Ergonomic evaluation of cashew nut shelling machine

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ABSTRACT

This paper presents the ergonomic evaluation of a manually operated village-level cashew nut shelling machine. A manually operated cashew nut cracking machine was evaluated. Fifty subjects took part in the study, with physiological, postural, and subjective measurements being taken. Comfort Questionnaire for cashew nut cracking machine (CQC) was also evaluated. Using the machine resulted in postural discomfort. The perception of the subjects as per the efficiency of the machine was neutral; 50% accepted that the machine is efficient, while the other 50% were unsatisfied. Following a participatory ergonomic process and using appropriate anthropometric measurements, an improved, adjustable prototype was developed. The lever arm was designed based on 5th percentile of the subjects; blades were welded into the cracking lid to reduce the amount of impact force used for cracking, so as to reduce crushing of the nuts. Also the ergonomic seat and worktable allow posture change from sitting to standing. Other features include; feeding tray, foot rest. The work surface height is made to be 100mm below the elbow height. i.e. 1200mm. The length of the work table (work space) was designed to accommodate 95th percentile of the Bicromial breadth of the subjects. The foot and the knee room was 150mm. The cracking machine is bolted to the worktable, so that it can be easily disassembled. The study demonstrated how ergonomics could play an important role in reducing drudgery and improving user satisfaction and acceptability in technology development and transfer in developing country.

Keywords: Cashew nuts, cracking machine, Ergonomics, CQC, Anthropometric.

1. INTRODUCTION

The main economic characteristic of agriculture in developing countries is the low level of manual productivity. While the benefits of technology have been shown in many and varied circumstances, even rational and intelligent farmers may resist their implementation, so any machine improvement involves a slow rather than instantaneous acceptance (Mahendra and Awadhesh, 2010). This is a factor, which may affect efficiency in any labor operation.

Ergonomics focuses on human beings and their interaction with machines, materials, information, procedures and environments used in work and everyday living (Sanders et al., 1992). The branch of ergonomics that deals with human variability in size, shape and strength is called anthropometry. Anthropometry refers to the measurement of humans. Anthropometry has been considered as the very basic core of ergonomics in an attempt to resolve the dilemma of 'fitting people to machine' (Wang et al, 1999). Bridger, (1995), and Chou and Hsiao (2005) believed anthropometry is a research area in ergonomics dealing with the measurement of human body dimensions and certain physical characteristics. Anthropometric data can be used in ergonomics to specify the physical dimensions of workspaces, workstations, and equipment as well as applied to product design.

Cashew (Anacardium occidentale L.) is an evergreen tropical tree from northeast Brazil, which produces a valuable nut that is widely consumed as snacks all over the world. Cashew nut ranks third among the edible tree nuts of the world with a current output of about 700,000 metric tons nut in shell (FAO, 2004). Nuts may be sold raw or as processed kernels and may be further processed into value-added products such as fried, roasted or chocolate-coated kernels and confectioneries, etc.

McNeill and Westby (1999) evaluated a manually operated machine for chipping cassava. This study demonstrated how agricultural machinery developed for use in a developing country could be improved by employing a participative and iterative approach to design, paying closer attention to human factors. By incorporating ergonomics into the design process, drudgery associated with the machine was reduced and productivity, user comfort and satisfaction were increased. Improving the posture adopted to operate the machine resulted in a significant reduction in physical strain and incidence of body-part discomfort.

Kölsch et al (year?) proposed an objective measure for postural comfort. The proposed method allows for assessment of postural comfort. They determined the comfort zone by measuring compensating motion that allows participants to freely pick a comfortable posture range with the body part under scrutiny. Their method does not rely on acquisition of subjective data. Instead, it is entirely objective and allows for participants that are naïve to the study purpose body part under scrutiny. Mahendra and Awadhesh (2010) carried out the design, development and ergonomics evaluation of hand-operated spade (PHAWRA). This paper addresses ergonomics factors that can increase the utility of a hand-operated spade or hoe.

