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Performance evaluation of screw augers in paddy grains handling

H. Zareiforoush[1*], *M.H. Komarizadeh*[1], *M.R. Alizadeh*[2], *M. Masoomi*[1], *and H. Tavakoli*[3]

[1]Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agriculture, University of Urmia, P.O. Box 165, Urmia 57135, Iran
[2]Rice Research Institute of Iran (RRII), P.O. Box 1658, Rasht 41235, Iran
[3]Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, P.O. Box 4111, Karaj 31587-77871, Iran

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A b s t r a c t. The performance characteristics of screw augers were investigated as a function of auger dimensions, screw rotational speed and conveying inclination. The performance characteristics were studied in terms of the augers output, volumetric efficiency and power requirements. Three screw augers with diameters of 15.5, 20 and 25 cm were evaluated at four conveying angles of 0° (horizontal), 10, 20 and 30° and five rotational speeds of 200, 300, 400, 500 and 600 r.p.m. The experiments were conducted to a factorial statistical design. The results revealed that with increasing the screw rotational speed, the augers volumetric output increased and reached to a maximum point and after the point, the output started to be decreased. The volumetric output of the augers increased significantly ($P<0.01$) with increasing the auger dimensions. As the conveying inclination of the screw augers increased, the volumetric output and efficiency decreased, significantly ($P<0.01$). The power requirements of the augers increased with increasing the screw rotational speed and conveying inclination ($P<0.01$), while the value found to be deceased with increasing the auger dimensions ($P<0.01$). Comparing the results obtained in this study with the results had been previously reported for other cereal grains, it was concluded that the performance characteristics of screw augers can be affected by the properties of materials being conveyed.

K e y w o r d s: screw auger, performance, rotational speed, conveying inclination, power, throughput

INTRODUCTION

Screw augers are very effective conveying devices for free flowing or relatively free flowing bulk solids, giving good throughput control and providing environmentally clean solutions to process handling problems because of their simple structure, high efficiency, low cost and maintenance requirement. They are available as independent mobile items or as a part of other grain handling systems such as harvesters, field bins, dryers, storage or silo systems, and feed mixing and distribution systems. In recent years, evaluation of screw augers performance has been carried out.

Chang and Steele (1997) investigated the performance characteristics of the inlet section of a screw conveyor for two corn lots. Burr *et al*. (1998) designed and evaluated an auger with linear tapered inside diameter having a minimum flighting height for uniform unloading particulate materials from rectangular cross-section containers. Nicolai *et al*. (2004) determined the output, volumetric efficiency, and power requirements for a 20 cm and a 25 cm diameter conveyor in transporting corn operating in a speed range of 250 to 1100 r.p.m. and inclination angles of 13, 20, and 30°. Moysey and Thompson (2005) developed a new 3D model for solids conveying in a single screw extruder using DEM. The model has been shown to be suitable tool for studying the local phenomenon of solids flow within the screw channel. Maleki *et al*. (2006) evaluated the seed distribution uniformity of a multi-flight auger as a grain drill metering device. Dai and Grace (2008) developed a theoretical model for the torque requirement of a screw feeder by considering the bulk solid mechanics of a material element within a pocket. Asghari *et al*. (2008) studied the effect of auger speed and air flow on discharge rate of bagasse.

However, reviewing of the literature showed that there is no result concerning the auger conveyors performance evaluation in handling the paddy (*Oriza sativa* L.) grains. Nowadays, screw augers are widely being used in paddy

*Corresponding author's e-mail: hemad.zareiforoush@yahoo.com

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harvesting and post-harvesting equipments. For example, in a rice combine, augers are used to move cut crop on the platform to the feeder housing, clean grain from the bottom of the cleaning shoe to the grain tank, and to unload the grain tank onto a wagon or a truck. Augers are also used at grain elevators and farmsteads to load grain storage bins and on feedlots for feed distribution. Moreover, designing of the screw augers performance characteristics such as their dimensions, rotating speed and conveying angle is dependent to the properties of the materials being conveyed (Nicolai *et al*., 2006).

The aim of this research was to analysis of throughput and power requirements of screw augers, in transporting the paddy grains. Considering the widely use of this type of conveying equipments in agricultural applications, the results offered in this study can be helpful in proper design and adjusting the screw augers performance characteristics according to the type of application and specifications of the materials being conveyed.

