Research Articles

Indian Journal of Agricultural Sciences **88** (11): 1676–81, November 2018/Article

Development of solar powered pneumatic grain/seed cleaning system

ALKA MISHRA[1], J P SINHA[2], J K SINGH[3] and B S TOMAR[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received: 15 June 2018; Accepted: 27 June 2018

ABSTRACT

Vegetables are important constituents of Indian agriculture and nutritional security due to their short duration, high yield, nutritional richness, economic viability and ability to generate on-farm and off-farm employment. Despite being the second largest producer of vegetables in world, India lags far behind in its productivity in comparison to developed countries. The major challenge, which lies ahead, is to harness maximum yield potential as well as reduce production cost to enhance quality and productivity of vegetables under reducing land, declining natural resources and increasing biotic and abiotic stresses.The most of seed industry grow seeds at farmers' field. The farmers do not have primary processing machines or situated at uninsured grid power remote places. In this situation, either produced seed get damage or exploited by seed industries. In this context, a solar powered pneumatic grain/seed cleaning system was developed with specific functional, structural and operational design parameters. The developed pneumatic cleaner was tested for garden pea, bottle gourd, sponge gourd and radish seed lots of different impurity levels. It was found that the processed lot achieved more than 99% physical purity irrespective of type of seed and impurity levels. The cleaning efficiency of the system was more than 96%. The throughput capacity was observed to be garden80, 50 and 75 kg/h for pea, battle gourd and radish respectively.

Key words: Cleaning efficiency, Pneumatic, Seed cleaning, Solar, Winnower.

Primary processing is the most important operation for reducing losses during further operations up to final consumption point.The common operations are winnowing, cleaning, grading, sorting, drying *etc.* Cleaning is one of the important unit operations by which dockage can be reduced efficiently and the significant reduction, minimizes threat of pest attack (Paliwal *et al.* 2003). It also had been observed that the presence of dockage diminishes the effectiveness of protectants during storage (Anderegg and Madisen 1983). Mostly small lots are cleaned manually. However, some power operated systems are available. The manual cleaning is interlaced with problem of drudgery, capacity, consistency and efficiency. On the other hand, the commercially available power operated cleaner is of higher capacity and of lower efficiency and lack human safety. The grid power assurance specifically in rural sector is pitiable. India suffers from an acute shortage of electricity and power, one-third of total population, especially in the rural parts of the country remains without power. The shortage translate into massive power cuts and intermittent supply issues (FICCI 2012). Furthermore, in view of global climate change, volatile crude oil prices and limited supply of fossil fuels, it becomes imperative to use of alternative renewal energy sources. Solar energy are increasingly being relied upon in order to utilize clean energy sources and also bridge the demand-supply gap and increasing assurance of energy (Jha 2013). Fortunately, solar energy is abundantly available in most of part the country throughout the year. Average daily radiation varies between 4.5 to 6.5 kWh/m^2 (Gupta and Ramchandran 2003). Thus, utilizing solar energy for cleaning is an effective alternative for energy conservation as well as viable option for small and marginal farmers, who contributes about 41% of the country's production with higher productivity than medium and large farmers (Chand *et al.* 2011).

India is the second largest producer of vegetables in the world next to China with 2.8% of total cropped area under vegetables. Present production of 163 million tonnes (NHB 2014) with availability of 318 g per capita per day against recommended requirements of 400 g (Sachdeva *et al.* 2013). The potential yields of vegetables are 5-10 times higher than any cereal crop (Thooyavathy *et al.* 2013). Vegetable production is more remunerative than cereals and other field crops, specifically in Indian conditions. Vegetables are important constituents of Indian agriculture and nutritional security due to their short duration, high yield, nutritional richness, economic viability and ability to generate on-farm and off-farm employment. Despite being the second largest producer of vegetables in world, India lags far behind in its

