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An ergonomic intervention in operation of a rotary maize sheller

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ABSTRACT

Research work on the ergonomics of bicycle, reported in literature, mainly deals with sports and rehabilitation activities. However, the use of pedal power for occupational work such as stationary farm operations has got scant attention in the past. Keeping these points into consideration a study was conducted at CIAE, Bhopal to optimise the design parameters for a pedal operated rotary device (dynapod), which could be used as an interface between human worker and any rotary type process machine. The developed dynapod was interfaced with a hand operated rotary maize sheller and the performance of the machine and drudgery reduction while operated in pedalling mode was quantified and compared with those of hand cranking mode. The results indicated a significant increase in output capacity of the machine (282.7 kg/h versus 144.42 kg/h) with a significant reduction in work pulses (ΔHR) during the operation of the machine (35 beats/min versus 59.4 beats/min) in pedalling mode using dynapod. It was concluded that the rotary maize sheller should be popularised along with the dynapod for its better adoptability by the farmers.

Key words: Dynapod, Physiological responses, Psychophysical responses, Rotary maize sheller, Shelling capacity, Shelling efficiency

Because of the socio-economical conditions of farmers in several developing countries including India, human muscle power is going to contribute energy requirements for performing many farm activities at least for next 25 years. In remote villages of India, where electricity is not available and repair and maintenance facilities for internal combustion engines are scarce, human and animal power are still the major contributors of energy requirement for production agriculture as well as for post harvest agricultural operations. Several studies (Kang *et al.* 1997, Marais *et al.* 2002 and Schneider *et al.* 2002) have demonstrated the superiority of pedalling over hand cranking for producing power from human muscles. Pedal power enables a person to drive devices at the same rate as that achieved by hand cranking, with less effort and fatigue. Pedal power also enables to drive devices at a faster rate (winnower), or operate devices that require much power for hand cranking (thresher). Pedal power can be utilised for the operation of any machine by simply using the chain and sprockets used on cycle rickshaws, however, the efficiency is lower.

A dynapod is a portable pedal operated rotary device that consists of a stand, saddle, handlebar, chain, sprocket wheels, cranks and pedals. The device can be used as an interface between human worker and any rotary type machine to utilize the human power in most efficient way. A dynapod can operate a pump during the crop-growing season, run a thresher at harvest time, and power a grain mill throughout the year. Its portability allows it to be moved from site to site. Dynapod power varies according to the size and fitness of the operator and the length of time spent in pedalling. Keeping these points into consideration a dynapod was designed and developed at CIAE, Bhopal on the basis of optimized design parameters for Indian agricultural workers.

Maize (*Zea mays* L.) is an important cereal crop, which had been supplementing carbohydrates in the human's diet and in organizations such as schools, hospitals and prisons. The bulk of the crop is shelled by beating the dehusked cobs either heaped on bare ground or loosely packed in sacks with bamboo/wooden sticks. The method has low productivity, causes high physical damage and contamination with foreign matter resulting in lower market value and reduced shelf-life of the crop. Other methods such as hand priming, shelling using sickle and tubular maize sheller are time consuming and tedious. Taking these points into consideration various types of manually operated and power operated maize dehusker/shellers have been developed. Hand operated rotary maize shellers have been found suitable for shelling maize especially for seed purposes, as damaged grains are lower in comparison to

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power maize shellers. However, they are not very popular amongst the farmers. One of the reasons for low adoption of these machines by the farmers may be the drudgery involved in its operation. Keeping these points into consideration the developed dynapod was interfaced with a hand operated rotary maize sheller to operate the latter in pedalling mode. The performance of the machine and drudgery reduction while operating in pedalling mode with dynapod was quantified and compared with those of hand cranking mode.

MATERIALS AND METHODS

The rotary maize sheller was operated in pedalling as well as hand cranking mode and physiological responses of the subjects were studied under both the conditions, to compare the performance of maize sheller and physiological responses of operators during operation of the machine in pedalling mode using dynapod with those of hand cranking mode. The study was conducted during the year 2010.

The optimal power output and pedalling rate for Indian agricultural workers has been worked out as 60 W and 50 rev/min, respectively (Tiwari *et al.* 2011). The speed of output shaft of dynapod at pedalling rate of 50 rev/min is about 167 rev/min. On the other hand, the results of a simulation study conducted on rotary maize sheller indicated that the optimum operating speed for maximum shelling capacity and minimum torque is 70 rev/min (Tiwari *et al.* 2011). Power from the output shaft of dynapod was transferred to input shaft of rotary maize sheller using V-belt and pulleys. To get the operating speed of about 70 rev/min at power input shaft of maize sheller a 101.6 mm pulley was used on the output shaft of dynapod and a 254.0 mm pulley was used on input shaft of rotary maize sheller.

