FINAL TECHNICAL REPORT / RAPPORT TECHNIQUE FINAL

ANNEX 2.12 RESEARCH INITIATIVES FOR ADDRESSING THE TECHNOLOGY GAPS IN PRIMARY PROCESSING OF SMALL MILLETS

DHAN Foundation;McGill University;Tamil Nadu Agricultural University;

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IDRC Grant / Subvention du CRDI: 108128-002-Scaling Up Small Millet Post-Harvest and Nutritious Food Products (CIFSRF Phase 2)

Research initiatives for addressing the technology gaps in primary processing of small millets

Research Institutions
Tamil Nadu Agricultural University
McGill University
DHAN Foundation

Report Type
Research report

Location of Study
India

Date
April 2018

Scaling up Small Millet Post-harvest and Nutritious Food Products Project

Contents

Research initiatives for addressing the technology gaps in primary processing of small millets

A detailed assessment of existing small millet processing machines and the issues related to primary processing of small millets by the experts indicated that improvement is needed in the following areas:

1. Improving the separation of materials other than grains from grains in the raw material supplied to the processing units
2. Optimising the hulling technology to process different small millet crops based on scientific principles.
3. Improving the separation mechanism in hullers to reduce removal of grits and other usable materials along with the husk.
4. Improving the grader in terms of its sieving efficiency to meet pre- and post-hulling segregation requirements of different small millet crops and its footprint.
5. Improving the post hulling machinery to separate unhulled from the hulled grains and to remove finer stones and mud balls similar in size and weight as rice and grits.
6. Optimising the 'process line' for improving the versatility, head rice recovery, and product quality, for minimizing the cost of processing, and for reducing pest incidence; this in turn will increase the viability of the processing enterprise.
7. Reduction of the cost of the machines in the process line by reducing the footprint, height, weight and energy requirements; this will help in making them more affordable.
8. Improving the ease of use, ease of maintenance and servicing, and safety, considering the power requirements, skill requirements, and gender concerns, to reduce the downtime and to reduce the pest infestation.
9. Improving the capacity of the huller and other processing equipment to meet the processing requirements at the SME level.
10. Improving the shelf life of hulled small millets.

Some of the research activities taken up to address these issues are shared in detail below.

1. Testing of equipment designed for other crops/commodities for hulling small millets

1.1 Testing of Otake centrifugal rice huller for processing small millets

Issues and problems:

During the assessment of existing equipment available in the market for processing small millets, it was found that the centrifugal hullers are not energy efficient as they were disproportionately heavy and large when compared to the quantum of hulling. So, it was decided to test some of the latest grain processing machines for their efficiency in hulling small millet grains.

Trials using Otake centrifugal rice huller for processing small millets

A search has been made to identify s that are designed using scientific principles for ensuring performance in terms of rice recovery and hulling efficiency along with being energy efficient, compact, lightweight and most importantly user friendly. The explorations led to OTAKE impeller pickpocket unit FSE28G-M working on the centrifugal principle. Many trials of this rice were conducted by DHAN- on its own, with earth360 Eco Ventures Pvt. Ltd. and with SAS Technologies, Canada.

Parameters considered

1) Suitability to hull different small millets
2) Hulling efficiency
3) Rice recovery
4) Capacity of huller
5) No. of pass required
6) Ease of operation

The above parameters were tested for different grain flow rates.

Otake huller

Results:

Sl. No.	Millet used	Moisture %	Hulling efficiency %	Avg. rice recovery %	Husk%	Broken %	Avg. O/P Kg/hr	No of pass required for 90-95% hulling
1	Foxtail Millet	11.7	95	75	19	< 5%	420	1
2	Little Millet	11.1	95	77	17.7	< 5%	470	1
3	Proso Millet	11.3	90-95	73	18.3	Between 7-10%	407	1
4	Kodo Millet	8.9	90-95	66	25	8%	200	3
5	Barnyard Millet	11.1	90-95	66	21	10%	250	2

The data generated from the trials undertaken at Kadiri, Andhra Pradesh are given in Annex (i). It was found that the Otake huller fared well on two aspects: (i) performance and (ii) improved design features. The performance data from trials with earth360 Eco Ventures Pvt. Ltd. are shared below: The hulling efficiency ranged from 90 to 95 % and rice recovery varied from 66 to 77%. Otake huller performed quite well for foxtail millet, little millet and proso millet. In terms of design features, it is relatively light, low noise, required only a small motor, compact, portable and has a low hopper that makes it easier to operate. Using a one horsepower motor and weighing 85 kg, it was able to process 200kg (kodo millet) to 470kg (little millet) per hour. The hullers available in the market use 5 to 7 HP for the same performance and weigh more than 300 kg.

Otake huller- Improved design features

1) Compact, low weight and portable

Ease of lifting and transporting

The dimensions are Length-0.92 m, Breadth-0.68 m & Height-0.80m; area occupied is 0.625 sq.m; volume is 0.5 cu.m; weight is 78 kg; and has wheels at one side of bottom

2) Safe to operate- Motor, belts, pulleys and all moving parts are covered and the frame is totally closed on all sides


Power transmission

3) Less power requirement- very low power of 1 H.P required to hull and separate rice & husk, three phase motor; single shaft for both hulling and aspiration. Power from motor transferred through belts and pulleys.


Better grain flow control

4) Better grain flow control-Better control of grain flow because of two controls-a) Push & pull type-hole smaller or bigger at bottom of hopper and b) Gears in impeller housing- hole size progressively bigger. Due to 16 gear teeth, wide range of grain flow rate adjustment is possible

5) Improved hulling chamber design- The design is such that the grains are directed accurately towards the impact surface before hitting and towards exit after hitting. In the case of centrifugal huller models available in the market, the grain moves in many directions, especially after hitting, thereby reducing the control over hulling. Due to uniform impact surface, the grains hit at the same rate and angle. The impeller has 16 vanes and is made of plastic, which helps in reducing the operational power required by the machine. The hulling chamber can be easily opened with hands.


Lining rubber – Uniform impact surface

6) Possibility of using lining rubber many times- Uniform impact surface is ensured through lining rubber. Rubber surface can be flipped and used, once one side gets worn out. The lining rubber is the only component that needs replacement.

7) Effective outward movement of grains in the hulling chamber- There is no collection of material at one side of hulling chamber, as is the case of centrifugal impact small millet hullers available in the market.


Ease of dismantling

8) Aspirator coupled with impeller in same shaft -It being driven by the same shaft as that of the impeller, the number of machine parts is reduced. Regulating airflow is easy with a long handle and small opening at the side body.

Spring clips

9) Ease of dismantling, cleaning & maintenance- Does not require tools to dismantle parts for cleaning as wing screws, hand screws and spring clips are used instead of nuts and bolts.

10) Use of food grade stainless steel for inner parts- The hulled output from the hulling chamber passes through rust proof stainless steel food grade parts before coming out of the outlet and it satisfies government regulation on food grade machines.

Level indicator

11. Level indicator-The machine has a simple needle hanging at one side of the frame to help in aligning the machine properly with the ground surface.

12. Improved hopper design- High capacity of hopper-15 kgs; Easy to feed the grains (waist high) and ergonomic design makes the machine gender neutral.

Attached grader and Output collection

13. Attached grader - Helps in removing grits, dust and broken from the final rice output.

14. Ease of output collection- Inbuilt elevator, which helps in easy collection of the output in sacks directly.

15. Good quality bearings- Agricultural grade bearings used, which does not get heated on long hours of usage.

The observations made by the team of experts from the trials conducted with earth360 Eco Ventures Pvt. Ltd. include,

(i) The Otake huller design holds promise for the efficient small scale dehulling of different types of small millets.

(ii) It is easy to operate and to clean in between batches.

(iii) The efficiency of the Otake huller is superior to all other Indian hullers with a higher rate of rice recovery and also reduced breakage.

(iv) The power consumption is very minimal compared to the current design of hullers available in India.

The observations of Dr. Sam Sotocinal, SAS Technologies is shared below:

This machine performed well beyond expectations. It is relatively light, low noise, required a small horse power motor, mobile and has a low hopper that made it easier to operate. Using a 1/2 horsepower motor it was able to process 300 kilograms of little millet per hour at almost 100% milling efficiency. An add-on grader unit allowed for clean, graded grain at the output of the machine. A modification of this design is the best option to end the search for an energy efficient and effective millet dehuller. Reverse engineering this design and employing laser cutting technology will result in a cheaper and more efficient millet mill.

