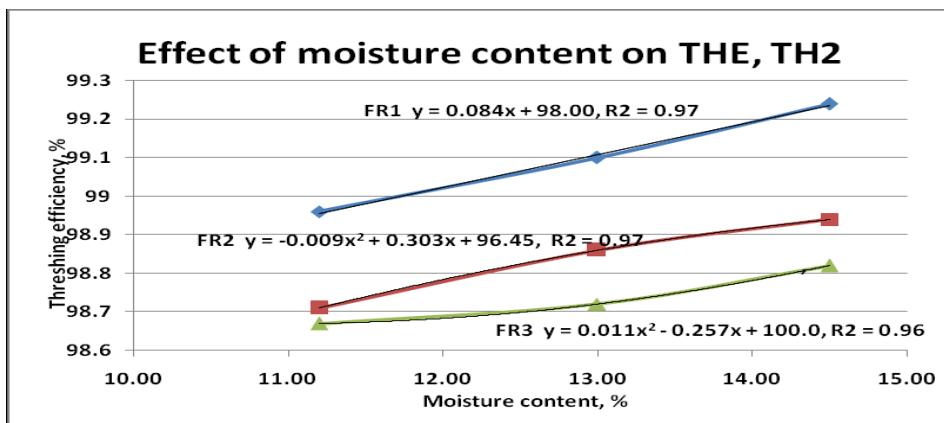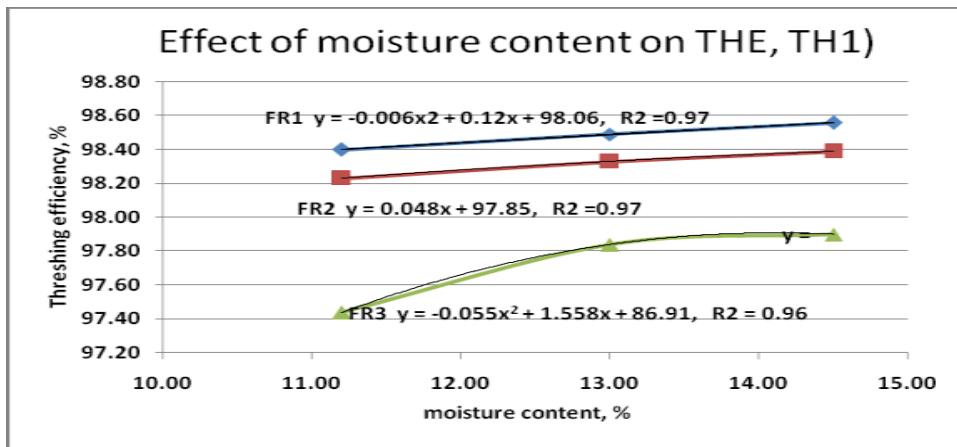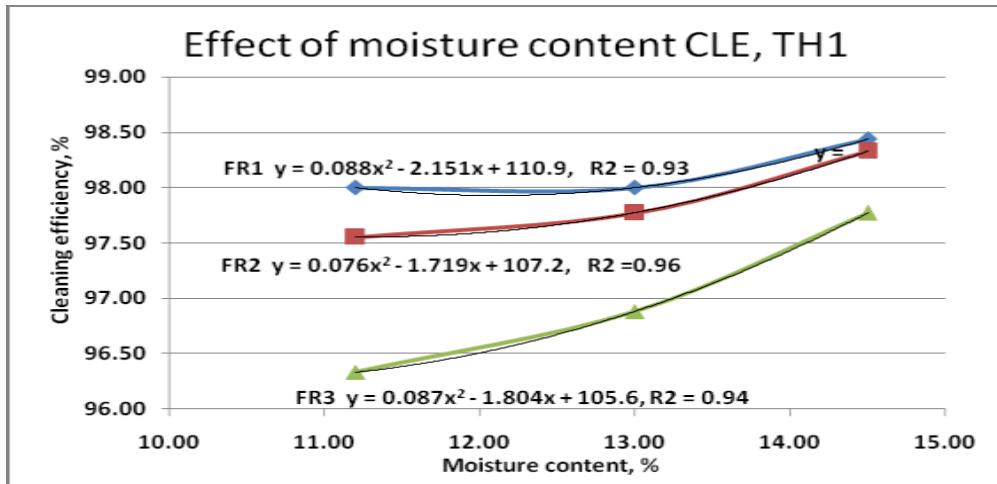

Figure 9: Effect of Moisture Content on Threshing Efficiency
with Threshers (TH1 & TH2)