Ojolo and Ogunsina (2007) carried out the development of a cashew nut cracking device. The device was developed to improve the efficiency of the shelling operation in cashew nut processing. The performance of the machine is fairly satisfactory but an improvement on the percentage of whole kernels is achievable with further modification and testing. They concluded that a device of this nature can be manufactured in small machine shops in the developing countries for small entrepreneurs and village level applications.

Further research is carried out to evaluate the machine base on ergonomic considerations and to improve the design of the machine for better performance and user acceptance. The need to determine a suitable user and machine interface leads us to ergonomic evaluation of the cashew nut cracking device.

2. MATERIALS AND METHODS

2.1 CASHEW NUT CRACKING MACHINE DESIGN

Ojolo and Ogunsina (2007) developed the cashew nut cracking machine. The machine was conceived as a village-level, low-cost, simple-to-operate and easy-to-fabricate manually operated device capable of cracking many cashew nuts at a time. The machine is a simple device, which allows for adjustment and proper alignment of the nuts before cracking. It comprises of four major components assembled together by welding to form a compact device. The components are: the metal casing, the feeding tray which is supported by mild steel box, the cracking lid, and the lever arm. The complete machine assembly is shown in Figure 1a.

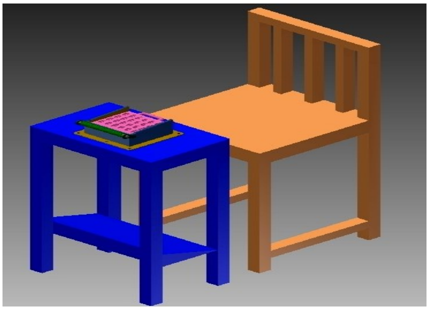


Fig. 1a: Cashew nut cracking machine Fig.1b: Ergonomically designed cashew nut cracker

A preliminary investigation was carried out to determine some properties such as dimension (length, thickness and width), cracking force and absorbed energy of the roasted nuts were determined; these nuts were shelled and the dimension of the kernels were determined (Table1).

Table 1: Design parameters of the cashew nut sheller			
Parameters	Mean	Mean deviation	Std deviation
Nut			
Length (mm)	30.40	1.36	1.61
Width (mm)	20.45	1.14	1.48
Thickness (mm)	18.71	0.89	1.08
Kernel			
Length (mm)	26.38	1.38	1.56
Width (mm)	13.43	0.68	0.86
Thickness (mm)	8.00	1.30	1.47
Cracking			
parameters Nut weight (g)	5.67	0.83	0.98
Cracking force	488.80	33.94	42.31
(N)			
Absorbed	1.36	1.14	0.89
Energy (MJ)			
Required power (W)	1.61	1.48	1.08

2.2. EXPERIMENTAL PROCEDURE

The experiment was based on a participatory ergonomics approach to improve the design of the cashew nut cracking device. This majorly comprise of two stages viz;

1) Testing of the existing cashew nut cracking device in the field and evaluation of comfort questionnaire.
2) Modification of the design of the existing cashew nut cracking device using the feedback from the users and relevant anthropometric data

2.3. SAMPLE PREPARATION

The cashew nuts obtained from ABOD cashew processing industry were subjected to pre-cracking treatments. The pre-treatment of cashew nuts prior to shelling makes the shell more amenable to fracture (Ogunsina and Bamgboye, 2011). The cashew nuts were roasted in batches in hot oil. Each batch was roasted by dipping the nuts inside pre-heated cashew nut shell liquid (CNSL) at the temperature of 190-200^{0}C for 1.5mins as specified by Ogunsina and Bamgboye (2011). The roasted nuts were discharged on saw dust to remove the residual coating of CNSL on the surface of the shell. Afterward, the nuts were allowed to cool naturally for 18h.

2.4 LIST OF EQUIPMENTS

Below are the lists of the equipment used for this survey:

1) Body weight scale
2) Stop watch
3) Measuring tape
4) Heart rate monitor
5) Digital balance

2.5 THE SUBJECTS

The study was carried out on farm with fifty users at ABOD cashew processing company in August 2012. The emphasis was on cracking. It was ensured that the participants have sound mental and physical health. Personal details of the subjects were obtained and the average values for the population were tabulated (Table 2).