Dissemination of results:

The design features of this huller are considered as a benchmark for designing hullers for small millets. Efforts were taken to share the design and performance advantages of this huller with equipment manufacturers and potential buyers. Demonstrations were organised at Grain Tech 2017, Madurai Symposium, at Salem (for AVM), Organics and Millets 2018, Bangalore, at Krishnagiri (for Victor, Earth 360 (processor) and Bigstamp (machine designer)) and at Virudhunagar (for government departments and FPOs). The lessons learned were shared at the national seminar on "Emerging Trends in Processing & Value Addition of Small Millets". Convinced by the performance of the Otake rice for small millets, Tumkur Organic Farmers Federation, Udupi Organic Farmers Federation and Anandam Enterprises from Virudhunagar have purchased it for their processing units.

Way forward:

Efforts were made for incorporating some design changes in their existing models based on the Otake design. A new prototype huller based on this machine is being developed and the details are given in the next section.


Trials with Otake rice huller

1.2 Trials on using specific gravity separator for removal of unhulled grains from rice and grits

Issues & problems:

Removing materials other than grains like weed seeds, stones and dust from grains, and unhulled grains from hulled grains has been difficult for small millets with the existing destoners and size based graders. Similarly segregating small millet rice of different sizes was also found to be difficult due to the small size of small millet grains.

Trials on using specific gravity separator for removal of unhulled grains from rice and grits

To address the above mentioned issues, the specific gravity separation method was tried as it makes use of a combination of weight and surface characteristics of the grain to be separated and also employs the principle of floatation which is a novel method not tried yet on small millets.

Procedure adopted and details of trials undertaken

The specific gravity separator of Westrup model was used for the trials on segregation. The parameters selected for the study is given in the Table. 1.

Table 1: Parameters for separation of unhulled grains from the dehulled grains

Parameters	Variables
Feed Rate	2 kg, 3 kg, 4 kg
Angle of Deck (Vertical)	0, 10, 20
Angle of Deck (Horizontal)	0, 10, 20
Frequency of Oscillation	250, 300, 350
Air Velocity	2 m/s, 3 m/s, 4 m/s

The de-hulled millets of Kodo, Foxtail, Barnyard and Little millet were processed with specific gravity separator. Response Surface Methodology was used with Box Behnken Method for conducting the trails. The details are given in the Table 2.

Separation of unhulled grains from dehulled grains

Table .2: Trails of variable for separation of unhulled grains from dehulled grains

			Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Std	Run	Block	A:Feed Rate	B:H.Angle	C:V.Angle	D:Frequency of oscillation	E:air velocity
			kg	theta	theta	hz	m/s
11	1	Block 1	3	0	10	300	4
24	2	Block 1	3	20	20	300	3
37	3	Block 1	3	0	10	250	3
15	4	Block 1	2	10	20	300	3
25	5	Block 1	2	10	10	250	3
34	6	Block 1	4	10	10	300	2
22	7	Block 1	3	20	0	300	3
40	8	Block 1	3	20	10	350	3
12	9	Block 1	3	20	10	300	4
33	10	Block 1	2	10	10	300	2
2	11	Block 1	4	0	10	300	3
17	12	Block 1	3	10	10	250	2
13	13	Block 1	2	10	0	300	3
42	14	Block 1	3	10	10	300	3
1	15	Block 1	2	0	10	300	3
39	16	Block 1	3	0	10	350	3
23	17	Block 1	3	0	20	300	3
10	18	Block 1	3	20	10	300	2
46	19	Block 1	3	10	10	300	3
30	20	Block 1	3	10	20	300	2
8	21	Block 1	3	10	20	350	3
18	22	Block 1	3	10	10	350	2
3	23	Block 1	2	20	10	300	3
28	24	Block 1	4	10	10	350	3
14	25	Block 1	4	10	0	300	3
4	26	Block 1	4	20	10	300	3
26	27	Block 1	4	10	10	250	3
21	28	Block 1	3	0	0	300	3
38	29	Block 1	3	20	10	250	3
5	30	Block 1	3	10	0	250	3
31	31	Block 1	3	10	0	300	4
9	32	Block 1	3	0	10	300	2
43	33	Block 1	3	10	10	300	3
19	34	Block 1	3	10	10	250	4
6	35	Block 1	3	10	20	250	3
29	36	Block 1	3	10	0	300	2
44	37	Block 1	3	10	10	300	3
41	38	Block 1	3	10	10	300	3
20	39	Block 1	3	10	10	350	4
7	40	Block 1	3	10	0	350	3
35	41	Block 1	2	10	10	300	4

45	42	Block 1	3	10	10	300	3
36	43	Block 1	4	10	10	300	4
32	44	Block 1	3	10	20	300	4
16	45	Block 1	4	10	20	300	3
27	46	Block 1	2	10	10	350	3

Results

The deck angle (both vertical and horizontal), frequency of oscillation and air velocity were standardized for little, proso, barnyard, foxtail and kodo millets. The efficiency of separation of unhulled grains from hulled ones ranged from 97 to 98.5 %, indicating the suitability of the specific gravity separator for post-hulling operations.

Table 3: Optimized Parameters

De-hulled millets	Deck angle (vertical)	Deck angle (horizontal)	Frequency of oscillation	Air velocity (m/s)	Separation efficiency
Kodo	10	20	350	4	98
Barnyard	0	30	300	3	98.5
Little millet	20	20	250	2	98.5
Foxtail	10	20	350	4	97
Proso millet	20	10	250	3	98

From this experiment it is revealed that impurities like dust and stones are removed from de-hulled millets by using specific gravity separator of Westrup model. It also aids in grading of grains with identical particle size. Hence it can be used to get millets with good quality grade and is very effective than traditional cleaning methods *Viz*. air, screen, and indented cylinder. This machine can be used in conjugation with existing graders and destoners in the primary processing section to get better segregation of grains, rice and grit.

Way forward

More trials with different specific gravity separators need to be conducted and suitable models can be recommended to the small millet processors.

2. Development of additional processing equipment to fill the gaps in the processing line

The project developed the following equipment:

2.1 Improved centrifugal huller

2.2 Pneumatic grain cleaner prototype

2.3 Hand-operated huller

2.4 Enterprise scale rubber roller type huller

2.5 Vibro-grader

More detailed information is shared below.

2.1 Improved centrifugal huller for small millets

Need for improved huller:

The commercially available small millet hullers are not very energy efficient, bulky, have limited safety features. Benefiting from the learning from the trials with Otake rice huller mentioned above, an effort was made to develop an improved centrifugal huller for small millets with involvement of SGS Technologies, Hosur. Trials were taken with the newly developed prototype and Otake huller using foxtail, proso and barnyard millets. The details of the trails and the data generated are shared below:

Testing of new huller prototype

Table 4: Comparative testing of our prototype with Otake for capacity & Output

DHAN Proto-type – Capacity									
SI. No.	Description	Pass	Hopper Gear	Input (kg)	Total time		Time in sec	Time in hour	Capacity in kg/hr
					min	sec			
1.1	Foxtail (*Thinai*)	1st	1st	10.00	3	30	210	0.0583	171
2.1	Barnyard *(Kuthiraivali)*	1st	1st	10.00	3	32	212	0.0588	170
2.2.	Barnyard *(Kuthiraivali)*	2nd	1st	7.90	2	5	125	0.0347	228
3.1	Barnyard *(Kuthiraivali)*	1st	4th	10.00	1	25	85	0.0236	424
3.2	Barnyard *(Kuthiraivali)*	2nd	4th	8.23	0	53	53	0.0147	559
Otake - Capacity									
1.1	Foxtail (*Thinai*)	1st	1st	10.00	2	20	140	0.0388	257
2.2	Barnyard *(Kuthiraivali)*	1st	1st	10.00	2	12	132	0.0366	273
2.3	Barnyard *(Kuthiraivali)*	2nd	1st	7.20	1	23	83	0.0230	312
3.1	Barnyard *(Kuthiraivali)*	1st	4th	10.00	1	8	68	0.0188	529
3.2	Barnyard *(Kuthiraivali)*	2nd	4th	7.82	0	44	44	0.0122	640