TH1 FR1 THE% = -0.006MC2 + 0.12MC + 98.06, R2 =0.97 T19

TH1 FR2 THE% = 0.048MC + 97.85, R2 =0.97 T20
TH1 FR3 THE% = -0.055MC2 + 1.558MC + 86.91, R2 = 0.96 T21
TH2 FR1 THE% = 0.084MC + 98.00, R2 = 0.97 T22
TH2 FR2 THE% = -0.009MC2 + 0.303MC + 96.45, R2 = 0.97 T23
TH2 FR3 THE% = 0.011MC2 - 0.257MC + 100.0, R2 = 0.96 T24

Data regarding the effect of wheat grain moisture content on grain cleaning efficiency for three selected feed rates during threshing by both the threshers were analyzed and regression analysis performed. The regression models had been presented in Figure 10 and equations T25-T30. The high values of R2 depicted that quadratic models well suited for the data of CLE for grain moisture content range of 11.2% to 14.5%. The Figure 10 depicted that the CLE increased with the increase in moisture content. Feed rate FR2 had lower CLE values than feed rate FR1 but greater than FR3 at all the moisture contents under both the threshers. At feed rate FR3 the cleaning efficiency increased at faster rate with the increase in grain moisture content under both the threshers.

Keeping in view the above conclusions of decrease in grain damage, increase in threshing efficiency, and increase in cleaning efficiency with the increase in moisture content from 11.2% to 14.5%, it could be concluded that at high moisture content (14.5%) there would have been uniform grain separation and chopping of straw which would have affected the crop parameters positively.
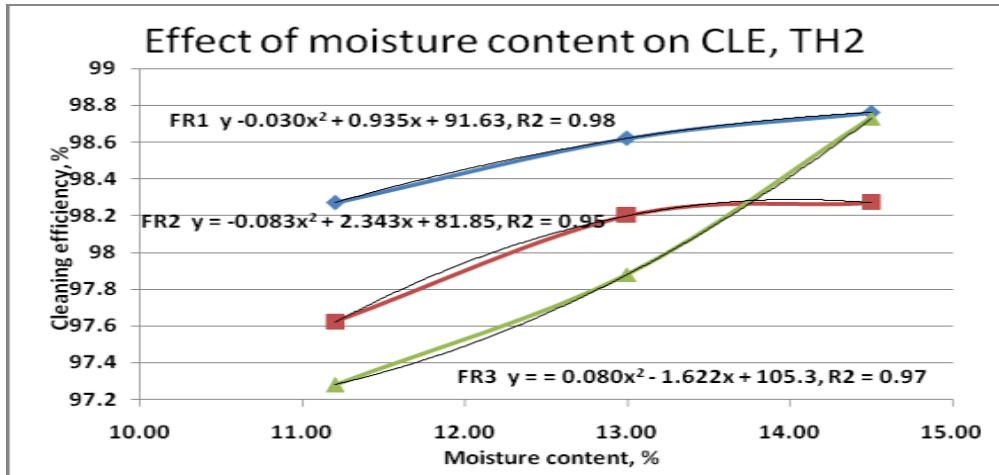
*Figure 10: Effect of Moisture Content on Cleaning Efficiency
with Threshers (TH1 & TH2)*

TH1 FR1 CLE%= 0.088 MC2 - 2.151MC + 110.9, R2 = 0.93 T25
TH1 FR2 CLE% = 0.076 MC2 - 1.719MC + 107.2, R2 =0.96 T26
TH1 FR3 CLE% = 0.087 MC2 - 1.804MC + 105.6, R2 = 0.94 T27
TH2 FR1 CLE%= -0.030 MC2 + 0.935MC + 91.63, R2 = 0.98 T28
TH2 FR2 CLE% = -0.083 MC2 + 2.343MC + 81.85, R2 = 0.95 T29
TH2 FR3 CLE% = = 0.080 MC2 - 1.622MC + 105.3, R2 = 0.97 T30

SUMMARY AND CONCLUSIONS

1) Total weight of redeveloped wheat thresher was reduced from 1600 kg to 1300 kg by improving beaters in thresher drum and the grain damage in redeveloped thresher reduced four times.
2) The mean threshing efficiency is increased from 98% to 99% in redesigned thresher.
3) The replacement of the three flywheels by one wheel of required size saved 24.37KN-m energy.
4) The fluctuation in speed was reduced to 2.055 times and coefficient of energy two times than that of conventional thresher.
5) By redesigning and redeveloping the direction of fan blower exhaust, the mean grain cleaning efficiency improved from 97.44 to 98.18 % causing elimination of grain loss through straw blowing process.
6) Crop feeding system used on conventional thresher caused many fatal accidents every year. In improving the crop feeding system by designing, developing and fabricating a new conveyor, not only

smooth uniform feed rate was improved yet intake was also doubled than the conventional feed rate i.e. 2770kg/hour.

7) The economic return of the redeveloped thresher was found to be 26% higher and saving of 1.3 L/hr (15 kW) was assured.

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