2.6 ANTHROPOMETRIC MEASUREMENT

Thirteen measurements described by Pheasant (1990), that are relevant to the cashew nut cracking device were gathered from the subjects and used in developing a model cashew nut cracking device. The definition of the anthropometric dimensions used in this study is shown in Appendix 2. The 5th and 95th percentile values were obtained. Also, the mean and standard deviation is also presented. Measurements were taken to the nearest millimeter. During the measurements, the subjects were without shoes. The measurements were taken in accordance with the procedure described by Pheasant (2003).

2.7. POSTURAL DISCOMFORT

The postural analysis was based on a modified body map (Corlett and Bishop, 1976). Thirteen parts were identified to locate postural discomfort. Due to difficulties in presenting rating scales to illiterate subjects, they were asked whether they felt any pain or discomfort in each body part, with a yes or no response. To avoid any mix up with the names of body parts, the experiment pointed at each area in turn. This was repeated before and after cracking. Pain was defined as any numbness, stiffness, tingling, pulling, burning or aching. The specified area of study are as follows; neck, shoulder, upper arm, fore arm, wrist, upper back, waist, thigh, lower leg, feet, buttock, fingers.

2.7.1. COMFORT QUESTIONAIRE FOR CASHEW NUT CRACKING MACHINE (CQC)

The subjects were asked to crack 18.1kg (approximately 2745 nuts) of cashew nuts. After the subject had finished the cracking operation, the descriptors of the comfort questionnaire were rated and (where necessary) the meanings of the descriptors were explained. At last the subject rated the overall comfort.

2.7.2 WORK RATE

The time required to crack 18.1kg of cashew nuts was recorded as an indication of work rate. Weight was measured using a digital balance. The entire subject worked for the one hour; however, 20% the total population selected were unable to complete the cracking within the stipulated time.

2.7.3 MAXIMUM WORKING HEART RATE

Table 2: Personal details of the subjects from ABOD cashew essing industry

Subjects	Age	Sex	Weight	Height	Resting heart rate (bmp)	Max Heart rate(bmp)
1	27	M	72	1798	62	193
2	31	M	64	1600	70	189
3	28	M	66	1798	63	192
4	27	M	66	1707	64	193
5	26	M	59	1750	62	194
6	29	M	68	1768	65	191
7	22	M	60	1680	62	198
8	31	M	60	1750	65	189
9	25	M	70	1798	64	195
10	29	M	73	1700	67	191
11	25	M	68	1676	64	195
12	25	M	68	1770	63	195
13	29	M	63	1768	65	191
14	32	M	66	1706	68	188
15	28	M	65	1798	63	192
16	25	M	56	1524	65	195
17	27	M	72	1800	62	193
18	21	M	59	1560	62	199
19	18	F	50	1540	65	202
20	30	F	51	1570	71	190
20	31	F	56	1524	63	189
22	20	F	53	1522	64	200
23	39	F	58	1646	65	181
24	28	F	50	1500	64	192
25	35	F	68	1524	64	185
26	41	F	60	1554	76	179
27	33	F	62	1615	62	187
28	30	F	69	1640	63	190
29	32	F	78	1640	64	188
30	40	F	60	1520	78	180
31	19	F	55	1554	63	201
32	31	F	57	1524	64	189
33	30	F	64	1524	62	190
34	22	F	54	1585	64	198
35	34	F	68	1600	64	186
36	42	F	58	1615	74	178
37	18	F	46	1372	61	202
38	37	F	70	1524	70	183
39	42	F	78	1524	71	178
40	38	F	65	1615	63	182
41	21	F	56	1502	62	199
42	23	F	50	1550	65	197
43	25	F	60	1370	61	195
44	29	F	65	1650	63	191
45	35	F	63	1620	68	185

46	18	F	60	1524	62	202
47	27	F	66	1600	63	193
48	39	F	64	1550	65	181
49	34	F	69	1690	65	186
50	26	F	55	1400	62	194
Mean	29.08		62.26	1612.78	64.94	190.92
SD	6.461		7.28	112.45	4.33	7.58

Heart rate was measured using heart rate monitors and logged at one-minute intervals. Resting heart rates were taken, and maximum heart rate was estimated according to the formula 220 - age (Rodahl, 1989). To enable a more meaningful comparison, individual differences between subjects were minimized by expressing working heart rates as a percentage of an individual effective heart rate range. This was calculated from resting and predicted maximum heart rates. Therefore, the maximum working heart rate formula is defined as follows;

$$WHR_{MAX} = (HR_{MAX} - RHR) \times 0.85$$
(1)

$$HR_{MAX} = 220 - age$$
(2)

Where, WHR_{MAX} is the percentage maximum working heart rate

HR_{MAX} is the maximum heart rate (bpm)

RHR is resting heart rate (bpm).