MATERIALS AND METHODS

The paddy grains used in the current research were obtained from the Rice Research Institute of Iran (RRII), Rasht, Iran. The variety evaluated in this research, Hashemi, is one of the local varieties of rough rice in the northern provinces of Iran, which is characterized by slender kernels and long awns (Zareiforoush *et al*., 2009). Before starting the experiments, the samples were cleaned to remove all foreign materials such as grits, straw, and stems. The initial moisture content of the samples was determined by oven drying method at 130°C for 24 h (Pan *et al*., 2008). Consequently, it was revealed that the initial moisture content of the samples was 11.2% (w.b.). The bulk density of the paddy grains at this level of moisture content was 390 kg m^{-3} (Zareiforoush *et al*., 2009).

The performance characteristics of screw augers were investigated with respect to auger dimensions, conveying inclination and screw rotational speed. Three tubular screw augers with different dimensions were evaluated in the current research for throughput and power requirements. The 15.5 cm (6 in) auger was constructed with 13 cm (5 in) screw diameter and 3.5 cm (1.4 in) shaft diameter. The 20 cm (8 in) auger was made with 17.5 cm (7 in) diameter for screw and 4.5 cm (1.8 in) diameter for screw shaft; and finally, the 25 cm (10 in) auger had a 22.5 cm (9 in) screw diameter and 6 cm (2.4 in) shaft diameter. All of the evaluated augers were 150 cm long with standard screw pitch. Pitch is defined as the distance between adjacent screw flights (ASABE, 2006).

In order to investigate the effect of conveying inclination on the performance specifications of the screw augers, four angles of conveying, namely, 0° (horizontal handling), 10, 20 and 30° were considered. For achieving to these angles, an apparatus was specifically made for this research with the capability of adjusting the inclination angle for the inlet charge hopper, screw auger and its drive electromotor. The conveying angle was adjustable using a hinge joint and a lifting jack. The inlet charge hopper and the auger tubular housing were all together inclined gradually by the lifting jack allowing the screw auger to follow and assume the desired conveying inclination. The apparatus was such designed as the conveyors tubular housing could be bolted to the foreside wall of the inlet charge hopper. The inlet charge hopper was 40×30 cm at the bottom, 50×40 cm at the top opening, and 70 cm high with inclined side walls. The inlet section of the conveyors was 32 cm long. The conveyors were driven by a 1.5 kW electromotor through belt and pulley.

The effect of screw rotational speed on the augers performance characteristics were studied by selecting five rotational speeds of 200, 300, 400, 500 and 600 r.p.m. The desired rotational speeds of screw augers were adjusted using a speed inverter (LG model IC5, Korea) which was contacted to the drive electromotor, and then the rotational speed of screw augers was measured using a digital photo/contact tachometer (Lutron model DT-2236, Taiwan) on the conveyors shaft.

At each experiment, the paddy grains were poured from a big gravity flow charge hopper to the conveyor inlet charge hopper and allowed the conveyor to operate at selected condition for a few minutes. This was defined as the conveyor run-in time. During experiments, adequate flow from the big gravity flow charge hopper was maintained to the inlet charge hopper to assure that the inlet section of the auger was totally submerged.

The conveyors throughput was determined through measuring the weight of conveyed grains over a known time. A weigh scale with an accuracy of 0.01 g (SA IRAN model PDS-600, Iran) was used for this purpose. In reality the actual output of an auger is considerably less than the theoretical output. This results in loss of volumetric efficiency. The volumetric efficiency (η_v) is defined as (Srivastava *et al*., 2006):

$$\eta_v = \frac{Q_a}{Q_t}, \tag{1}$$

where: Q_a is the actual volumetric output (m^3 min^{-1}) and Q_t is theoretical volumetric output (m^3 min^{-1}) that can be expressed by the following (Srivastava *et al*., 2006):

$$Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)l_p n, \tag{2}$$

where: d_{sf} is screw flight diameter (m), d_{ss} is screw shaft diameter (m), l_p is the pitch length (m) and n is the screw rotational speed (r.p.m.).

In order to express the screw augers throughput in terms of the volumetric output, the values of Q_a and Q_t should be multiplied at the conveying grains bulk density (ρ_b). The bulk density of the paddy variety used in the current research at the moisture content of 11% was obtained 390 kg m^{-3} (Zareiforoush *et al*., 2009).