Physiological responses of 10 agricultural workers (subjects) were measured while operating the maize sheller in pedalling mode using the dynapod as an interface between human worker and the rotary maize sheller (Fig 1) and in hand cranking mode. The subjects were very well familiar with bicycle riding and were screened for postural abnormalities or movement restrictions. Before conducting the experiments for measurement of physiological responses each subject was checked for cardiovascular, neuromuscular and musculoskeletal disorders. Basic physical and physiological characteristics namely age, weight, stature and maximum heart rate of the selected subjects were measured in laboratory. Personal weighing balance (100 kg capacity, least count 0.1 kg) was used for the measurement of weight of the subjects. Stature of the subjects was measured using stadiometer (Least count 1 mm). Maximum heart rate of subjects was determined by using the equation "220 - age (in years)". The basic physical and physiological characteristics of the subjects participated in the experiment are given in Table 1. Table 2 presents the morphological characteristics of maize cobs used for evaluation of maize sheller.

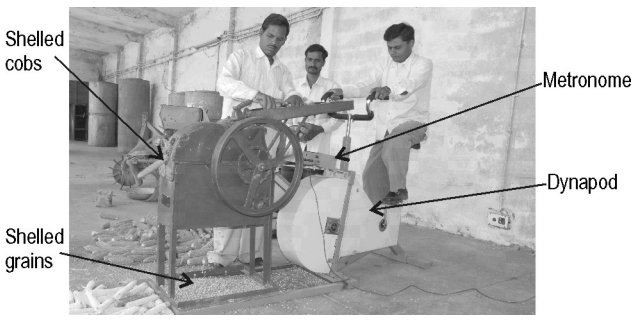

Fig 1 Rotary maize sheller during operation in pedalling mode using dynapod

Table 1 Physical and physiological characteristics of subjects participated in the experiments

Subject No.	Age (Years)	Weight (kg)	Stature (m)	Age predicted HR_{max}, (beats/min)
1	22	60.0	1.71	198
2	27	58.5	1.66	193
3	22	49.0	1.57	198
4	33	59.0	1.63	187
5	36	51.5	1.70	184
6	24	44.0	1.57	196
7	26	59.0	1.70	194
8	43	60.0	1.67	177
9	33	42.0	1.60	187
10	33	54.0	1.59	187
Mean	29.9	53.7	1.64	190.1
SD	6.84	6.80	5.52	6.84

Heart rate of the subjects was measured using polar NV heart rate monitor. Heart rate responses for first 5 minutes were taken while the subject was resting. Saddle height (vertical distance measured from the axis of the pedal when the pedal was at its distal position to the top surface of the saddle) for each subject was decided on the basis of trochanteric height (vertical distance from standing surface to the most superior point of the greater trochanter, one of the bony prominences developed near the upper extremity of the femur to which muscles are attached). The saddle height was kept equal to 96% of trochanteric height (optimised saddle height on the basis of an experiment conducted at different saddle heights). Before each trial the

Table 2 Morphological characteristics of maize cobs used for evaluation of maize sheller

Parameters	Description/value
Variety of maize	JM-15
Moisture content of kernel at the time of shelling, % (db)	15.29
Average no of cobs in 50 kg sample	265
Kernel/pith ratio	4.35
Average cob length (mm)	167
Maximum diameter of cob at base end (mm)	47.2
Minimum diameter of cobs at head end (mm)	33.2
Weight of single cob (g)	183.4

saddle height was set equal to 96% of trochanteric height of the subject. After the initial 5 minutes rest the subject was asked to pedal the dynapod at a pedalling rate of 50 rev/min. An audio-cum-light metronome set at 50 beeps/min and placed in front of the subject guided him for maintaining the pedalling rate. Weight of maize cobs shelled during 15 min period of operation was noted. Heart rate was calculated by averaging the heart rate data for last 10 minutes.

To have a meaningful comparison of physiological responses during operation of maize sheller in two modes of operation the increase in heart rates over resting values (ΔHR) were calculated. The data on ΔHR obtained for 10 agricultural workers during operation of maize sheller in two modes of operation were subjected to statistical analysis to know the effect of modes of operation on physiological responses.