3. RESULTS AND DISCUSSION

3.1. ANTHROPOMETRIC MEASUREMENTS

The personal details and anthropometric characteristics of the subjects selected for this study are as presented in Table 1 and 2. The mean age of the population is 28.09years; the mean weight is 62.26kg; while the average height is 1612.78mm. Also the average resting heart rate 64.94bmp and the average maximum heart rate is 190.92bmp. In table 2, the 5th and 95th percentile values are presented.

Table 3: Anthropometric of selected subjects

	Men (n=18)				Women (n=32)					
Percentile	5th	50th	95th	SD	5th	50th	95th	SD	Min	Max
Stature	1554.6	1554.6	1798.3	84.8	1387.4	1550	1647.8	75.5	1387.4	1798.3
Shoulder height	1314	1450	1560.5	80.6	1195.5	1365	1420	83.2	1195.5	1560.5
Elbow height	1059.5	1130	1300	72.7	895.5	1050	1194.5	86.4	895.5	1300
Knuckle height	670	760	918	83.0	577.5	700	763.5	67.8	577.5	918
Shoulder to fingertip	720	800	900.3	55.1	586.5	730	824.5	77.9	586.5	900.3
Elbow to fingertip	430	505	625.5	76.2	320	465	520	65.3	320	625.5
Biacromial breadth	380	440	613	68.6	385.5	445	487.3	36.0	380	613
Propliteal height	350	430	525	68.8	401.1	440	500	34.8	350	525

Thigh thickness	500	570	715	73.0	416.5	510	584.5	51.1	416.5	715
Knee height	388.5	470	586.5	76.4	445.5	500	570	46.9	388.5	586.5
Length of hand	150	190	224.5	34.3	140	195	215	14.8	120	224.5
Length of palm	99.1	114.5	151.5	17.5	100	120	140	17.3	99.1	151.5
Palm breadth	88.5	110	150.75	19.8	96.65	102.5	120	8.9	88.5	150.75

3.2 POSTURAL DISCOMFORT

The mean and percentage frequency of reporting for the subjects are as shown in Table 3. After using the equipment, maximum number of populations representing 96% felt pain at their wrist. This is due to the repetitive motion of the wrist when closing the cracking lid. 80% percent of the population felt pain on their; shoulder, upper arm, forearm, and knee. This was felt mostly by the subjects that maintain stooping position during cracking operation.

Table 4: Body parts' comfort consideration at the end of the cracking operation

PART	SUCCESS (NO)	FAILURE (YES)	% YES)	% (NO)
Neck	20	30	60	40
Shoulder	10	40	80	20
Upper arm	10	40	80	20
Fore arm	10	40	80	20
Waist	9	41	82	18
Wrist	2	48	96	4
Thigh	35	15	30	70
Upper back	19	31	62	38
Lower leg	25	25	50	50
Feet	30	20	40	60
Buttock	40	10	20	80
Knee	10	40	80	20
Fingers	6	44	88	12

3.3 COMFORT QUESTIONAIRE FOR CASHEW NUT CRACKING MACHINE (CQC)

Overall comfort rating in Table 4 gives the capacity of the worker to work with the machine and also their level of satisfaction. It was noted that the major part of the subjects that maintain the stooping position during the cracking operation could not finish the cracking; this was due to the severe pain at their waist. The average overall comfort of the entire population is 3.18. This indicates that the entire population was only "somewhat" satisfied with the machine. 90% of the subjects accepted that;

1) The machine is simple in use.
2) It needs a hand grip.
3) It is very easy to move.
4) It is usable in the absence of electricity.

