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Pressure drop and airflow resistance of African yam beans (*Sphenostylis Stenocarpa*)

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Abstract

Pressure drop and airflow resistance of African Yam Beans (*Sphenostylis Stenocarpa*) were determined at moisture levels of 5, 10, 15 and 20% ; five bed depth levels of 20, 40, 60, 80 and 100 cm; three packing types (methods) of loose, dense type 1 and dense type 2 and four airflow rate (0.025, 0.035, 0.045 and 0.055m^3/s). This is to provide data for designing drying and handling machines of this seed. The aerodynamic equipment used for measuring pressure drop, was developed by the Department of Environmental and Agricultural Engineering Laboratory University of Agriculture Makurdi, Nigeria The pressure drop data measured was used to calculate the airflow resistance. Values of pressure drop and air flow resistance measured ranges from 14 to 20 Pa and 16 to 93 Pa/m, respectively. ANOVA and mean separation (Duncan multiple range test) shows that moisture content, packing types and bed depth had significant effect ($p < 0.05$) on the different airflow rate for both pressure drop and air flow resistance. This study recommend that to either dry or aerate a dry bed of yam beans a fan should be selected to overcome a resistive air force of 93 Pa/m.

Keywords: African yam beans; Pressure drop; Airflow resistance; Moisture Content, Packing Type and Airflow rate.

Introduction

African yam bean was reported to have originated in Ethiopia. Wild and cultivated types now occur in tropical Africa as far as Zimbabwe, throughout West Africa from Guinea to southern Nigeria, being especially common in the latter and in Togo and the Ivory Coast, and in East Africa from northern Ethiopia (Eritrea) to Mozambique, including Tanzania and Zanzibar. The centre of diversity of African yam bean is only in Africa. Nigeria has the highest production of African yam bean (Potters and Doyle, 1992; Abbey and Berezi; 1988). Stirniman et al. 1931 were the first researches to study the behavior of air through agricultural product. Other researchers who reported the pressure drop and airflow resistance of some agricultural product includes: Haque et al., 1982; Grama et al., 1984; Agrawal and Chand, 1974; Shahbazi 2011; Gunasekaran and Jackson (1988); Łukaszuk et al (2008); Sorour (2006); Shoughy (2001); Hindey et al. (1988); Abou-El Hana (1986); Abou El – Hana, and Younis, 2008 for grains and peas, Parson 1971; Rajabipouret al., 2001 for nuts, Neale and Messer, 1976; Abram and Fish, 1982; Chaug et al., 1985; Tabil et al., 1999 for fruits, roots, and vegetables. No data on the resistance to airflow through African yam beans seeds have been compiled in the ASABE standard D272.3 (ASABE, 2007), which gives the resistance to airflow of 33 crops. Despite all of these research accounts, there is very little information on the pressure drop and airflow resistance of African yam beans characteristics that will help broaden its utilization base. The aim of this study is to provide data of pressure drop and air flow resistance of African yam bean (*Sphenostylis Stenocarpa)* for development of drying and handling equipment. Also to study the interaction of moisture, packing types, bed depth and airflow rate on these properties.

Results and discussions

The results for pressure drop in a dry bed for African yam beans with moisture range of 5 to 20% at an airflow range of 0.025 to 0.055m^3/s ranges from 14 to 20Pa. similar results range were also achieved by Rajabipouret al., 2001; Pagano et al, 1987; Nabiha et al, 2008; for walnut , flax seeds, and corn respectively. Also the airflow resistance in a dry bed for moisture range of 5 to 20% at an airflow range of 0.025 to 0.055m^3/s ranges from 16 to 93 Pa/m. Similar results were obtained by Kenghe et al. 2012; Siebenmorgen and Jindal 1987; Gunasekaran, and Jackson 1988, for soya beans, Rice and sorghum respectively. This results show that for effective drying or aeration of Africa yam beans in a dry bed the selected fans should be able to overcome a resistive force ranging from 16 to 93 Pa/m and the pressure that will be generated along the bed depth of 0.2 to 1m are in a range of 14 to 20Pa.