Since the augers were driven by an electromotor, their power requirements were measured by means of a power meter with the capability of monitoring (Roohi, 2003; Roohi *et al*., 2005). The instantaneous values of power data was continuously monitored on a computer every second. At each experiment, all power data was recorded with the computer using a software program and the recorded data was stored on a spreadsheet for later statistical analysis and regression determination.

The experiments were conducted to a factorial statistical design. Considering combination of the evaluated factors, 60 treatments were evaluated in the form of completely randomized block design. At each treatment, the experiments were replicated four times and then the mean values were reported. The experimental data were analyzed using analysis of variance (ANOVA) and the means were separated at the 5% probability level applying Duncan multiple range tests in SPSS 16 software program and analysis of regressions was performed using Microsoft Excel 2007 software.

RESULTS AND DISCUSSION

The results of statistical analysis revealed that the effects of auger dimension, screw rotational speed and conveying inclination were all significant on the both values of volumetric output and volumetric efficiency, at the 1% significance level. The mean values of volumetric output for the three evaluated screw augers at different rotational speeds and conveying inclinations are given in Table 1. As it can be seen, the volumetric output of the conveyors increased with increasing the auger dimensions. This can be attributed to the greater space provided for conveying the grains with an increase in auger dimension. The volumetric output of the three evaluated screw augers with regard to screw rotational speed and conveying inclination is illustrated in Fig. 1. As shown, for all of the evaluated conveyors, with increasing the screw auger rotational speed, the volumetric output increases and reaches to a maximum point and after this point, the volumetric output starts to decrease. Srivastava *et al*. (2006) has suggested that there may be two factors responsible for this behaviour: the restriction as grain flows into the intake of the conveyor, and the centrifugal force due to the rotation of the grain mass at higher speeds. Konig and Riemann (1990) examined the influence of inlet screw diameter on screw conveyor output and reported a nearly linear increase in output with increasing inlet screw diameter up to a maximum point. After reaching to the point, output decreased.

The results also revealed that for all of the evaluated augers, increasing the conveying inclination caused the volumetric output of the augers to be decreased (Fig. 1). This may be due to the fact that grain flows from an inclined intake at one-third the rate from a comparable horizontal orifice (Srivastava *et al*., 2006). Bloome *et al*. (1996) reported that the conveying output for a 3 m long screw conveyor with a screw diameter of 15 cm and intake length

T a b l e 1. Mean values of volumetric output for the three evaluated screw augers at different screw rotational speeds and conveying inclinations (standard deviations are in parentheses)

Conveyor diameter (cm)	Screw speed (r.p.m.)	Volumetric output (m^3 min^{-1}) at conveying inclination (°)			
		0	10	20	30
15.5	200	0.1059 (0.0137)	0.0971 (0.0127)	0.0775 (0.0168)	0.0596 (0.0125)
	300	0.1292 (0.0258)	0.1233 (0.0188)	0.1029 (0.0161)	0.0765 (0.0131)
	400	0.1431 (0.0218)	0.1386 (0.0191)	0.1167 (0.0117)	0.0901 (0.0151)
	500	0.1439 (0.0166)	0.1375 (0.0221)	0.1124 (0.0192)	0.0942 (0.0102)
	600	0.1383 (0.0172)	0.1244 (0.0198)	0.1004 (0.0106)	0.0821 (0.0113)
20	200	0.2683 (0.0194)	0.2523 (0.0168)	0.2125 (0.0260)	0.1801 (0.0178)
	300	0.3181 (0.0136)	0.3142 (0.0136)	0.2638 (0.0165)	0.2157 (0.0225)
	400	0.3588 (0.0290)	0.3475 (0.0258)	0.3175 (0.0237)	0.2406 (0.0194)
	500	0.3546 (0.0191)	0.3346 (0.0179)	0.3156 (0.0109)	0.2371 (0.0149)
	600	0.3444 (0.0191)	0.3165 (0.0194)	0.2861 (0.0141)	0.2206 (0.0190)
25	200	0.5558 (0.0153)	0.5423 (0.0327)	0.5008 (0.0092)	0.4306 (0.0201)
	300	0.6513 (0.0219)	0.6190 (0.0104)	0.5586 (0.0149)	0.4859 (0.0184)
	400	0.6940 (0.0197)	0.6785 (0.0208)	0.6221 (0.0273)	0.5264 (0.0146)
	500	0.7046 (0.0142)	0.6892 (0.0071)	0.6404 (0.0290)	0.5335 (0.0285)
	600	0.6890 (0.0114)	0.6504 (0.0310)	0.6167 (0.0186)	0.5111 (0.0249)