DHAN Proto-type - Output						
SI.No.	Millets tested	Pass	Hopper Gear	Input (kg)	Output(Kg)	%age output
1.1	Foxtail (*Thinai*)	1st	1st	10.00	7.76	77.60
2.1	Barnyard *(Kuthiraivali)*	1st	1st	10.00	7.90	79.00
2.2.	Barnyard *(Kuthiraivali)*	2nd	1st	7.90	6.87	68.67
3.1	Barnyard *(Kuthiraivali)*	1st	4th	10.00	8.23	82.33
3.2	Barnyard *(Kuthiraivali)*	2nd	4th	8.23	7.43	74.30
Otake - Output						
1.1	Foxtail (*Thinai*)	1st	1st	10.00	7.34	73.4
2.2	Barnyard *(Kuthiraivali)*	1st	1st	10.00	7.2	72
2.3	Barnyard *(Kuthiraivali)*	2nd	1st	7.20	6.162	61.6
3.1	Barnyard *(Kuthiraivali)*	1st	4th	10.00	7.82	78.2
3.2	Barnyard *(Kuthiraivali)*	2nd	4th	7.82	6.75	67.5

DHAN Huller performance (10 Kg sample size)							
SI.No.	**Millet used**	**Hulling efficiency %**	**Avg.Output Kg/hr**	**Avg. rice recovery %**	**Husk%**	**Broken%**	**No of pass for 90-95% hulling**
1	Foxtail Millet-1st gear	95	170	73.7	23	0.1	1
2	Barnyard Millet-1st Gear	73	230	50.1	31.3	2.8	3
3	Barnyard Millet-4th gear	75	560	55.7	25.7	2.2	3

Otake huller performance (10 Kg sample size)							
SI.No.	**Millet used**	**Hulling efficiency %**	**Avg. Output Kg/hr**	**Avg. rice recovery**	**Husk %**	**Broken%**	**No of pass for 90-95% hulling**
1	Foxtail Millet-1st gear	96	250	70.4	27	0.1	1
2	Barnyard Millet-1st gear	89	312	54.8	38.3	2.4	3
3	Barnyard Millet-4th gear	85	600	57.3	32.5	2.1	3

Results:

The preliminary results of the trials indicated that the new prototype perform better than those of the small millet hullers currently in the market in terms of hulling efficiency, rice recovery, energy efficiency, user friendliness, and machine cost. On comparison with Otake huller, it was found that the Indian version was performing slightly less than the Otake huller in terms of average output per hour and share of unhulled grains. These slight variations can be set right by keeping the angle at which the grains fall from the shaft same as that of the Otake huller.

Way forward:

Efforts will be made for fine-tuning and commercialising of the prototype in the near future. Even though the prototype gave results better than any known commercially available huller, we feel that it can be improved in the following two directions-1) Taking out the elevator part and increasing the base height of the huller so that the hulled rice fall freely outside with help of gravitational force. Taking out the elevator part (two bearings, elevator, pipe assembly, one V-belt, one shaft, elevator outer covering) will reduce the capacity of motor needed and a 0.5 HP single phase motor would be sufficient to run it instead of the 1 HP 3 phase motor currently used besides reducing the number of moving parts and also reducing overall weight of the machine.2) Adding two heavy duty 6 inches or more size wheels at the bottom will make the machine unit more portable and easy to transport.

2.2 Pneumatic grain cleaner prototype

Issues and problems:

The presence of unfilled chaffy grains considerably increases the difficulty in processing and there are difficulties in removing chaffy grains completely using size and weight based segregation in vogue now. The impurities in the source grains add to the overall weight of the consignment which has an unnecessary cost bearing on transportation. The stones and other foreign materials if not separated pre-processing will get in contact with machine parts and erode or damage the processing machinery. Processors are ready to pay premium price for uniform grains without impurities. Similarly in this age of instant mixes and fixes people are ready to purchase good quality graded and sorted millet rice at a higher price rather than get involved in removing stones or other materials before cooking.

Presently sieve graders and destoners are used to segregate input materials containing millet grains or rice. The sieve graders segregate based on size difference and destoners segregate based on weight difference. But it is difficult to remove same size materials like lighter or hollow grains from whole grains in a grader or same weight and size mud balls from grains in a destoner or grader.

Reason for this innovation:

Segregation using buoyancy is being practiced for cleaning grass seeds, which are very light in weight. Given the small size and less grain weight of small millets and the difference between buoyancy of small millet grains and that of unfilled chaffy grains and impurities, an attempt was made to develop pneumatic grain cleaner by DHAN and SAS technologies, Canada.

Objective

To remove extraneous materials from the grain prior to further processing, as they hamper the effectiveness of succeeding equipment

Methods and materials testing protocol

Materials used:

1) Unclean source grains from the market (25 kgs each of kodo, little and foxtail millet)
2) Electronic weighing machine-10 kgs capacity
3) 3 phase power connection
4) Buckets & sacks
5) Timer

Methods:

Unclean & ungraded kodo, little and foxtail millet procured from the local market were run in the machine for a specific time to calculate the capacity range of the machine. The output from the machine was examined and weighed to find out if the stated objective of removing lighter materials from the grain sample is possible and effective.

The feed hopper of the machine was filled with the sample grains and the air blower was started passing air into the airflow chamber. Next the auger was started and control valve of the feed hopper opened to let the grain sample fall into the auger. The auger pushed the grains into the air flow chamber against the air flow. The air flow was regulated with the help of ball valves to control the up thrust and with a little bit trial the air flow was kept constant. The output from air chamber bottom and cyclone separator was collected, examined and weighed

Specifications:

1.	**Machine Capacity**	:	70 to 125 kg/hr
2.	Suitable for	:	Little, foxtail and proso millet, Kodo millet, barnyard millet
	Air Chamber		
3.	Chamber Size	:	Ø 4”x
4.	Chamber grain outlet	:	Ø 4” X
	Feed Auger		
5.	Specification		4” auger, 12 volts, 10 amp
	Blower	:	
6	Specification		3 phase centrifugal roots blower, 210 m3/hr
7	Overall Size of the machine	:	
8	Overall Weight of the machine	:	150 kg
	Feed hopper	:	Suitable feed hopper for all grains
9	Cost of the machine	:	
10	Cost of operation	:	
11.	Additional fittings required	:	Cyclone separator


Feed


Auger


Cyclone


Pneumatic grain cleaner developed


Airflow


Air blower

Table 5 :Auger flow rate

Sl. No.	Small millet	Time	quantity	Flow rate (Kg/min)	Flow rate(Kg/hr)	AVG Flow rate
1	kodo					
1.1		1 minute	1.182 kg	1.182	70.92	71
1.2		1 minute	1.187 kg	1.187	71.22	
1.3		1 minute	1.189 kg	1.189	71.34	
2	Foxtail					114
2.1		1 minute	1.880 kg	1.880	112.8	
2.2		1 minute	1.910 kg	1.910	114.6	
2.3		1 minute	1.891 kg	1.891	113.46	

Table 6: Pneumatic grain cleaner test

Sl. No.	Small Millet	Time (in Min)	quantity (in kg)	Good grains	Immature +dust	Capacity (Kg/min)	Capacity(kg/hr)	Average capacity
Time constant								
1	Foxtail	3	5.55	3.517	2.033	1.85	111	114
		5	9.87	7.33	2.54	1.97	118	
Quantity constant								
1	Kodo	21	25	22.452	2.548	1.19	71	71
2	Little millet	12	25	23.057	1.943	2.083	125	125

Results

The prototype developed was capable of removing hollow or unfilled chaffy grains from the source grains effectively. As can be seen in the data table, prototype was effective for all three different small millets. The capacity of the machine was in the range of 70 kg/hr to 125 kg/hr. The capacity of this pre-cleaner is affected mainly by three parameters which can be controlled. They are,

1) Blower- air flow control
2) Auger- speed of rotation
3) Airflow chamber- size

Way forward

Presently the blower capacity is way above the required airflow and only less than 50% air is sent to the airflow chamber, as increasing the flow pushes the heavier desired grains into the cyclone instead of letting it fall down via gravity into the output bucket. Increasing the airflow chamber width from the present 4” to 6” and attaching a small motor directly to the auger to increase its rpm will considerably increase the capacity of the pre-cleaner. The height of the feed hopper from ground level is more than 7 feet which can be reduced to 5 feet for ease of operation and feeding the feed hopper.