[1]Research Scholar (e mail: 29alkamishra@gmail.com), CIAE, Bhopal. [2]Principal Scientist (e mail: jpsinha@gmail.com), FOSU, ,[3]Principal Scientist (e mail: jksiari@gmail.com), Division of Agricultural Engineering, [4]Principal Scientist (e mail: bstomar@iari.res.in), Division of Vegetable Science, IARI.

productivity in comparison to developed countries (Verma *et al.* 2002). Productivity of vegetables in India (17.34 t/ha) has been observed to belower than Spain (37.2 t/ha) and world average (18.8 t/ha). Hence, the major challenge, which lies ahead, is to harness maximum yield potential as well as reduce production cost to enhance quality and productivity of vegetables under reducing land, declining natural resources and increasing biotic and abiotic stresses. Envisaging the significance of vegetable seed in Indian context, vegetable seed industry is rapidly mounting and major players are multinational companies (Mazumdar 2012). This matrix is exploiting the resource poor Indian farmers. The major chunk of vegetable producing farmers belongs to small and marginal category. The most of seed industry grow seeds at farmers' field and after processing and packaging sale it at premium prices. In this way, they are multiplying money on the backbone of processing infrastructure as framers cannot afford to have cost intensive processing machines. In this context, a solar powered pneumatic grain/seed cleaning system was developed.

MATERIALS AND METHODS

The functional parts of the system comprise of main frame, hopper, air duct, fan, motor, control module and solar power pack (Fig 1).

The size of hopper was aimed to accommodate at least 45 kg. The shape should be as the seed mass should discharged through hopper bottom by utilizing gravitational force. Hence, determined lowest bulk density of selected seed and maximum angle of coefficient of friction was taken into consideration. The lowest bulk density was observed to be 450 kg/m^3 for bottle gourd among all the selected seeds under the study. Hence, volumetric capacity for hopper was computed as

$$\text{Volumetric capacity} = \frac{45}{450} m^3 = 0.1 m^3$$

Fig 1 Solar powered pneumatic grain/seed cleaning system.

The coefficient of friction plays important role in gravitational flow of material. The maximum angle of friction was considered for deciding the slope of hopper side and more than the maximum coefficient of friction was taken as design value for hopper side slope. As the highest coefficient of friction was observed (0.58) for bottle gourd among all the selected seeds under the study, the 30º slope was undertaken for hopper design.

The fan blade number and orientation had been found of utmost importance which were affecting air flow characteristics (Kumar and Rubinson 2014, Sahay and Singh 2010). The impellers were designed using CAD software. Flat blade of size 23×9 cm of mild steel sheet of thickness 1.7 mm were mounted on hub so as it could be fixed on drive shaft. The shaft was supported with ball bearing at both ends and fixed with frame using bearing housing. Total 27 arrangement of impellers (number: 3,4 and 6; tilt angle: 10º, 15º and 20º; Direction of tilt: forward, backward) were undertaken in the study.

An experimental setup was done to optimize blade number and its orientation for developing maximum air velocity at minimum power expenditure. An AC motor 1.5 kW, 3 phase was powered through Variable Frequency Drive (VFD) of EMERSON Industrial Automation. The frequency of AC supply could be varied with help of VFD control. At five levels of AC frequency: 10, 20, 30, 40 and 50 Hz motor current load and voltage was measured to determine power requirement of the motor at no load condition. The power requirement was computed by multiplying current load, voltage and power factor for the particular set frequency. The developed pneumatic system was hooked with the AC motor. All the 27 blade arrangements were subjected for estimation of power consumption. For each set of blade arrangement at five levels of frequency 10, 20, 30, 40 and 50 Hz, the current load and voltage were recorded with the help of digital multimeter and digital clamp meter. Simultaneously air velocity produced by the system was measured using digital hot wire anemometer. The rotation of fan and motor shaft was recorded by digital contact tachometer. The experiments were conducted in three replications. These data sets were used to compute power expenditure for specific condition of fan shaft rotation. It also gave insight of air velocity produced with the specific setting, i.e. motor rotation, blade number and blade orientation (tilt angle). The net power expenditure for the specific setting was reckoned by deducting the no load power expenditure from corresponding load condition power expenditure. The computed data were subjected to statistical analysis for finalizing design values for number of blade and its orientation.