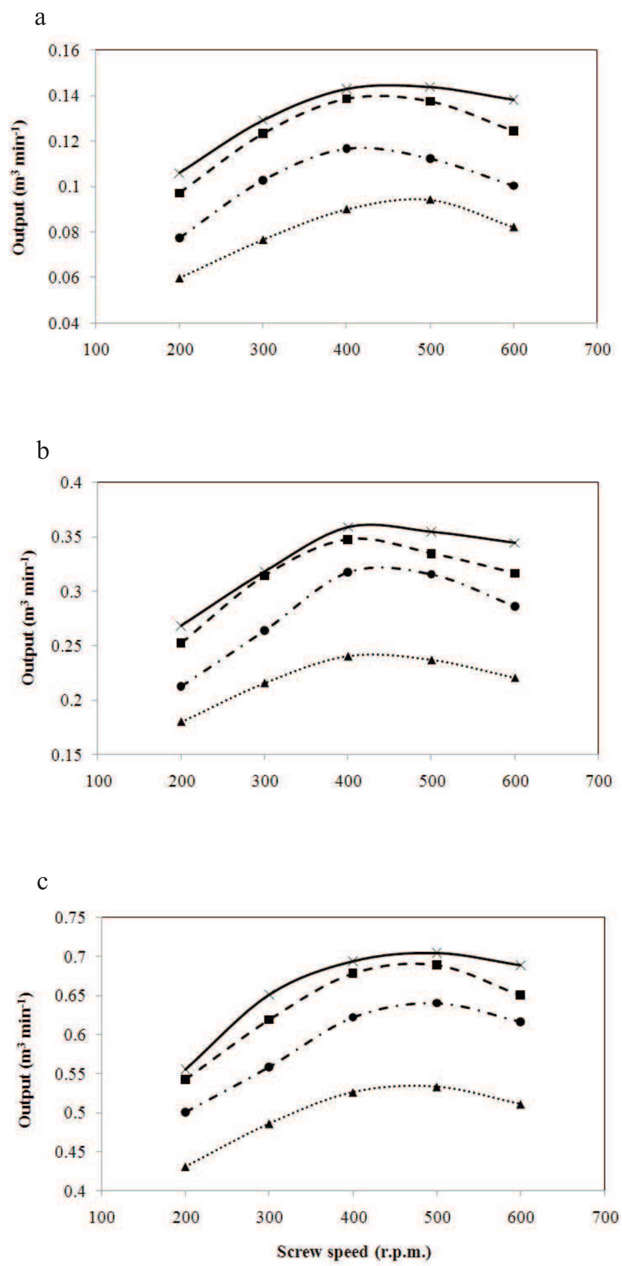

Fig. 1. Effect of screw rotational speed and conveying inclination on the volumetric output for: a – 15.5, b – 20, and c – 25 cm screw augers; × horizontal conveying, ■ 10, ● 20, and ▲ 30°.

of 30 cm in handling corn at 14.5% moisture increased from 0.64 to 0.86 m^{-3} min^{-1}, as the rotational speed of the conveyor increased from 400 to 600 r.p.m., at the conveying angle of 45°. Chang and Steele (1997) evaluated the performance characteristic of the inlet section of a 15.2 cm screw conveyor. They reported that the output of the inlet section of a screw conveyor increased from 32.1 to 42.8 and 24.9 to 34 t h^{-1}, respectively, for two corn lots evaluated, as the rotational speed of conveyor increased from 413 to 690 r.p.m. They also indicated that with increasing the conveying inclination from 30 to 40°, the output decreases from 39.2 to 35.7 and 31.0 to 27.8 t h^{-1}, respectively, for the two corn lots tested.