2.3 Hand-operated huller

The hand-operated huller for household level is in the stage of testing and modification. This is the work of Subhash Palaniswamy, a M.Sc. Eng. student at McGill. The latest update on the work on this can be seen in https://drive.google.com/open?id=0B-GLyu05QcnCb3hLSmtMRGxpY00.

Overview

The hand operated millet huller was developed as a study model in McGill University, Canada and brought to DHAN foundation, Krishnagiri, India to evaluate its performance on a few millet varieties.

Machine testing

The huller was tested using three local varieties of millets namely foxtail, barnyard and little (black) millets. The hulling ability of the machine was studied by feeding a small quantity (5 grams) of each variety at 0.20 mm and 0.25 mm roller spacing, due to time shortage and lower capacity of the machine. The hulling performance was analyzed for three consecutive passes in terms of hulling efficiency, whole rice recovery and percentage broken grains in each pass.

Observations

The hulling efficiency of the machine, rice recovery and percentage broken grains for each variety in each pass was determined by counting and weighing method. In counting method, simply 100 grains were taken at random from the output containing a mixture of dehulled, unhulled and broken grains, obtained after each pass. From those 100 grains, number of dehulled, unhulled and broken grains were counted and expressed as percentage (table). In weighing method, the grain output was separated as dehulled, broken and unhulled grain fractions. Each fractions were weighed and hulling efficiency, rice recovery and percentage broken grains were expressed as follows.

Hand operated millet huller



*Hulling efficiency (Weighing method) = [mass of dehulled grains including broken/(mass of input - mass of hulls)] *100*

*Whole rice recovery % = (mass of dehulled grains excluding broken / mass of input)*100*

*Percentage broken grains = (mass of broken grains in output/mass of input)*100*

Machine performance at 0.20 mm rubber roller spacing

Counting method

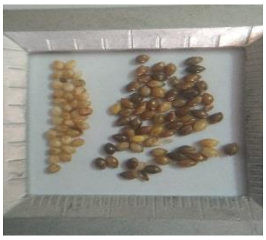
1. Foxtail millet

No of Pass	Input (g)	Output (g)	Hulled grains	Unhulled grains	Broken rice	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.9	35	65	0	35	35	0
2nd pass	4.87	4.62	52	43	5	57	52	5
3rd pass	4.64	4.09	83	10	7	90	83	7

2. Little millet

No of Pass	Input (g)	Output (g)	Hulled grains	Unhulled grains	Broken rice	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.85	13	87	0	13	13	0
2nd pass	4.8	4.54	36	61	3	39	36	3
3rd pass	4.57	4.28	64	31	5	69	64	5

1st pass **2nd pass** **3rd pass**



3. Barnyard millet

No of Pass	Input (g)	Output (g)	Hulled grains	Unhulled grains	Broken rice	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.61	7	92	1	8	7	1
2nd pass	4.8	4.43	42	55	3	45	42	3
3rd pass	4.4	3.87	71	24	5	76	71	5

1st pass **2nd pass** **3rd pass**

Weighing method

1. Foxtail millet

No of Pass	Input (g)	Out put (g)	Hulled + broken grains	Hulled grains (g)	Unhulled grains (g)	Broken rice	(input-hulls) or total grain output (in g)	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.9	1.93	1.87	2.67	0.06	4.6	41.95	38.16	1.22
2nd pass	4.87	4.62	3.01	2.93	1.28	0.08	4.29	70.16	63.41	1.73
3rd pass	4.64	4.09	3.54	3.44	0.54	0.1	4.08	86.76	84.10	2.44

2. Little millet

No of Pass	Input (g)	Output (g)	Hulled + broken grains	Hulled grains (g)	Unhulled grains (g)	Broken rice	(input-hulls) or total grain output (in g)	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.85	0.74	0.73	3.92	0.01	4.66	15.87	15.05	0.20
2nd pass	4.8	4.54	1.6	1.57	2.74	0.03	4.34	36.86	34.58	0.66
3rd pass	4.57	4.28	2.67	2.61	1.42	0.06	4.09	65.28	60.98	1.40

3. Barnyard millet

No of Pass	Input (g)	Output (g)	Hulled + broken grains	Hulled grains (g)	Unhulled grains (g)	Broken rice	(input-hulls) or total grain output (in g)	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5	4.61	0.54	0.53	3.85	0.01	4.39	12.30	11.49	0.21
2nd pass	4.8	4.43	1.64	1.61	2.45	0.03	4.09	40.09	36.34	0.67
3rd pass	4.4	3.87	2.61	2.56	0.96	0.05	3.57	73.10	66.14	1.29

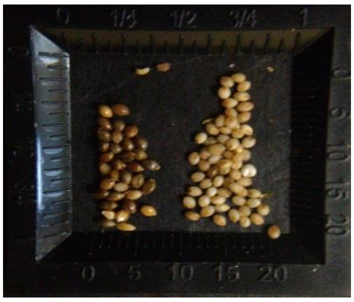
Machine performance at 0.25 mm rubber roller spacing

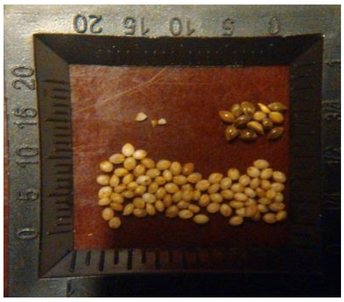
Counting method

1. Little millet

No of Pass	Input (g)	Output (g)	Hulled grains	Unhulled grains	Broken rice	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5.04	5.04	31	69	0	31	31	0
2nd pass	4.54	4.54	64	34	2	66	64	2
3rd pass	4.03	4.03	85	13	2	87	85	2

1st pass **2nd pass** **3rd pass**

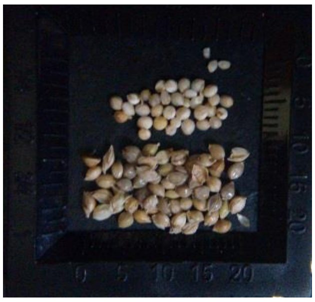




2. Barnyard millet

No of Pass	Input (g)	Output (g)	Hulled grains	Unhulled grains	Broken rice	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5.06	5.06	33	64	3	36	33	3
2nd pass	4.27	4.27	67	30	3	70	67	3
3rd pass	3.63	3.63	91	6	3	94	91	3

1st pass **2nd pass** **3rd pass**



Weighing method

1. Little millet

No of Pass	Input (g)	Output (g)	Hulled + broken grains	Hulled grains (g)	Unhulled grains (g)	Broken rice	(input-hulls) or total grain output (in g)	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5.04	5.04	1.55	1.54	2.99	0.01	4.54	34.14	33.92	0.19
2nd pass	4.54	4.54	2.99	2.91	1.04	0.03	4.03	74.19	72.20	0.66
3rd pass	4.03	4.03	3.26	3.22	0.41	0.04	3.67	88.82	87.73	0.99

2. Barnyard millet

No of Pass	Input (g)	Output (g)	Hulled + broken grains	Hulled grains (g)	Unhulled grains (g)	Broken rice	(input-hulls) or total grain output (in g)	Hulling efficiency %	Whole rice recovery %	Broken %
1st pass	5.06	5.06	1.18	1.17	3.09	0.01	4.27	27.63	27.40	0.19
2nd pass	4.27	4.27	2.69	2.63	0.94	0.06	3.63	74.10	72.45	1.40
3rd pass	3.63	3.63	3.02	2.94	0.27	0.08	3.29	91.79	89.36	2.20

Issues faced

From the observations and results obtained at Krishnagiri, it was clear that the hulling ability of the machine varied as when compared to the same when it was tested in Canada. Several machine parameters and environmental factors have affected the hulling performance.

- Misalignment of the gears during transportation and wearing of the bush that holds the fan shaft, due to heat and friction lead to improper functioning of the aspirator.
- Repeated scraping of the rubber surface, as the feed chute is kept in contact with the surface to ensure singulation of the grains.
- Difference in moisture content of the grains and significant increase in ambient temperature would also have an impact on hulling.
- The resulting grain output included more of immature grains, which also affected the hulling ability.
- While the machine was tested at 0.20 mm spacing, the hulling performance was too low since much of the grains were not subjected to shearing between the rollers. This outcome is more likely due to the improper handling (shaking) of the machine.

Recommendations

The hulling ability of the huller can be improved further by making few modifications.