Duct was designed for flowing of air, which separate out the lighter impurities and allows the clean seeds to settle down by gravity to the discharge chute. The length of duct was designed to 1 m for exposing the cleaning mass for sufficient residence time in air line for separation of impurities. The designed value of the duct sections was 25.5 × 12.5 cm in rectangular shape. The slope of duct was kept 45^0 as the maximum coefficient of friction was found 0.58 among selected vegetable seed *ie.* bottle gourd. It facilitates self-cleaning of duct. A discharge chute which was connected to the duct had dimensions: 67.5 × 12 × 10 cm.

In order to reduce chance of turbulence of air in duct just after the outlet of centrifugal fan a directional control grill was installed. The directional control grill was fabricated with 25 mm straight leap separated at 25 mm apart. A wire mesh screen (mesh size 10) was positioned before discharge chute for restricting material return back to impeller assembly.

The centrifugal fan was driven by DC motor using solar energy through designed control module. Power requirement of 4 blade 70^o tilt angle was found to be 225 W. Considering 10% safety factor 250 W, DC motor was selected as prime mover for the system. The commercially available DC motor of 250 W, the electrical and mechanical characteristics were Max. Current: 18; Voltage: 28; Shaft: 22 mm Ø and RPM: 3000.

The SPV array size was designed on the basis of peak power requirement, peak current and voltage characteristics of motor, solar insolation, module efficiency, module electrical characteristics, ambient temperature and geographical location. The sizing of various components of the PV system had been done in such a way that the utility factor should remain as close to 1.0. The theoretical daily expected energy output of the PV array in Wh was reckoned by the equation:

$$\rho_{th.output} = n \times A \times S_{Ins} \times \eta_{mod} \quad (1)$$

where, n = number of PV modules, A = the module area, (m^2), S_{Ins} = the total insolation, ($Wh/m^2/d$), η_{mod} = the overall module efficiency (%).

Solar cell efficiency was be computed by following equation:

$$\eta = \frac{P_m}{E \times A_c} \quad (2)$$

Where, P_m = cells power output at its maximum power point (W), E = input light (W/m^2), A_c = surface area of solar cell (m^2)

Fill factor was calculated as follows:

$$FF = \frac{P_m}{V_{oc} \times I_{sc}} \quad (3)$$

where, P_m = cells power output at its maximum power point (W), V_{oc}= open circuit voltage (V), I_{sc} = short circuit current (A).

The commercially available SPV module of 100 Wp was selected. The number of PV module was calculated on basis of module $Power_{max}$ 100 Wp and net power requirement (250 W) for the system as well as balancing of system considering different factors- temperature correction factor 0.95; production tolerance factor 0.89; dust loss factor 0.95; ohmic loss factor 0.98; control power factor 0.98 and safety factor 0.75.

Total module power

$$= \frac{\text{Net power requirement}}{\text{temp. corr. F} \times \text{prod. toler. F} \times \text{dust loss F} \times \text{ohmic loss F} \times \text{cont. pw. F} \times \text{safety F}}$$

$$= \frac{250}{0.89 \times 0.95 \times 0.95 \times 0.98 \times 0.98 \times 0.75} = 432 \text{ Wp}$$

$$\text{Number of module required} = \frac{\text{Total module power}}{\text{Module power}_{Max}}$$

$$= \frac{432}{100} = 4.32 \cong 5$$

As per computation number of module required for array was five. But voltage required for the prime mover (DC motor) was 24 V, which could not be harnessed from the selected panel voltage characteristic V_{mp} = 17V. Hence, the number of module was increased to 6. In order to get 24 V the panels were paired in series and all the three pairs were connected in parallel. The module efficiency and per day power availability was calculated as