As it can be seen from Fig. 1, the maximum output of the conveyors occurred between the rotational speeds of 400 and 500 r.p.m. This range of the conveyors speed for maximum output was independent of the conveyors dimension and also the angle of inclination. Nicolai *et al*. (2004) reported that the maximum output for 20 and 25 cm augers at all of the conditions evaluated in handling corn occurred between 784 and 853 r.p.m. Comparing these findings with the results obtained in the current study for the corresponding augers, it can be concluded that the volumetric output of screw augers and also the rotational speed gives the highest output for the augers can be affected by the properties of materials being conveyed. Since the bulk density of paddy grains is lower than that of corn, the real mass of the materials entered into the space between the screw flights at each revolution of the auger, that is to say the degree of fill, in the case of paddy grains is lower than that of corn. This can be also expounded by the effects of materials vortex motion resulting from higher centrifugal forces at higher rotations of the screw flights. Vortex motion arises as a result of internal friction, friction between the granular material and surface of the helical blade, and the infinitely variable helix angle of the helical flight from the outer periphery of the blade to the shaft. The vortex motion, together with the degree of fill, govern the volumetric efficiency and, hence, the volumetric throughput (Roberts, 1999).

Considering the results presented in Fig. 2, it becomes evident that as the rotational speed of augers increases, the volumetric efficiency of screw augers decreases. It seems that if the screw rotational speed is increased sufficiently, the centrifugal force may become so restrictive as to cause the volumetric efficiency to be declined. An analysis of the vortex motion in vertical or steeply inclined screw conveyors was conducted by Roberts (1999). He reported that a passive state of stress is generated within the bulk granular materials because of the dominance of the centrifugal pressure due to the motion of the screw. He also indicated that the vortex motion is characterized by the tangential component of the absolute grain velocity being substantially constant with the radial position of a point on the blade. On this basis, an expression for the volumetric efficiency was derived and the volumetric throughput was predicted.

As shown in Table 2, the corresponding mean values of the augers volumetric efficiency at the different evaluated speeds and inclinations were obtained approximately near together. The volumetric efficiency for the 15.5, 20 and 25 cm augers at the conveying angle of 30° were respectively 60.01,

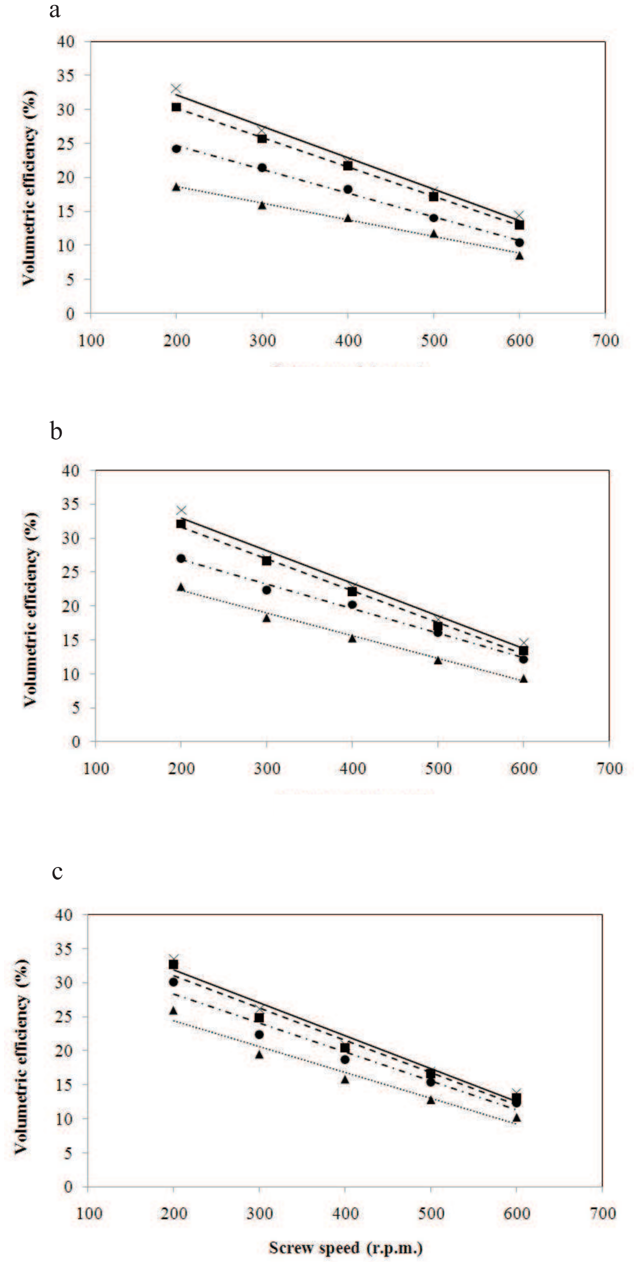

Fig. 2. Effect of screw rotational speed and conveying inclination on the volumetric efficiency for: a – 15.5, b – 20, and c – 25 cm screw augers; × horizontal conveying, ■ 10, ● 20, and ▲ 30°.