- The capacity of the huller could be increased manifolds by using wide rollers, since the rollers that were used in this huller is 4 inch in length with 3 ¾ inch contact surface.
- The number of passes required to completely hull the grains can be reduced by using rollers with increased hardness and durability.
- Pre-cleaning of the grains to remove immature grains, unfilled grains and other foreign impurities would improve the hulling performance of the machine.
- Increasing the gear ratio and reducing the number of pairs of spur gears simultaneously would reduce the torque requirement and increase the aspirating function of the blower.
- Instead of a hand cranking system, pedal operated system or implementing solar energy for operating the huller would significantly reduce the amount of human labour.

Way forward

The machine is still at the lab stage and the output in relation to time spent is too low to be commercially viable. It is necessary to increase the output many folds as given in the recommendations above to make it commercially viable.

2.4 Enterprise scale rubber roller type huller

A large scale rubber roller huller with a theoretical processing capacity of 175 kg millet per hour was designed and built at McGill by Dr. Samson Sotocinal of SAS Technologies, and initially tested with little millet. Tests on the rubber roll mill showed a high milling efficiency for little millet. Kodo millet tests were inconclusive as the machine requires adjustments to reduce breakage when the rollers are too close and reduced milling efficiency when the roller distance is wider. Long term testing of the rubber roll mill is needed to generate specific adjustments for individual crop type. When these adjustments are confirmed in long term testing, the mill can be effectively utilized in areas where hard to dehull grains such as Kodo millet and Barnyard Millet are grown predominantly

Way forward

The machine is still at the lab stage and the output in relation to time spent is too low to be commercially viable. It is necessary to increase the output many folds as given in the recommendations above to make it commercially viable.

2.5 Vibro-grader

To improve the performance of the grader and to reduce the footprint and cost of the same, DHAN has tried to develop a vibro-grader prototype with the involvement of SAS Technologies, Canada. A prototype vibratory grader was designed employing rotational motion of the direct drive motor and relies on resonance frequency of four springs with the eccentric load coupled to the drive shaft of an electric motor. It is relatively simple in operation and consisting of a drive motor mounted under a grain colleting pan, a set of 3 sieve frames of different apertures for a specific variety of millets, four compression spring mountings and a base frame. The 1/2Hp motor is driven by a variable frequency drive to regulate the rotation of the motor shaft where the shaft has a mounted 500 gram eccentric load. The resonance frequency generated by the eccentric load and the spring tension results in a vibratory rotational motion of the sieve mounted on top of the grain collecting pan. Initial tests on the machine confirm the operating principle works.

Vibro grader developed

Testing of Vibro grader

However, the construction of the machine components suffers from several issues, which prevent optimum performance. The important issues identified are, (i) use of pedestal mounting for the drive motor, which tends to dissipate the energy generated by the eccentric load on the motor, (ii) the sieve casing being made of heavy gauge metal dampening the vibration generated by the motor, (iii) the sieve materials being made of wire mesh having square apertures instead of perforated plates with round holes; round holes are more efficient for grading spherical shaped grains, (iv) the sieves "funnelling" in the middle pooling the grain and preventing thin layer spread to effectively differentiate sizes of grains to drop or retain above the sieve, and (v) the discharge spouts of each sieve being elevated from the sieve level preventing smooth flow of grain over the spout.

Recommendations & way forward

Optimization of this machine can only be accomplished once these major issues are corrected. The simple, lightweight, and easily cleaned grader will be an important component in grading millet grains before milling as well as millet rice after dehulling. Being lightweight and requiring a low power drive, this machine is suited for use in farms and community centers to prevent carryover of materials other than grain (MOTG's) into processing centers thereby easily recycling organic matter in farms.

At this stage of development, the machine requires further testing and modifications to be able to perform their valuable contribution to millet grain processing. Focused efforts in testing, modification and integration of both machines- Pneumatic grain cleaner & Vibro-grader- with new improved prototype will eventually provide a viable option for processors for efficient processing.

3. Developing suitable technologies for enhancing the shelf life of hulled grains and the flour of the millet

Introduction

The shelf life of dehulled millets is three months only. Millet grain contains a higher amount of fat than other cereals, and the de-hulled millets have poor keeping quality, especially under conditions of moderately high moisture and oxygen exposure. This is attributed to deterioration of its triglycerides through lipolysis and subsequent oxidation of de-esterifies unsaturated fatty acids. Lipase enzyme, which is concentrated in the pericarp, aleurone layer and germ, accounts for the triglyceride hydrolysis in millet grain, resulting in off odour and taste in the flour and its products. Due to these aspects the shelf life of the de-hulled millet is not more than two to three months

Purpose of Packaging

In order to increase the shelf life, the de-hulled millet were stored under three different environments namely Vacuum packaging, Modified Atmosphere Packaging, and Hermetic storage. The vacuum condition was attained using Vacuum packaging machine (SEVANA) and the Modified atmosphere was ensured with varying proportions of O_2 (2-5%), CO_2 (2-5%) and N_2. The hermetic storage was carried out using tin cans and there was no exchange of air between the environment and the grains. The de-hulled millet was stored in the above conditions and the analysis was carried out once in ten days.

Three different methods were evaluated to enhance the shelf life of dehulled millets. They are

1. Vacuum Packaging
2. Modified Atmosphere Packaging
3. Hermetic storage.
4. Flexible package

1. Vacuum Packaging

Two hundred grams of de-hulled millets was taken in Polypropylene film pouch of 60 microns thickness and it was vacuum packed with vacuum packaging machine of SEVANA make. The vacuum packed samples are stored in room condition.

Vacuum packaging of Kodo millet

Vacuum packaging of Foxtail millet

Vacuum packaging of Little millet

2. Modified Atmosphere Packaging

Millets sample (200g) was filled in PolyPropylene film pouch and it was filled with O2 (2-5%), CO2 (2-5%) replacing the air and the rest is N2. The compositions of the gases that are filled in pouches are as given below.

Table 7: Composition of gases that are filled in MAP

O_2 (%)	**CO_2 (%)**	**N_2 (%)**
2	2	96
2	3	95
2	4	94
2	5	93
3	2	95
3	3	94
3	4	93
3	5	92

4	2	94
4	3	93
4	4	92
4	5	91
5	2	93
5	3	92
5	4	91
5	5	90

The required composition of the gas was filled in the pouches using SWISS VAC- STAR machine. After sealing the samples are stored in room conditions.

3. Hermetic storage

To store the de-hulled grains the tin cans of 200cc was taken and 150g of samples was filled and closed with lids tightly. The lids were fixed with silicone septum to draw the gas samples during storage.

Hermetic storage of millets

4. Flexible package

Two hundred grams of de-hulled millets was taken in High density polypropylene film pouch of 60 microns thickness and stored in room condition.

During storage the moisture, starch, proteins, free fatty acid, dietary fibre and Phenolic content were analyzed at 10 days interval for 120 days of storage in four different methods of stored samples. At the end of the storage period moisture and free fatty acid content were increased and protein, starch, dietary fibre and Phenolic content were decreased. Among the packaging materials hermetic storage gave the best result followed by flexible package, Modified Atmosphere Packaging and Vacuum packaging.

Results

The moisture, starch, proteins, free fatty acid, dietary fibre and phenolic content of stored samples were analysed at 10 days interval for 120 days of storage in four different storage methods. At the end of the storage period, moisture and free fatty acid content had increased and protein, starch, dietary fibre and phenolic content had decreased. Hermetic storage gave the best results followed by storage with flexible package, modified atmosphere packaging and vacuum packaging.