An ANOVA (table 1 and 2) was done on three factors (moisture, packing types and bed depth) for pressure drop and airflow resistance (at p<0.05). The result shows that for

Table 1. ANOVA showing the effect of moisture content, packing type and bed depth at different air flow rate on pressure drop of African yam beans.

Source	Flow rate (m^3/s)	Type III Sum of Squares	Df	Mean Square	F	Sig.
Moisture	0.025	676.117	3	225.372	666.125	0.000*
	0.035	679.237	3	226.412	672.512	0.000*
	0.045	720.437	3	240.146	809.479	0.000*
	0.055	662.787	3	220.929	646.621	0.000*
Packing	0.025	39.140	2	19.570	57.842	0.000*
	0.035	34.407	2	17.203	51.099	0.000*
	0.045	36.587	2	18.293	61.663	0.000*
	0.055	34.580	2	17.290	50.605	0.000*
Bed depth	0.025	138.580	4	34.645	102.399	0.000*
	0.035	136.600	4	34.150	101.436	0.000*
	0.045	126.853	4	31.713	106.899	0.000*
	0.055	140.353	4	35.088	102.698	0.000*
moisture * packing	0.025	98.433	6	16.406	48.489	0.000*
	0.035	89.193	6	14.866	44.155	0.000*
	0.045	103.093	6	17.182	57.918	0.000*
	0.055	99.233	6	16.539	48.407	0.000*
moisture * bed depth	0.025	13.633	12	1.136	3.358	0.000*
	0.035	10.813	12	.901	2.677	0.002*
	0.045	14.347	12	1.196	4.030	0.000*
	0.055	13.513	12	1.126	3.296	0.000*
packing * bed depth	0.025	3.960	8	.495	1.463	0.171*
	0.035	4.860	8	.607	1.804	0.077*
	0.045	4.147	8	.518	1.747	0.088^{NS}
	0.055	4.387	8	.548	1.605	0.124^{NS}
moisture * packing * bed depth	0.025	28.867	24	1.203	3.555	0.000*
	0.035	27.007	24	1.125	3.342	0.000*
	0.045	28.973	24	1.207	4.069	0.000*
	0.055	26.467	24	1.103	3.228	0.000*

*Significant(P<0.05), ^{NS} Not Significant

pressure drop there is a significant effect on all the main effects, while the interactions shows significant effects except on packing vs bed depth at airflow rate of 0.045 and $0.055m^3/s$. This phenomenon occurs because as main effect like moisture increases, the sizes of the seeds increase which increases the porosity. Another main effect is the packing type which change the orientation of the seeds which as affect its porosity. The last main effect the bed depth will affect the measurement because different bed depth will have different porosity. The no- effect of packing vs bed depth at high flow rate shows that the porosity at these depths is the same.

Means separation (Table 3) shows that for pressure drop in a dry bed in all airflow rates considered, the means at different moisture content are statistically different form each other. This could be because the moisture differences increase the size of the seeds causing the seeds at different bed depth to have different porosities thereby causing different pressure drop at different depths. Packing types also shows that at the entire airflow rate considered the means values of pressure drops are statistically different from each other. This is cause by the fact that the packing types cause the seeds to be arranged along the beds differently. These arrangements causes different pressure drop along the dry bed. Means values of pressure drop for bed depth for the entire airflow rate considered are statistically different from each other except for 0.6 and 0.8m which are statistically the same. This difference could have been due to insufficient compaction the seeds along the bed. This suggests that if more compaction is done each bed depth considered would have been statistically different from each other. Similar observations were reported by ;Łukaszuk et al (2008); Sorour (2006); Shoughy (2001); Hindey et al. (1988); Abou-El Hana (1986).