$$\text{Solar module efficiency} = \frac{100}{900 \times 1.615} = 14.535$$

$$\rho_{th.output} = 6 \times 0.7705 \times 5.20 \times 0.1453$$

$$\rho_{th.output} = 3.5 \text{ kWh/d}$$

The varying solar intensity over sunshine hours intended to design power storage system with charge controller for harnessing maximum solar energy and utilizing it for operating a system where consistent electrical power required. In order to achieve the consistent power to the prime mover irrespective of insolation intensity a suitable MPPT charge controller was selected and two lead acid battery 42 Ah, 12 V was hooked with MPPT charge controller. The important feature of the MPPT charge controller was on line load and battery charging of 30 A and 24 V.The stored energy surplus served as buffer for off hour operation or cope up of temporary interruption effect of irradiation to SPV. There is significant differences ofterminal velocity of different seed.It necessitated varying air velocity for pneumatic cleaning of seed. The required terminal air velocity for different seed could be achieved efficiently by regulating the motor speed to specific level. The Pulse Wave Modulation (PWM) was selected for speed regulation of DC motor. The PWM of characteristic: Working voltage; 20-30V and Load current; 35 A was selected for the particular system. The MPPT charge controller and PWM module was integrated in control module. The control module was circuited in series with SPV pack and parallel to battery (Fig 2).

The set up was initially operated without any load, and mechanical as well as electrical critical points were thoroughly inspected. Abnormal noise and electrical parameters such as voltage and current were considered as alarming parameters. Five samples in three replications of bottle gourd, sponge gourd, garden pea and radish of five levels (2, 4, 6, 8 and 10%) of lighter impurities were prepared. The sample size of bottle gourd, sponge gourd, garden pea and radish were 5, 5, 10 and 5 kg; respectively. The samples were subjected for cleaning by the developed machine.

The outputs of different outlets were collected separately. The collected outputs were analyzed for their compositions. Fraction of clean seed was determined for feed, product outlet and reject outlet. The cleaning efficiency of the machine was calculated through the formula suggested by Sahay and Singh (2010).

$$\eta = \frac{100 \times E\,(F - G)\,(E - F)\,(1 - G)}{F\,(E - G)^2\,(I - F)} \qquad 4$$

where, η = cleaning efficiency (%), E = fraction of clean seeds in clean seed outlet, F = fraction of clean seeds at feed, G = fraction of clean seeds in foreign matter outlet.

Physical purity analysis was done as per ISTA (2015) rules. The working sample was separated into three components i.e. pure seed, other seed, and inert matter. The percentage of each part was determined by weight. The working sample weight for purity analysis was determined so as it should contain at least 2500 seeds. Working sample for bottle gourd, sponge gourd, garden pea and radish were taken for the study (1000 g, 700 g, 1000 g and 300 g), respectively. Amount of impurities, viz. other seeds and inert material, was separated manually. The physical purity was calculated in percentage by weight of pure seed.

RESULTS AND DISCUSSION

The regression analysis between number of blades and tilt angle over power consumed were found highly significant at 1% level of significance with coefficient of determination 99.72% (Table 1). Similarly, the regression analysis between number of blades and tilt angle over air velocity were found significant at 1% level of significance with coefficient of determination value of 99.92%. The interaction of blade number and its orientation was also found highly significant for power consumption as well as air velocity. Statistical analysis exposed that the effect of number of blade and orientation (tilt angle) was significant [for power consumption of blade; mean square (MS)= 3624.29, F value=520.87, and $p<0.0001$; of orientation, MS=23187.12, F value=3332.30, and $p<0.0001$; and of blade × orientation interaction, MS=346.72, F value=49.83, and p<0001 and for air velocity of blade; MS = 3.541, F value = 977.65, and $p<0.0001$; of orientation, MS = 1.713, F value = 472.80, and $p<0.0001$; and of blade × orientation interaction, MS = 1.104, F value = 304.67, and p<0001]. It clearly implied that number of blade and its orientation were of utmost importance for selecting the power economy of pneumatic system. The rotation speed (RPM) of fan was also significantly affecting the power consumption as well as air velocity. The interactions of RPM with blade, orientation were found significant at 1% level of significance. It originates that RPM may be efficient parameter for generating power economy air velocity in combination with blade number with its orientation.