After the 15 min trial the subject was asked to sit on a chair and quantify his overall discomfort rating (ODR) due to the work he had just finished. For this purpose a ten-point Visual Analogue Discomfort Scale (VADS) described by Leg and Mahanty (1985) was used, with '0 (no discomfort)' and '10 (extreme discomfort)' marked at its left and right-hand ends, respectively. The subject was asked to indicate the point on the scale, which represented his current level of overall discomfort by sliding a pointer on it. The overall discomfort ratings (ODR) given by each of the 10 subjects were averaged to get the mean value. It is to mention here that prior to conducting the main experiments the subjects were anchored to the ten-point VAD scale during preliminary trials. For this anchoring the subjects pedalled a bicycle ergometer (Monark, Ergomedic 839 E, Sweden) at different workloads and pedalling rates.

The data on performance of rotary maize sheller, i.e. shelling capacity and physiological responses, i e increase in heart rate over resting values (ΔHR) during its operation in pedalling mode as well as hand cranking mode were statistically analysed using t-test. Analysis of variance (ANNOVA) was used for comparing the results.

RESULTS AND DISCUSSION

Performance of maize sheller during pedalling and hand cranking modes

The major performance parameters, which were studied during evaluation of rotary maize sheller in pedalling and hand cranking modes of operation, were shelling capacity (throughput) and shelling efficiency. Visible kernel damage and cob break-up were also observed during these tests. Table 3 presents the data on these performance parameters during the operation of maize sheller in both the operating modes.

Table 3 Performance of rotary maize sheller in pedalling and hand cranking modes of operation

Performance parameter	Value	
	Hand cranking	Pedalling using dynapod
Average operating speed of maize sheller (rev/min)	54.2	68.6
Time taken for shelling 50 kg sample (min)	16.89	10.60
Shelling capacity (throughput) (kg of cobs/h)	177.62	282.70
Shelling capacity (output) (kg of kernel/h)	144.42	229.86
Shelling efficiency (%)	98.53	98.52
Visible kernel damage (%)		
Cob break up (%)		

Effect of mode of operation on shelling capacity of rotary maize sheller

It is evident from Table 3 that the shelling capacity of maize sheller increased by about 59% when operated in pedalling mode using dynapod in comparison to that during hand cranking mode. The major reason for this increase in shelling capacity was the increased operating speed of maize sheller when operated in pedalling mode as compared to hand cranking mode. In pedalling mode of operation it was possible to operate the maize sheller at optimal operating speed of 70 rev/min as obtained on the basis of simulation studies (Tiwari *et al.* 2011). In hand cranking mode the optimal operating speed of 70 rev/min could not be achieved because higher operating speed in hand cranking mode caused more stress on the operator and also the operator was not able to synchronize the rate of feeding with that of higher operating speed. Further, due to flywheel incorporated in dynapod the operating speed of maize sheller was more uniform in comparison to hand cranking mode.

Another reason for increased shelling capacity of maize sheller in pedalling mode of operation was the continuous and uniform feeding of cobs into the sheller. This was because another person was engaged for feeding the cobs. The person feeding the cobs was performing the operation by using his both the hands. In doing so, he used his right hand for picking/guiding the cobs from the feeding trough and feeding it into the throat of the machine. Sometimes, he had to push the cobs into the throat with another cob when forward movement of the cob was impeded while feeding a cob with diameter larger than the average diameter of cobs. His left hand was used for holding the cobs at place in the feeding trough. It was observed that when two or more cobs entered into the throat of the machine at a time, none of them got entry inside the machine. The operator had to remove all the cobs except one to let it go inside the machine. The cobs must be put one after the other for easy entry of cobs into the machine.

On the other hand in the hand cranking mode of operation the operator performed the hand cranking operation by his right hand and fed the cobs into the sheller by his left hand. In doing so he had to perform three functions simultaneously by his left hand. First he has to hold the cobs at place in the feeding trough to avoid them falling two or three at a time into the throat; second he has

to pick/guide the cobs to slide into throat of the machine one by one and third he has to push the cobs into the throat of the machine using another cob, if required. While doing all these activities simultaneously, once he concentrated on feeding the cobs to maintain continuous feeding, his cranking speed reduced and when he tried to maintain the cranking speed the cob feeding became improper.