The means of airflow resistance were separated in table 3. It shows that the mean values were statistically different from each other for all air flow rate considered. This could also be because the moisture differences increase the size of the seeds causing the seeds at different bed depth to have different porosities thereby causing different airflow resistance at different depths. The means shows that airflow resistance decreases with increase in moisture content. Similar results were obtained by Shahbazi, 2011; Parson, 1971; Haque et al., 1982; Grama et al., 1984; Agrawal and Chand, 1974. The mean separation for packing type also shows that they are statistically different from each other. This is also due to the different arrangement of seeds as at different compaction type. The results also show that the highest air resistance the offer occurs at the lowest compaction while the lowest occurs at the highest compaction. This suggests that compaction or vibration could alter the airflow resistance of the seeds. The mean values of airflow resistance for the entire airflow rate considered are statistically different from each other along the bed depth. The results also show that airflow resistance reduces as the bed depth increases. Similar results were obtained by Parson 1971; Haque et al., 1982; Grama et al., 1984; Agrawal and Chand, 1974.

Table 2. ANOVA showing the effect of moisture content, packing type and bed depth at different air flow rate (pressure drop of African yam beans.

Source	Flow rate (m^3/s)	Type III Sum of Squares	Df	Mean Square	F	Sig.
Moisture	0.025	3428.023	3	1142.674	515.254	0.000*
	0.035	3429.179	3	1143.060	486.945	0.000*
	0.045	3526.468	3	1175.489	630.630	0.000*
	0.055	3241.213	3	1080.404	461.911	0.000*
Packing	0.025	206.600	2	103.300	46.580	0.000*
	0.035	190.069	2	95.035	40.485	0.000*
	0.045	209.176	2	104.588	56.110	0.000*
	0.055	173.465	2	86.732	37.081	0.000*
Bed depth	0.025	154386.728	4	38596.682	17403.981	0.000*
	0.035	153885.579	4	38471.395	16388.868	0.000*
	0.045	155666.141	4	38916.535	20878.069	0.000*
	0.055	154438.971	4	38609.743	16507.039	0.000*
Moisture * packing	0.025	525.882	6	87.647	39.522	0.000*
	0.035	494.088	6	82.348	35.080	0.000*
	0.045	518.844	6	86.474	46.392	0.000*
	0.055	505.298	6	84.216	36.005	0.000*
Moisture * bed depth	0.025	1257.812	12	104.818	47.264	0.000*
	0.035	1278.616	12	106.551	45.391	0.000*
	0.045	1174.042	12	97.837	52.488	0.000*
	0.055	1088.219	12	90.685	38.771	0.000*
packing * bed depth	0.025	99.573	8	12.447	5.612	0.000*
	0.035	116.726	8	14.591	6.216	0.000*
	0.045	106.329	8	13.291	7.130	0.000*
	0.055	68.972	8	8.621	3.686	0.000*
moisture * packing * bed depth	0.025	267.183	24	11.133	5.020	0.000*
	0.035	299.104	24	12.463	5.309	0.000*
	0.045	250.549	24	10.440	5.601	0.000*
	0.055	239.664	24	9.986	4.269	0.000*

*Significant (P<0.05),

Table 3. Mean separation (Duncan multiple range test) for the effect of moisture, packing and bed depth on pressure drop and airflow Resistance.

		Harmonic Mean Sample Size	Pressure drop (Pa) Airflow Rate m^3/s				Airflow Resistance (Pa/m) Airflow Rate m^3/s			
factors			0.025	0.035	0.045	0.055	0.025	0.035	0.045	0.055
Moisture content	5%	75	17.08^c	16.93^c	17^c	17.05^c	37.84^c	37.59^c	37.74^c	37.76^c
	10%	75	19.89^d	19.83^d	19.93^d	19.84^d	44.41^d	44.25^d	44.45^d	44.20^d
	15%	75	16.44^b	16.36^b	16.37^b	16.4^b	36.66^b	36.43^b	36.59^b	36.56^b
	20%	75	16.07^a	16.01^a	15.99^a	16.07^a	35.84^a	35.75^a	35.7^a	35.96^a
Packing Types	Loose	100	17.25^b	17.18^b	17.23^b	17.26^b	38.39b	38.23^b	38.35^b	38.34^b
	Dense 1	100	17.86^c	17.74^c	17.79^c	17.79^c	39.82c	39.59^c	39.77^c	39.66^c
	Dense2	100	17.86^a	16.93^a	16.95^a	16.97^a	37.86a	37.69^a	37.79^a	37.86^a
bed Depth	20cm	60	16.17^a	16.13^a	16.2^a	16.17^a	80.83^e	80.67^e	81^e	80.83^e
	40cm	60	17.12^b	16.97^b	17.07^b	17.05^b	42.79^d	42.42^d	42.67^d	42.63^d
	60cm	60	17.72^c	17.57^c	17.65^c	17.6^c	29.53^c	29.28^c	29.42^c	29.34^c
	80cm	60	17.75^c	17.68^c	17.6^c	17.73^c	22.19^b	22.1^b	22^b	22.17^b
	100cm	60	18.1^d	18.07^d	18.1^d	18.15^d	18.1^a	18.07^a	18.1^a	18.15^a