The power consumed was observed positive correlation with air velocity. It was also evident that the number of blade and its orientation had considerable effect on power as well as air velocity (Fig 2). The power consumption increased significantly with increasing number of blades irrespective of orientation (tilt angle) of blades. Interestingly, the air velocities were increased up to four blades and then after

Table 1 Anova of regression analysis of power consumption and air velocity.

Source	DF	Power (P)/Air velocity (A)	Sum of squares	Mean square	F value	Pr > F
RPM	4	P	354944.00	88736.0010	12752.9	<.0001
		A	927.554	231.888	64012.7	<.0001
B	2	P	7248.57	3624.29	520.87	<.0001
		A	7.0831	3.541	977.65	<.0001
RPM*B	8	P	700.45	87.5565	12.58	<.0001
		A	1.756	0.219	60.62	<.0001
O	6	P	139122.73	23187.12	3332.30	<.0001
		A	10.276	1.713	472.80	<.0001
RPM*O	24	P	10186.58	424.4408	61.00	<.0001
		A	3.966	0.165	45.61	<.0001
B*O	12	P	4160.70	346.72	49.83	<.0001
		A	13.244	1.104	304.67	<.0001
RPM*B*O	48	P	1276.04	26.5842	3.82	<.0001
		A	4.754	0.099	27.34	<.0001

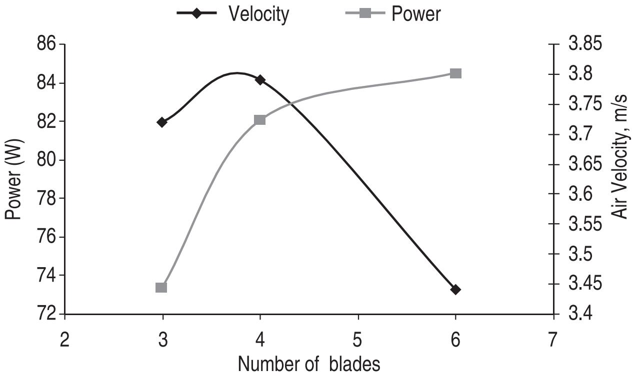

Fig 2 Effect of number of blade on power consumption and air velocity.

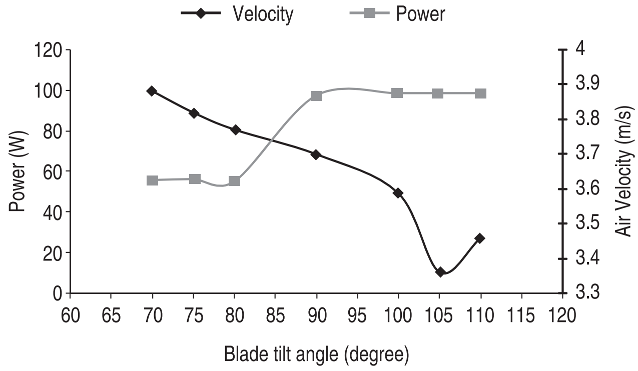

Fig 3 Effect of blade orientation on power consumption and air velocity

decreased for six blades. The reason might be due to by increasing the number of blades from 3 to 4 more air was pushed from the blades but when it was increased further up to 6 blades the area available for air intake was considerably reduced and eventually reduced the resulting air velocity. It was evident that the air velocity was maximum with four blades with considerably low power. The results were found to be alike with findings reported by Singh *et al.* (2011).