5) Operable with both left and right hand.

However, the perception of the subjects as per the efficiency of the machine was neutral.50% accepted that the machine is efficient, while the other 50% were unsatisfied.

3.4 WORK RATE

The work rate was significantly faster when compared with the manual method used at ABOD. The average subjects were able to crack 18.3kg of cashew nuts in an hour as against 15kg that can be cracked by most experience operator using manual method in an hour. Eight subjects withdrew from the operation after 45mins, complaining of fatigue and discomfort.

Table 4: Overall comforts rating of the subjects

Subjects	CQC	Subjects	CQC
1	4	26	3
2	3	27	4
3	2	28	4
4	5	29	4
5	4	30	5
6	2	31	2
7	2	32	3
8	3	33	2
9	4	34	3
10	5	35	4
11	5	36	3
12	4	37	3
13	2	38	2
14	3	39	5
15	3	40	2
16	3	41	5
17	2	42	5
18	2	43	4
19	3	44	4
20	4	45	3
21	2	46	3
22	2	47	3
23	2	48	5
24	2	49	2
25	2	50	1
		Sum	159
		Average	3.18

3.5 HEART RATE

The resting and working heart rate is shown in Table 5. All the resting heart rate falls within the range of 60-100bmp which is normal.

Table 5: Heart rate of the subjects

Subjects	Resting heart rate	Max heart Rate	Max working Heart rate
1	62	193	111.35
2	70	189	101.15
3	63	192	109.65
4	64	193	109.65
5	62	194	112.2
6	65	191	107.1
7	62	198	115.6
8	65	189	105.4
9	64	195	111.35
10	67	191	105.4
11	64	195	111.35
12	63	195	112.2
13	65	191	107.1
14	68	188	102
15	63	192	109.65
16	65	195	110.5
17	62	193	111.35
18	62	199	116.45
19	65	202	116.45
20	71	190	101.15
20	63	189	107.1
22	64	200	115.6
23	65	181	98.6
24	64	192	108.8
25	64	185	102.85
26	76	179	87.55
27	62	187	106.25
28	63	190	107.95
29	64	188	105.4
30	78	180	86.7
31	63	201	117.3
32	64	189	106.25
33	62	190	108.8
34	64	198	113.9
35	64	186	103.7
36	74	178	88.4
37	61	202	119.85
38	70	183	96.05
39	71	178	90.95
40	63	182	101.15
41	62	199	116.45
42	65	197	112.2
43	61	195	113.9
44	63	191	108.8
45	68	185	99.45
46	62	202	119
47	63	193	110.5
48	65	181	98.6
49	65	186	102.85
50	62	194	112.2
Mean	64.94	190.92	107.08
SD	4.33	7.58	9.20

4.4. Ergonomic Design of The Cashew Nut Cracking Machine

After review of various components of a cashew nut cracking machine, it was discovered that there are some components that need to be redesigned for better performance. The features considered for ergonomic design of cashew nut cracking machine include;

1. Lever arm
2. Feeding Tray
3. Cracking lid
4. Ergonomic seat and work table.

4.4.1. LEVER ARM

A properly designed grip help to reduce fatigue and pain, and it instantly feel comfortable in the hand. The present lever arm does not allow a firm grip that is why the user feels pain on their wrists. The lever arm was changed to the hand grip that allows the fingers to coil around the handle. Based on anthropometric data of hand, the diameter of the hand has been fixed so as to achieve better grip facilities. The hand grip makes a fist with four fingers on one side and the thumb on the other side. The hand grip is designed to be used by the people using left or right hands. The right-sized handle is one that allows the hand to go more than halfway around the handle without the thumb and fingers meeting (Mahendra et al, 2010). The recommended grip diameter is based on the 5th percentile of the finger length population. A value of 35mm is selected. The material selected for the handle is mild steel. The grip surface of the hand grip should be smooth, non-conductive, and slightly compressible to dampen vibration and better distribute hand pressure. So, the grip surface is insulated with rubber because it is strong and comfortable enough to prevent crack and injured hand (Fig. 2).