Statistical analysis of data using t-test indicated that there was a significant difference in shelling capacity of maize sheller in two modes of operation. Shelling capacity in pedalling mode of operation using dynapod was significantly higher than that during hand cranking mode. ANOVA for the effect of two modes of operation on shelling capacity of the rotary maize sheller indicated that mode of operation affected the shelling capacity significantly ($P < 0.01$).

Effect of mode of operation on shelling efficiency of rotary maize sheller

Shelling efficiency of maize sheller is defined as the ratio of amount of grain removed from the cob during shelling operation to the total grain with the cob. Shelling efficiency of maize sheller was almost similar (98.52%) in both the operating modes.

Statistical analysis of data using t-test indicated that there was no significant difference in shelling efficiency of maize sheller in two modes of operation. ANOVA for the effect of modes of operation on shelling efficiency of maize sheller indicated that effect of modes of operation on shelling efficiency, was non-significant.

Effect of mode of operation on kernel damage

No visible kernel damage was observed in both the operating modes as the moisture content of kernels was low. Moreover, the operating speed of the machine was also low even in the pedalling mode of operation.

Physiological and psychophysical responses of agricultural workers during operation of maize sheller in pedalling and hand cranking modes

Data on physiological and psychophysical responses of agricultural workers during operation of the maize sheller in pedalling mode using dynapod and in hand cranking mode is presented in Table 4. It is evident from Table 4 that, ΔHR was about 67% higher during hand cranking mode as compared to pedalling mode of operation. The data clearly indicate that there was a substantial reduction in physiological cost during operation of maize sheller in pedalling mode in comparison to that during hand cranking mode. Further, the ΔHR during hand cranking mode (59.4 beats/min) was higher than the acceptable limit for continuous work for Indian agricultural workers (40 beats/min). On the other hand the ΔHR during pedalling mode (35 beats/min) was well within the acceptable limit for continuous work. Therefore, frequent rest pauses will be required during hand cranking mode, which will ultimately reduce the overall performance of man-machine system.

ANOVA for the effect of two modes of operation on ΔHR during operation of the rotary maize sheller indicated that mode of operation affected ($P<0.01$) the ΔHR significantly. The ΔHR during hand cranking mode of operation was significantly higher ($P<0.01$) than that during pedalling mode.

Average overall discomfort rating during operation of maize sheller in hand cranking mode was almost two times (7.0) to that achieved during pedalling mode (3.5).

The data clearly indicate that there was a substantial reduction in physiological cost during operation of maize sheller in pedalling mode in comparison to that in hand cranking mode. The major reason for this reduction in physiological cost during operation of maize sheller in pedalling mode was the mechanical advantage the operator was getting due to presence of a flywheel in the system. The flywheel stored the energy when in excess and supplied the same to the maize sheller when required. The speed of the maize sheller during operation in pedalling mode was almost uniform throughout the operation. On the other hand during the operation of maize sheller in hand cranking mode the speed of the machine reduced substantially when a larger diameter cob passed through the machine. In such condition, the torque required for rotating the crank increased and thus, operator had to exert more to rotate the crank. Further, in pedalling mode of operation the movement was only in the leg segments and the leg muscles performed the major activity in producing the required power. On the other hand, in the hand cranking mode apart from the movements in the hand segments, activity in the trunk muscles was also there for moving the body to and fro.

Average overall discomfort rating during operation of maize sheller in hand cranking mode was almost two times (7.0) to that achieved during pedalling mode (3.5). However, there is a need for study of psychophysical responses for longer duration of work for better quantification of reduction in these responses during operation of maize sheller in pedalling mode of operation.

The study demonstrated that the dynapod can be successfully used as an interface between the human worker and a hand operated rotary maize sheller to operate the machine in pedalling mode for getting more output from

Table 4 Physiological and psychophysical responses during operation of rotary maize sheller in two modes of operation

Physiological/psychophysical parameters	Value	
	Hand cranking	Pedalling using dynapod
Heart rate during operation of machine (beats/min)	139.6	115.5
Increase in heart rate over rest (ΔHR) during operation of machine (beats/min)	59.4	35.0
Average overall discomfort rating (ODR) on 10-point scale during operation of machine for 15 minutes	7.0	3.5

the machine with less effort and fatigue. Therefore, the dynapod-rotary maize sheller combination as such should be popularised amongst the maize growing farmers. Further studies with other low power rotary machines such as groundnut decorticator, grain mill, rotary type water pump etc. is required to quantify the improvement in performance of those machines and reduction in effort and fatigue due to operation of the machines in pedalling mode using the dynapod.

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