It was also found that the power increased with increase in blade tilt angle whereas, the air velocity decreased with increasing blade tilt angle (Fig 3). The ratio of power requirement to air velocity was observed maximum at 90 degree blade. It was the least for 70 degree blade tilt angle. It implies that the 70 degree blade tilt angle is efficient for generating higher air velocity at the lower cost of power consumption. The similar result was obtained by Sahay and Singh (2010) for forward curved blade accelerates the air to a high velocity event at lower speed of rotation, in comparison to a backward curved blade, forward curved blower power requirement was significantly higher and also confirmed by Kumar and Rubinson (2014) for the backward inclined radial blade impeller of centrifugal fan. They found that centrifugal impeller of 8 mm thick and 10 blades were selected for efficient performance, which also reduced the power requirement.

Further, Tukey's test revealed that the air velocity was significantly related with orientation of blades. The maximum air velocity was observed with 70° tilt angle and that of minimum with 105° tilt angle. The number of blades also meaningfully affected the air velocity. The maximum air velocity was observed with 4 blades and that of the minimum was with 6 blades (Table 2). The power consumption was also found to be significantly affected by number of blades as well as orientation of blades (Table 3). The maximum mean power requirement was observed with 6 blades or 110° tilt angle. However, the minimum mean power requirement was found with 3 blades. Blade tilt angle 70 and 75 degree were found at par and it was minimum with respect to power requirement. On analyzing the combination of blade number and its orientation, the 4 blades at 70º tilt angle was originated as an optimum combination for generating the maximum mean of air

Table 2 Effect of type of blade and its orientation on mean air velocity.

Blades	70º	75º	80º	90º	100º	105º	110º	Mean
3	3.523^{e}	3.706^{d}	3.724^{d}	4.046^{ab}	4.015^{b}	3.528^{e}	3.519^{e}	3.723^{b}
4	4.115^{a}	3.853^{c}	3.874^{c}	3.877^{c}	3.649^{d}	3.499^{e}	3.684^{d}	3.793^{a}
6	4.010^{b}	3.892^{c}	3.720^{d}	3.181^{f}	3.119^{f}	3.035^{g}	3.163^{f}	3.446^{c}
Mean	3.883^{a}	3.817^{b}	3.773^{c}	3.702^{d}	3.594^{e}	3.354^{g}	3.455^{f}	

Means with different superscripts are significantly different with P<0.01

Table 3 Effect of type of blade and its orientation on mean power consumption.

Blades	70º	75º	80º	90º	100º	105º	110º	Mean
3	57.191^{gh}	51.425^{j}	53.246^{ij}	85.898^{f}	90.872^{e}	85.718^{f}	89.426^{e}	73.397^{c}
4	52.365^{ij}	57.710^{gh}	55.508^{hi}	98.965^{d}	103.541^{abc}	103.490^{bc}	103.081^{c}	82.094^{b}
6	59.809^{g}	57.524^{gh}	57.126^{gh}	107.008^{a}	100.558^{cd}	106.923^{ab}	103.167^{c}	84.588^{a}
Mean	56.455^{b}	55.553^{b}	55.293^{b}	97.290^{a}	98.324^{a}	98.710^{a}	98.558^{a}	

Means with different superscripts are significantly different with P<0.01

Table 4 Physical purity and cleaning efficiency at different levels of impurity

Crop/ Impurity (%)	2	4	6	8	10
			Physical purity (%)		
Garden pea	99.796	99.684	99.787	99.782	99.722
Bottle gourd	99.592	99.582	99.855	99.783	99.778
Sponge gourd	99.336	99.003	99.866	99.866	99.799
Radish	99.776	99.626	99.479	99.244	99.074
			Cleaning efficiency (%)		
Garden pea	89.633	91.055	96.152	97.182	97.175
Bottle gourd	79.673	79.708	97.193	97.352	97.717
Sponge gourd	79.733	79.467	97.543	97.81	97.151
Radish	88.855	90.867	91.761	91.171	91.478

velocity (4.11 m/s) at minimum power consumption.