Annexes

I. Otake Huller Performance Trials

(i) Otake Huller Performance Trials on Foxtail millet						
Sl. NO.	**Particulars**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
	Input Millet	Foxtail Millet	Foxtail Millet	Foxtail Millet	Foxtail Millet	Foxtail Millet
	Moisture Percentage	11.70%	11.70%	11.70%	11.70%	11.70%
	Motor	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)
	Gear Setting	1	2	3	4	0
	Aspirator Setting No.	1	1	1	1	1
	Impeller Speed	3200	3200	3200	3200	3200
	Processing input material and output fractions in Kg					
	Raw Material Input	10	10	10	10	10
	Rice grain broken mix output	7.94	8.04	8.08	8.1	Trial not done
	Husk O/P Side	1.04	1.01	1.04	1.16	
	Husk O/P back	0.96	0.92	0.87	0.66	
	Total of milling fractions	**9.94**	**9.97**	**9.99**	**9.92**	
	Rice grain broken mix output - As % of input material	79.4	80.4	80.8	81	
	Husk o/p as percentage of raw material input	20	19.3	19.1	18.2	
	Time Taken	2min 8sec	1min 42sec	1min 12sec	1min 5sec	
	Minute	2	1	1	1	
	Seconds	8	42	12	5	
	Time taken in Hour	0.0356	0.0283	0.0200	0.0181	

Raw material processed per hour	281.25	352.94	500	553.85	
Observations on the milling performance	The hulling efficiency is very good - in 1st pass it was noticed close to 90 - 95%, the breakage was very minimal @ less than 5%				
Temperature after the trail run					
time					
Motor	52				
Motor end Shaft	44				
elevator	Not checked				
Input shaft	40				
Impeller	40				

(ii) Otake Huller Performance Trials on Little millet						
Sl. No.	**Particulars**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
	Input Millet	Little Millet	Little Millet	Little Millet	Little Millet	Little Millet
	Moisture Percentage	11.10%	11.10%	11.10%	11.10%	11.10%
	Motor	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)
	Gear Setting	1	2	3	4	1
	Aspirator Setting	1	1	1	1	4
	Impeller Speed	2800	2800	2800	2800	2800
	Aspirator fan speed	2800	2800	2800	2800	2800
Processing input material and output fractions in Kg						
	Raw Material Input	10	10	10	10	10
	Rice grain broken mix output	8.06	8.13	8.18	8.2	Not done
	Husk O/P Side	0.86	0.79	0.79	0.85	
	Husk O/P back	0.96	1.02	0.98	0.82	

	Total of milling fractions	9.88	9.94	9.95	9.87
	Rice grain broken mix output - As % of input material	80.6	81.3	81.8	82
	Husk o/p as percentage of raw material input	18.2	18.1	17.7	16.7
	Time Taken	2 min	1 min 24sec	1min 5 sec	1min
	Minute	2	1	1	1
	Seconds	0	24	5	0
	Time taken in Hour	0.0333	0.0233	0.0181	0.0167
	Raw material processed per hour	300	428.57	553.85	600
	Observations on the milling performance	The hulling efficiency is close to 95% and the broken percentage was about 5% which Is less than the breakage noticed in conventional hullers - which is about 10%			
	Motor	52			
	Motor end Shaft	44			
	elevator	Not checked			
	Input shaft	40			
	Impeller	40			

(iii) Otake Huller Performance Trials - Proso Millet

Sl. No.	**Particulars**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**
	Input Millet	Proso Millet (Markapur)	Proso Millet (Markapur)	Proso Millet (Markapur)	Proso Millet (Markapur)		Proso Millet (Markapur)
	Moisture Percentage	11.30%	11.30%	11.30%	11.30%		11.30%
	Motor	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)		3 Phase 1HP (1440)
	Gear Setting	1	2	3	4		0
	Aspirator Setting	1	1	1	1		1
	Impeller Speed	2800	2800	2800	2800		2800

Elevator pulley	1000	1000	1000	1000		1000
Raw Material Input	10	10	10	10		250
Rice, grain, broken mix output	7.94	8.05	8.15	8.16		**202.97**
Husk O/P Side	1.16	1.05	1.01	1.06		17
Husk O/P back	0.81	0.84	0.79	0.69		27
Total of milling fractions	**9.91**	**9.94**	**9.95**	**9.91**		496.97
Rice grain broken mix output - As % of input material	79.4	80.5	81.5	81.6		81.188
Husk o/p as percentage of raw material input	19.7	18.9	18	17.5		17.6
Time Taken	2 min 40sec	1 min 45sec	1min 16 sec	1 min 1 sec		31min 30 sec
minute	2	1	1	1		31
seconds	40	45	16	1		30
Time taken in Hour	0.0444	0.0292	0.0211	0.0169	0.0279	0.5250
Raw material processed per hour	225	342.86	473.68	590.16		476.19
Observations on the milling performance	Performance is promising - as the dehulling efficiency is as high as over 90 to 95% - the breakage was noticed but is much less than the breakage seen in the conventional hullers available from local manufacturers					
Motor	52					86
Motor end Shaft	44					64
elevator	Not checked					50
Input shaft	40					40
Impeller	40					48

(iv) Otake Dehuller Performance Trials - Kodo Millet

Sl. NO.	Particulars	Trial 1			Trial 2			Trial 3			Trial 4			Trial 5		
	Input Millet	Kodo Millet			Kodo Millet			Kodo Millet			Kodo Millet			Kodo Millet		
	Moisture Percentage	9.30%			9.30%			9.30%			9.30%			9.30%		
	Motor	3 Phase 1HP (1440)			3 Phase 1HP (1440)			3 Phase 1HP (1440)			3 Phase 1HP (1440)			3 Phase 1HP (1440)		
	Pass no.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Gear Setting	1	1	1	2	1	1	3		1	4	1	1	1	1	1
	Aspirator Setting	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4
	Impeller Speed	2800			2800			2800			2800			2800		
	Aspirator fan speed	2800			2800			2800			2800			2800		
	Processing Input material and output fractions in Kg															
	Raw Material Input	10	7.48	6.46	10	7.72	6.52	10	7.97	6.8	10	7.8	6.8	10	7.3	6.18
	Rice grain broken mix output	7.48	6.46	5.8	7.72	6.52	5.98	7.97	6.8	6.33	7.8	6.8	6.24	7.3	6.18	5.37
	Husk O/P Side	1.72	0.77	0.05	1.57	0.58	0.2	1.3	0.64	0.21	1.26	0.56	0.2	0.72	0.47	0.5
	Husk O/P back	0.65	0.22	0.1	0.79	0.21	0.08	0.82	0.28	0.1	0.8	0.26	0.12	1.9	0.46	0.12

Total of milling fractions	9.85	7.45	5.95	10.08	7.31	6.26	10.09	7.72	6.64	9.86	7.62	6.56	9.92	7.11	5.99
Rice grain broken mix output - As % of input material	74.80	86.36	89.78	77.20	84.46	91.72	79.70	85.32	93.09	78.00	87.18	91.76	73.00	84.66	86.89
Husk o/p as percentage of raw material input	23.7	13.23529	2.321981	23.6	10.23316	4.294479	21.2	11.54329	4.558824	20.6	10.51282	4.705882	26.2	12.73973	10.03236
Time Taken	2min 16sec	1min 33sec	1min 13sec	1min 47 sec	1min 13sec	54sec	1min 17sec	55sec	42sec	1min 5sec	44sec	38sec	2 min 18sec	1min 30sec	1min 9sec
Min	2	1	1	1	1	0	1	0	0	1	0	0	2	1	1
sec	16	33	13	47	13	54	17	55	42	5	44	38	18	30	9
Time taken in hour	0.038	0.043	0.037	0.046	0.037	0.048	0.038	0.049	0.045	0.035	0.046	0.044	0.038	0.042	0.036
Raw material processed per hour	264.71	176.00	174.86	215.57	208.96	134.90	262.77	163.95	151.11	288.00	171.22	154.94	260.87	175.20	172.47

Observations on the milling performance	The hulling efficiency less than 60% during the 1st pass, after 3rd pass the dehulling was close to 90 to 95%, the breakage is above 10%, fine brokens were noticed in the husk blown out
Motor	52
Motor end Shaft	44
elevator	Not checked
Input shaft	40
Impeller	40

(v) Otake Huller Performance Trials – Browntop Millet						
Sl. No.	**Particulars**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
	Input Millet	Browntop Millet	Browntop Millet	Browntop Millet	Browntop Millet	Browntop Millet
	Moisture Percentage	11.70%	11.70%	11.70%	11.70%	11.70%
	Motor	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)	3 Phase 1HP (1440)
	Gear Setting	1	2	3	4	0
	Aspirator Setting	1	1	1	1	
	Impeller Speed	3200	3200	3200	3200	3200
	Processing input material and output fractions in Kg					
	Raw Material Input	10	10	10	10	10
	Rice grain broken mix output	6.49	6.38	8.08	8.1	Trial not done
	Husk O/P Side	2.22	1.96	1.04	1.16	
	Husk O/P back	1.25	1.19	0.87	0.66	
	Total of milling fractions	9.96	9.53	9.99	9.92	
	Rice grain broken mix output - As % of input material	64.9	63.8	80.8	81	
	Husk o/p as percentage of raw material input	34.7	31.5	19.1	18.2	
	Time Taken	2min 48sec	2min	1min 12sec	1min 5sec	
	Minute	2	2	1	1	
	Seconds	48	0	12	5	
	Time taken in Hour	0.0467	0.0333	0.0200	0.0181	
	Raw material processed per hour	214.29	300	500	553.8461538	