* Different Alphabet along column are statistically different from each other (P<0.05)

The study shows that moisture, packing types and bed depth all had a significant effect on pressure drop and airflow resistance at the airflow ranges considered. Increase in moisture decreases both pressure drop and airflow resistance. High compaction reduces both pressure drop and airflow resistance while low compaction increases them. Pressure drop increase as bed depth increases while airflow resistance reduces as the depth increases. This study recommend that to either dry or aerate a dry bed of yam beans a fan should be selected to overcome a resistive air force of 93 Pa/m.

Materials and Methods

Sample material

The sample used in the study was, dry and matured seeds of African Yam Beans (*Sphenostylis Stenocarpa)*. This sample was obtained from North bank market in Makurdi, Benue State, Nigeria.

Sample preparation

The seeds sample was cleaned manually to remove all foreign matters and broken seeds. Seeds samples were divide into four groups and labeled 5, 10, 15 and 20%. Each group was conditioned to the labeled moisture level using the method described by Asoiro and Ani 2011 or ASAE standard (ASAE, 1998).

Determination of pressure drop and airflow resistance

Pressure drop of African Yam Beans (*Sphenostylis Stenocarpa)* seeds were measured using a constructed aerodynamic properties measuring apparatus. The apparatus was set up as shown in figure 1. A U-tube manometer containing water was connected to two air outlets (each air outlets were spaced 0.2m from each other) of the apparatus with a rubber hose. These hoses allow air to move from the air column to the manometer. A switch was connected to the fan's motor which was used to change the speed of the fan and the airflow rate produced inside the test column was measured using a digital anemometer. Airflow rates of 0.025, 0.035, 0.045 and 0.055m^3/s were marked switch. To measure the pressure drops of the seeds samples, a sample was poured into the air column (upper chamber of the apparatus) to the desired depth. The packing types of the seeds in the column were achieved by three different methods. The first method involved the pouring of the sample seeds from a height near zero from the apparatus to produce a ''loose fill''. The second packing method was achieved by loosely filing the column and then tapping it ten (10) times. This packing method is termed ''dense filled 1(D1)''. The third was also achieved by tapping the column twenty (20) times, this is called ''dense filled 2 (D2)'', Air was blown through the apparatus with seeds at different depths of 0.2, 0.4, 0.6, 0.8 and 1m. measurements of pressure drop reading at different depth were taken from the manometer. Each experiment was replicated five (5) times. Pressure drop was calculated using equation 1.

$$\Delta\rho = \rho g \Delta h \qquad (1)$$

Where;

Δρ = Pressure drop (pa), ρ = density of air (kg/m^3), $\Delta h = h_2 - h_1$ = height of water drop on the manometer (m).

Airflow resistance was calculated from the pressure drop data generated using equation (2).

$$Airflow\ Resistance = \frac{\Delta\rho}{L} \qquad (2)$$

Where;

Δρ is the pressure drop (Pa) and L is the depth (m).

Statistical analysis

A 4x3x5 factorial design (four levels of moisture, three levels of packing and four levels of bed depth) was used to analyze the results. Analysis of variance (ANOVA) was performed using SPSS (Version 20) at 95% confident level. The means were separated using Duncan multiple range test.

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