The physical purity of the material of the product outlet were found greater than 99% for all the seed under test and irrespective of level of impurity content in feed. It was witnessed that the physical purity of the product outlet was higher than the Indian Minimum Seed Certification Standards (IMSCS) of respective crop seeds. It signified that the developed system was efficient in removing the lighter impurities from the seed lots regardless the composition of seed lot as well as type of seed (Table 4). The mean cleaning efficiency was found to be maximum for garden pea seeds (94.24%) followed by radish (90.83), sponge gourd (90.34%) and bottle gourd (90.33%) (Table 4). It might be due to bold and spherical seed of garden pea and coarse type of impurity. Bottle gourd and sponge gourd were flat type of seed as well as the impurities were also medium-coarse or fine. The medium-coarse or fine impurities were removed to limited extent from the seed admixtures with pneumatic system of cleaning. The radish seed lots were found to be lesser cleaning efficiency as there was subtle differences of aerodynamic behavior between seed and impurities. It was important to note that the cleaning efficiency was considerably lower for the lot of lower impurity levels specifically lower than 4%, irrespective of type of seed under the study. The cleaning efficiency was found more than 90% for the lots containing more than 4% impurity. It signifies that cleaning of cleaner seed lots is more difficult than that of poor seed lots through pneumatic cleaning system. It was supported by the findings of experimentations reported by Muhammad *et al.* (2013). The throughput capacity was found to be minimum with Sponge gourd: 45 kg/h and that of maximum with garden pea: 80 kg/h. It was 50 and 75 kg/h for bottle gourd and radish, respectively. It might be due to differences in bulk volume and physical properties of lots. The developed system may be of utility for small or medium vegetable seed growers and advantageous in light of environmental safety.

ACKNOWLEDGEMENT

We would like to extend our gratitude to Dr Indra Mani, Head, Division of Agricultural Engineering, ICAR-IARI, New Delhi for constant encouragement and extending facilities of the division for executing the work.

REFERENCES

Anderegg B N and Madison L J. 1983. Effect of dockage on the degradation of (14C) Malathion in stored wheat. *Journal of Agricultural and Food Chemistry*. **31**(4):700-4.

Chand R, Prasanna P A L and Singh A. 2011. Farm size and productivity; Understanding the strengths of smallholders and improving their livelihoods. *Economic and Political Weekly* **27**: 5–11.

FICCI. 2012. Lack of Affordable and Quality Power: Shackling India's Growth Story. Bureau of Research on Industry and Economic Fundamentals.

Gupta C L and Rumachandran A. 2003. Solar energy for India-status, potential and impact. *Journal of Scientific and Industrial Research* **62**: 25–45.

ISTA. 2015. International rules for seed testing. *Seed Science and Technology* **27**: 1–333.

Jha G K. 2013. Energy growth linkage strategy for meeting the energy demand in Indian Agriculture. *Agricultural Economic Research Review* **26**: 119–27.

Kumar P N and Rubinson S S. 2014. Design optimization of backward inclined radial blade impeller using ansys. *International Journal of Engineering Developmentand Research* **2**(1): 404–9.

Mazumdar B. 2012. Vegetable hybrid seed industry in India. *Hand Book of Vegetable Crops,* pp 101-14. Peter and Hazra (Eds.). Stadium Press, LLC, USA.

Paliwal J, Viscn N S, Jayas D S and White N D G. 2003. Cereal grain and dockage identification using machine vision. *Biosystems Engineering* **85**(1): 51–7.

Sachdeva S, Sachdev T R and Sachdeva R. 2013. Increasing fruit and vegetable consumption: Challenges and opportunities. *Indian Journal of Community Medicine* **38**(4): 192-7.

Sahay K M and Singh K K. 2010. *Unit Operations of Agricultural Processing*, 2nd edn, p 75. Vikas Publishing House, New Delhi.

Thooyavathy R A, Pcrumal K, Suresh V and Vijayalakshmi K. 2013. *Seed Production Techniques for Vegetables*. Center for Indian Knowledge System, Chennai.

Verma A, Kalloo G, Singh K P and Banerjee M K. 2002. Production, productivity and export of vegetables. Technical Bulletin 7.