Observations on the milling performance	Performance is promising - as the dehulling efficiency is as high as over 70% - the breakage was noticed but is much less than the breakage seen in the conventional hullers available from local manufacturers
Motor	52
Motor end Shaft	44
elevator	Not checked
Input shaft	40
Impeller	40

(vi) Otake Huller Performance Trials – Barnyard millet

Sl. No.	Particulars	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
1	**Input Millet**	Barnyard		Barnyard		Barnyard		Barnyard		Barnyard		Barnyard	
2	**Moisture Percentage**	11.10%		11.10%		11.10%		11.10%		11.10%		11.10%	
3	**Motor**	3 Phase 1HP (1440)		3 Phase 1HP (1440)		3 Phase 1HP (1440)		3 Phase 1HP (1440)		3 Phase 1HP (1440)		3 Phase 1HP (1440)	
4	**Gear Setting**	1	1	2	2	3	3	4	4	1	1	1	3
5	**Aspirator Setting**	1	1	1	1	1	1	1	1	4	4	1	1
6	**Impeller Speed**	2800		2800		2800		2800		2800		2800	
	Processing input material and output fractions in Kg												
7	**Pass no.**	1	2	1	2	1	2	1	2	1	2	1	2
8	**Raw Material Input**	10	7.52	10	7.66	10	7.72	10	7.37	10	7.46	250	176.5
9	Rice grain broken mix output	7.52	6.64	7.66	6.85	7.72	6.73	7.37	6.37	7.46	6.23	176.5	166.1
10	Husk O/P Side	1.34	0.39	1.41	0.29	1.29	0.29	1.36	0.3	0.66	0.5	22.3	3.8

11	Husk O/P back	1.1	0.22	0.94	0.2	0.88	0.21	0.72	0.21	1.88	0.54	47.2	5.7
12	**Total of milling fractions**	**9.96**	**7.25**	**10.01**	**7.34**	**9.89**	**7.23**	**9.45**	**6.88**	**10**	**7.27**	**246**	**175.6**
13	Rice grain broken mix output As % of input material	75.2	88.2978723	76.6	89.42559	77.2	87.17617	73.7	86.43148	74.6	83.5120643		
14	Husk o/p as percentage of raw material input	24.4	8.112	23.5	6.396867	21.7	6.476684	20.8	6.919946	25.4	13.9410188		
15	**Time Taken**	2min 16sec	1 min 23sec	1min 47 sec	1 min	1min 17sec	49 sec	1min 5sec	55sec	2 min 18sec	1 min 20sec	1hr22min14sec	19min 30sec
16	**Min**	2	1	1	1	1	0	1	0	2	1	82	19
17	**Sec**	16	23	47	0	17	49	5	55	18	20	14	30
18	Time Taken in Hour	0.0378	0.0231	0.0297	0.0167	0.0214	0.0136	0.0181	0.0153	0.0383	0.0222	1.3706	0.3250
19	Raw material processed per hour	264.71	326.17	336.45	459.6	467.53	567.18	553.85	482.4	260.87	335.7	182.4077827	543.0769231
20	Observations on the milling	The percentage of dehulling after 2 pass is between 90 to 95% and the breakage was noticed over 10% as the material was hulled twice without grading after the first pass											

performanc e		
Motor	69	78
Motor end Shaft	60	69
elevator	Not tested	Not tested
Input shaft	44	44
Impeller	44	44

II. SHELF LIFE OF HULLED GRAINS

Table 1: Changes in the starch content (g) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	66.95	65.60	66.45	65.43	64.96
20	64.90	64.05	63.90	65.38	63.17
30	64.19	63.35	63.43	64.55	63.05
40	63.71	63.26	63.21	64.31	63.02
50	62.75	63.17	63.17	63.78	62.99
60	62.63	63.09	62.98	63.59	62.96
70	62.51	63.09	62.71	63.39	62.90
80	62.36	62.91	62.44	63.17	62.87
90	62.14	62.9	62.08	63.06	62.56
100	60.83	62.83	62.07	62.87	62.29
110	60.65	61.53	61.37	61.92	60.79
120	59.55	61.10	61.03	61.71	60.00

Table 2: Changes in the starch content (g) of de-hulled little millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	67.52	66.98	67.48	67.15	66.31
20	63.42	61.36	61.87	61.19	61.93
30	62.20	61.1	61.65	60.68	61.86
40	62.09	60.84	61.19	60.65	61.53
50	60.26	60.84	60.72	60.47	61.32
60	59.68	60.4	60.56	60.36	61.28
70	59.67	59.8	58.74	60.21	60.26
80	59.32	59.37	58.70	60.02	59.82
90	58.97	59.19	58.24	59.90	59.22
100	58.28	58.5	58.15	59.84	59.03
110	58.19	58.5	57.95	58.85	58.41
120	57.96	58.5	55.63	57.50	57.45

Table 3: Changes in the starch content (g) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	65.62	63.52	63.74	63.83	63.49
20	63.75	63	63.42	63.65	63.44
30	62.93	62.83	63.25	63.38	63.11
40	62.90	62.31	62.56	63.33	62.97
50	62.42	61.79	61.91	62.49	62.67
60	62.37	61.79	61.48	62.44	61.36
70	62.22	61.62	61.36	62.26	60.87
80	61.45	61.36	61.28	61.72	60.45
90	60.77	61.36	61.12	61.52	60.26
100	60.33	61.36	60.88	61.36	60.21
110	60.00	60.92	60.83	59.95	60.13
120	59.44	60.06	60.02	59.79	59.19

Table 4: Changes in the protein content (g) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	10.75	9.83	10.02	10.29	9.88
20	10.13	9.83	9.80	9.92	9.86
30	10.13	9.78	9.80	9.79	9.83
40	9.90	9.77	9.78	9.77	9.77
50	9.73	9.72	9.69	9.76	9.77
60	9.73	9.72	9.65	9.74	9.72
70	9.67	9.71	9.62	9.71	9.70
80	9.65	9.67	9.58	9.65	9.69
90	9.61	9.62	9.53	9.62	9.62
100	9.59	9.62	9.50	9.59	9.61
110	9.56	9.51	9.46	9.57	9.44
120	9.45	9.51	9.39	9.36	9.42

Table 5: Changes in the protein content (g) of de-hulled little millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	10.50	10	10.23	9.91	10.41
20	10.21	9.94	10.22	9.90	10.04
30	10.10	9.83	10.07	9.79	9.95
40	10.04	9.78	10.02	9.79	9.90
50	9.86	9.78	9.76	9.79	9.80
60	9.83	9.72	9.69	9.69	9.78
70	9.80	9.72	9.66	9.68	9.69
80	9.76	9.72	9.65	9.64	9.69
90	9.62	9.71	9.60	9.64	9.68
100	9.58	9.71	9.59	9.57	9.67
110	9.53	9.62	9.59	9.45	9.61
120	9.32	9.59	9.50	9.33	9.47

Table 6: Changes in the protein content (g) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	13.61	13.02	13.07	13.10	13.26
20	13.19	13	12.96	12.93	13.02
30	12.83	12.91	12.70	12.91	12.84
40	12.72	12.58	12.70	12.60	12.59
50	12.52	12.38	12.62	12.45	12.49
60	12.45	12.36	12.55	12.01	12.45
70	12.31	12.14	12.24	11.96	11.97
80	11.90	11.92	12.03	11.85	11.87
90	11.62	11.81	11.95	11.80	11.73
100	11.35	11.70	11.94	11.62	11.46
110	11.14	11.59	11.77	11.50	11.34
120	11.05	11.04	10.97	10.82	11.32