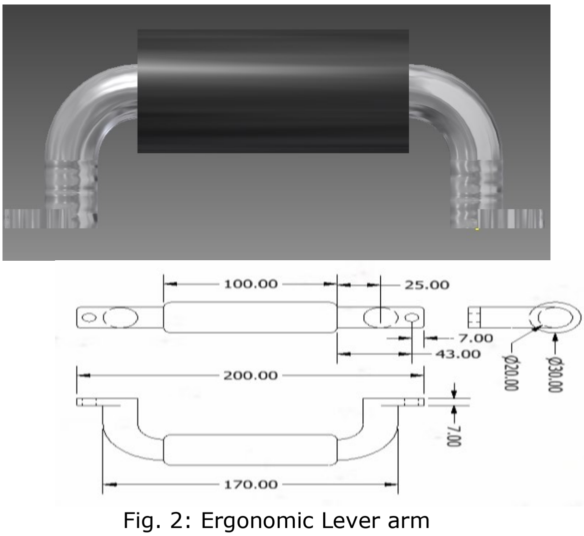
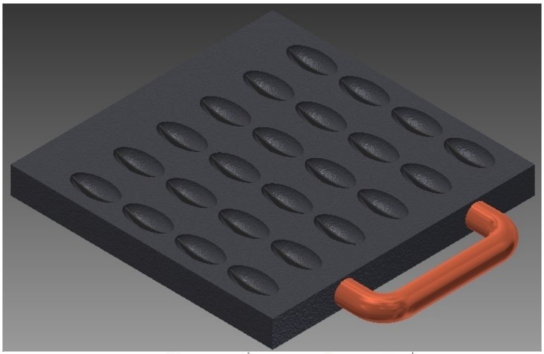


Fig. 2: Ergonomic Lever arm

4.4.2 FEEDING TRAY

The blade was incorporated into the feeding tray. This was done to ensure that the cashew nut is neatly cracked without damaging the kernel due to several impacts of the cracking lid on the nuts. The feeding tray is made of cast aluminum plate, with mild steel blade inserted into each groove. The thickness of the blade is 1mm. The tray is supported on both sides by flat plate made of mild steel welded to the main body to allow easy sliding of the feeding tray.



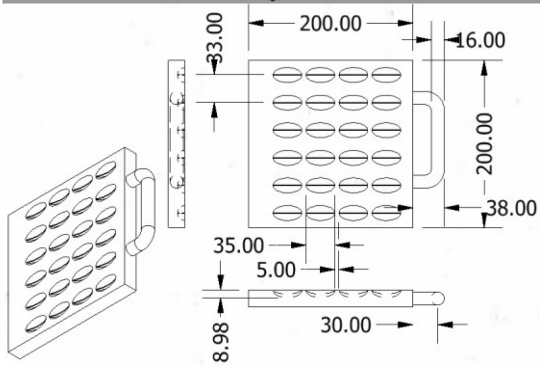


Fig. 3: Ergonomic feeding tray

4.4.3 CRACKING LID

The cracking lid is machined and dimensioned such that the working part that is in direct contact with the cashew nut is of varied extension into the box. A clearance of 20mm is allowed on each side of the lid. This serves as a guide, and also ensures that the force exerted on the cashew nut is not excessive. The extended part of the cracking lid was stepped (made of varied thickness) so as to ensure even contact between the cracking lid and the cashew nuts. The blade was also welded to the cracking lid so that some level of shearing is achieved in the course of cracking operations. The thickness of the blade is 1mm.The geometry of the blade is such that it mirrors the kidney shaped section of the cashew nut (Fig. 4). The average cracking force is 488.8N (Ojolo and Ogunsina, 2007). And since it is less than tensile strength of the mild steel, the mild steel was selected for the lid due to its low cost and availability.