Table 7: Changes in the dietary fibre content (g) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	6.6	6.5	6.7	6.2	6.6
20	6.5	6.3	6.5	6.2	6.3
30	6.3	6.2	6.4	6.2	6.2
40	6.2	6.2	6.2	6.1	6.2
50	6.2	6.1	6.2	6.0	6.2
60	6.0	6.0	6.1	6.0	6.1
70	6.0	6.0	6.1	6.0	6.1
80	6.0	6.0	6.0	5.9	6.0
90	6.0	6.0	6.0	5.9	6.0
100	5.9	6.0	6.0	5.8	5.9
110	5.6	6.0	5.9	5.8	5.8
120	5.4	5.9	5.7	5.8	5.6

Table 8: Changes in the dietary fibre content (g) of de-hulled little millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	4.2	4.0	4.1	4	4
20	4.1	4.0	4.0	4.0	4.0
30	4.1	4.0	4.0	4.0	4.0
40	4.1	4.0	4.0	4.0	4.0
50	4.1	4.0	3.9	3.9	3.8
60	3.8	3.8	3.8	3.7	3.5
70	3.7	3.8	3.8	3.7	3.5
80	3.6	3.8	3.6	3.6	3.5
90	3.6	3.8	3.5	3.5	3.5
100	3.6	3.6	3.4	3	3.5
110	3.4	3.5	3.4	3	3.5
120	3.2	3.5	3.1	3	3.1

Table 9: Changes in the dietary fibre content (g) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	4.2	4.2	4.2	4.2	4.2
20	4.1	4.0	4.2	4.1	4.1
30	4.1	4.0	4.1	4.0	4.1
40	4.1	4.0	4.1	4.0	4.1
50	4.1	4.0	4.1	4.0	4.1
60	4.0	4.0	4.0	4.0	4.0
70	3.9	4.0	4.0	4.0	4.0
80	3.9	4.0	3.9	4.0	3.9
90	3.9	4.0	3.9	4.0	3.9
100	3.9	4.0	3.9	3.9	3.9
110	3.9	3.9	3.8	3.9	3.9
120	3.8	3.8	3.8	3.8	3.8

Table 10: Changes in the moisture content (%) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	12	12.12	10.27	10.27	10
20	12	12.05	9.85	9.85	9.7
30	12.2	12.22	8.9	8.9	9.44
40	12.35	12.58	8.86	8.86	9.3
50	12.50	12.56	8.7	8.7	9.2
60	12.58	12.68	8.7	8.7	8.93
70	12.65	12.26	8.5	8.5	8.86
80	12.68	12.57	8.46	8.46	8.73
90	12.80	12.67	8.2	8.2	8.47
100	12.90	12.85	8	8	8.35
110	13.15	13.02	8	8	8.2
120	13.2	13.08	8	8	8

Table 11: Changes in the moisture content (%) of de-hulled little millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	12	12.26	10.7	10.7	11
20	12.23	12.13	10	10	10.7
30	12.35	12.16	9.46	9.46	10
40	12.42	12.51	9.33	9.33	9.33
50	12.55	13.09	8.9	8.9	9
60	12.63	13.15	8.61	8.61	8.6
70	12.73	12.59	8.53	8.53	8.5
80	12.85	13.39	8.4	8.4	8.43
90	12.98	12.78	8.35	8.35	8.3
100	13.29	13.06	8.24	8.24	8.2
110	13.38	13.45	8.2	8.2	8
120	13.4	13.37	8.1	8	8

Table 12: Changes in the moisture content (%) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	Modified Atmosphere packaging	Hermetic storage	Flexible packaging
10	12.30	12	10	10	10.27
20	11.85	12.25	9.7	9.7	9.85
30	12.10	12.39	9.2	9.2	8.9
40	12.05	12.49	9.06	9.06	8.7
50	12.31	12.55	9.2	9.2	8.5
60	12.66	12.63	8.93	8.93	8.46
70	12.82	12.75	8.86	8.86	8.4
80	12.88	12.80	8.83	8.83	8.37
90	12.92	12.88	8.73	8.73	8.2
100	12.75	12.90	8.63	8.63	8.1
110	12.46	12.98	8.13	8.13	8
120	13.08	13	8.2	8.4	8

Table 13: Changes in the total Phenolic content (mg/g) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	356.44	361.60	361.54	360.93	360.25
20	357.73	360.93	360.25	356.19	358.22
30	363.46	359.57	359.24	352.81	356.64
40	358.26	356.19	356.12	351.46	351.46
50	336.04	353.48	353.35	348.61	349.43
60	348.80	351.46	350.91	343.34	348.28
70	349.00	348.07	345.37	341.98	345.34
80	331.81	339.28	338.67	340.63	344.12
90	337.37	337.92	337.45	335.89	341.98
100	343.07	335.56	334.54	340.63	341.31
110	334.78	333.86	328.86	344.01	336.57
120	330.27	331.16	325.07	347.40	335.89

Table 14: Changes in the total phenolic content (mg/g) of de-hulled little millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	142.80	141.72	139.69	141.72	141.72
20	135.68	140.71	137.66	139.02	138.34
30	137.38	139.69	134.69	137.66	134.96
40	133.98	138.20	134.41	134.96	133.18
50	134.10	137.59	134.08	133.60	132.93
60	138.11	136.31	133.40	133.60	132.04
70	132.47	129.90	132.99	130.90	131.57
80	132.04	128.19	130.22	128.19	132.25
90	125.89	125.48	125.48	126.84	129.43
100	128.43	124.81	120.75	126.16	127.51
110	122.93	121.42	120.07	123.45	126.84
120	119.28	119.40	120.14	123.73	126.84

Table 15: Changes in the total phenolic content (mg/g) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	101.54	100.45	100.45	101.13	101
20	101.05	100.32	99.91	100.45	99.10
30	102.57	98.35	98.08	99.10	98.96
40	99.14	96.39	96.05	97.75	97.07
50	97.35	96.32	95.85	95.72	96.39
60	95.15	96.05	95.78	95.72	95.63
70	97.66	95.38	95.17	95.58	95.75
80	94.47	94.63	94.57	95.04	95.04
90	97.62	91.79	91.59	94.36	93.01
100	90.97	90.91	90.64	93.69	91.99
110	93.38	90.84	90.37	94.09	92.33
120	89.93	90.64	90.24	94.36	92.67

Table16: Changes in the free fatty acid (g) of de-hulled kodo millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	0.12	0.05	0.05	0.05	0.05
20	0.24	0.05	0.05	0.05	0.06
30	0.3	0.29	0.24	0.09	0.07
40	0.32	0.24	0.10	0.07	0.08
50	0.35	0.24	0.19	0.07	0.09
60	0.42	0.25	0.20	0.08	0.11
70	0.45	0.29	0.24	0.09	0.12
80	0.49	0.33	0.27	0.10	0.12
90	0.55	0.35	0.29	0.10	0.12
100	0.58	0.35	0.29	0.11	0.11
110	0.63	0.35	0.34	0.12	0.13
120	0.68	0.36	0.35	0.13	0.13

Table 17: Changes in the free fatty acid (g) of de-hulled little millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	0.25	0.05	0.05	0.05	0.05
20	0.29	0.08	0.08	0.06	0.05
30	0.32	0.21	0.13	0.06	0.06
40	0.38	0.27	0.21	0.07	0.07
50	0.42	0.36	0.29	0.08	0.08
60	0.49	0.37	0.33	0.08	0.08
70	0.52	0.38	0.34	0.10	0.10
80	0.58	0.40	0.36	0.12	0.10
90	0.64	0.40	0.38	0.13	0.12
100	0.72	0.41	0.40	0.13	0.13
110	0.81	0.42	0.40	0.14	0.14
120	0.9	0.43	0.41	0.16	0.16

Table 18: Changes in the free fatty acid (g) of de-hulled foxtail millet during storage

Days	Control	Vacuum packaging	MAP	Hermetic storage	Flexible packaging
10	0.08	0.05	0.05	0.05	0.05
20	0.15	0.05	0.05	0.05	0.05
30	0.24	0.07	0.05	0.06	0.06
40	0.3	0.08	0.06	0.06	0.07
50	0.32	0.08	0.10	0.08	0.07
60	0.36	0.09	0.14	0.08	0.07
70	0.42	0.10	0.16	0.09	0.09
80	0.45	0.13	0.13	0.10	0.10
90	0.5	0.17	0.21	0.10	0.10
100	0.54	0.24	0.27	0.10	0.11
110	0.58	0.29	0.28	0.11	0.12
120	0.6	0.29	0.29	0.12	0.12