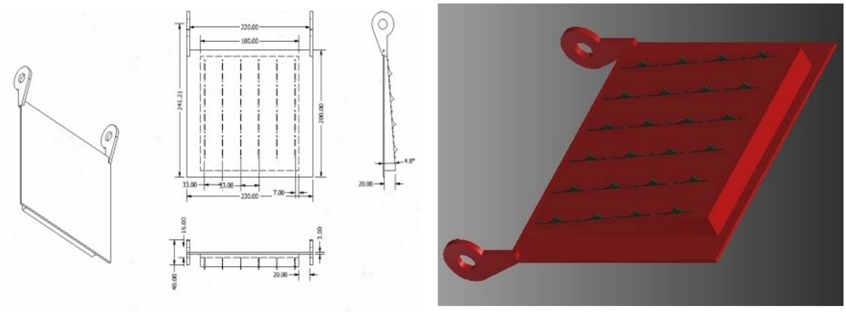


Fig. 4: Ergonomic cracking lid

4.4.4 ERGONOMIC SEAT AND WORK TABLE

A stooping posture adopted by some users during cracking operation is undesirable, with spinal flexion causing deformation of the intervertebral disc and exerting a risk of the nucleus been extruded (Pheasant,1991).The working height of the machine was raised so as to reduce the angle of flexion, hence, reduction in musculoskeletal pain or discomfort following cracking operation. Grandjean et al (1997) recommended that the work table could range between 28” to 43” depending on whether the table is meant for light, precision, or heavy work. This was clearly explained to mean 4” to 6” below the elbow height (www.site.iugoza.edu.ps/ddagga/file/201). The work surface height is designed based on 95th percentile of the users. The work surface height is made to be 100mm below the elbow height. i.e. 1200mm.The length of the work table (work space) was designed to accommodate 95th percentile of the Bicromial breadth of the subjects. The foot and the knee room were 150mm.The foot rest was provided to allow operator’s foot to be normal to the lower leg at an angle of 250. The foot rest is based on 95th percentile popliteal height of the female population, so, it is 500mm above the finish floor level, and it was made adjustable by 100mm to accommodate other users (Fig.5).

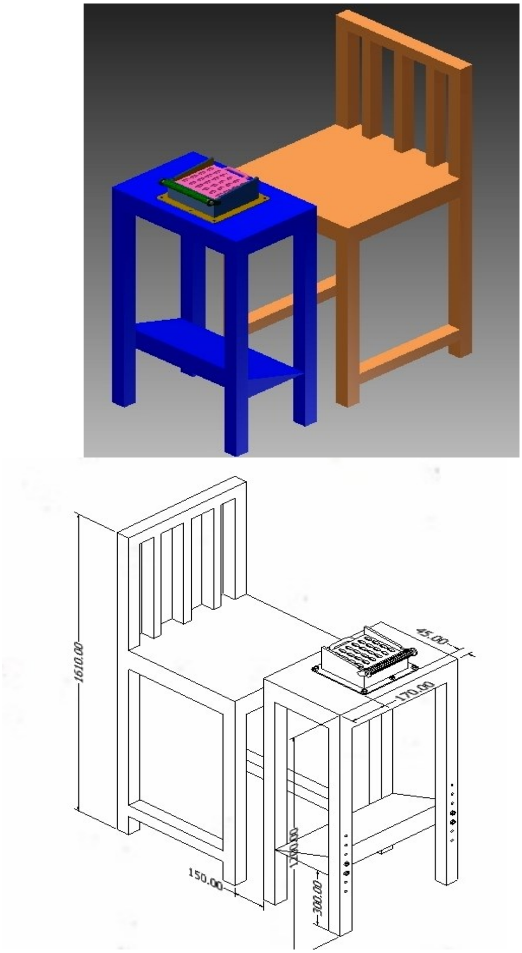


Fig. 5: Ergonomically designed work table and seat

4. CONCLUSION

The benefits of using a participatory ergonomics approach were demonstrated in this study. It allowed for a rapid identification of the problems encountered by the users and improvements to be developed with their co-operation, ensuring they perceived ownership of the technology. For the better and easier utilization of human power there is a need to develop a better working environment. In the process of making a better machine, this research first determined some dimensions in consideration of desirable ergonomics aspects. The study identified some areas in need of change. Availability of market for cashew nut is not questionable, but human and machine must be conditioned to meet up with this ever-growing demand. This research indicates a way forward to improve the design and construction of cashew nut cracking machine. It is believed that this will lead to improved labor productivity.

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