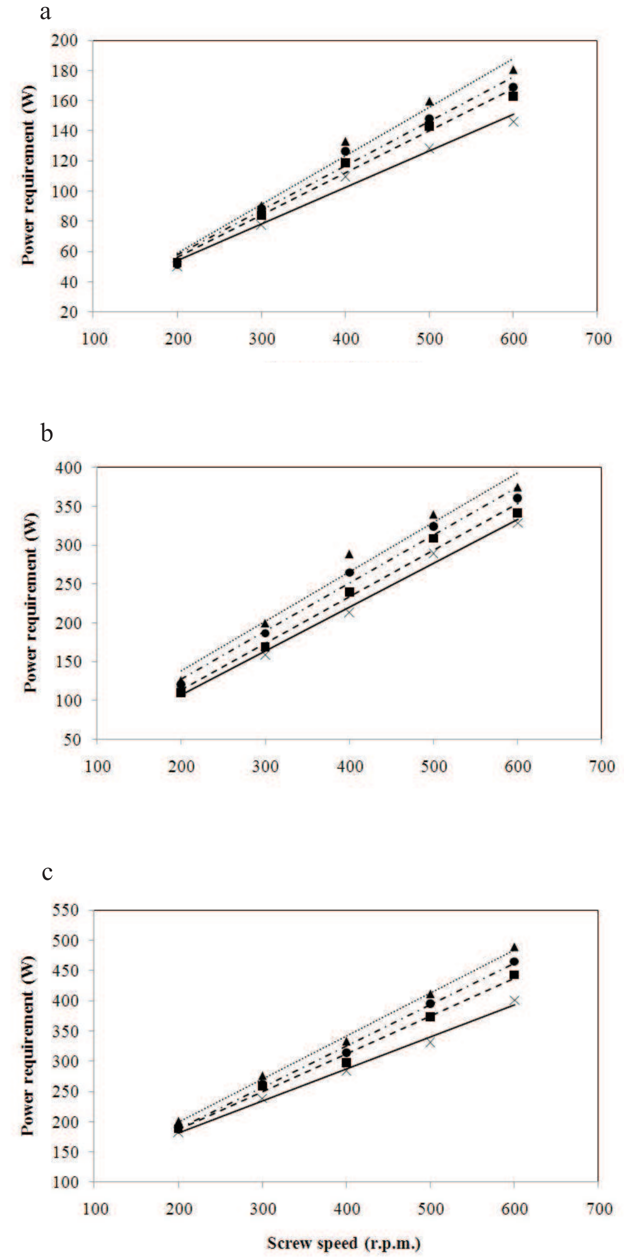

Fig. 3. Effect of screw rotational speed and conveying inclination on the power requirements for: a – 15.5, b – 20, and c – 25 cm screw augers; × horizontal conveying, ■ 10, ● 20, and ▲ 30°.

66.84, and 75.81% of their volumetric efficiency at horizontal transporting. The volumetric efficiency of the 20 and 25 cm augers was lower than that of corresponding augers investigated by Nicolai *et al*. (2004). This result can also be used to explain how the different properties of materials being conveyed can affect the screw augers performance. The equations representing relationship between the volumetric efficiency of the three evaluated screw augers with respect to the screw rotational speed at different conveying inclinations with their coefficient of determination (R^2) are presented in Table 3.

Based on the statistical analysis, the effects of auger dimensions, screw rotational speed and conveying inclination on the power requirements of the screw conveyors were all significant at 1% significance level. The mean values of power requirements for the three evaluated screw augers at different rotational speeds and conveying inclinations are given in Table 4. As shown, the power requirements of the screw augers increased with increasing the auger dimensions. It can be seen from Fig. 3 that for all of the conveyors investigated, the power requirements increased with increasing the screw rotational speed. This can be due to the fact

Table 2. Mean values of volumetric efficiency for the three evaluated screw augers at different screw rotational speeds and conveying inclinations (standard deviations are in parentheses)

Conveyor diameter (cm)	Screw speed (r.p.m.)	Volumetric output (m^3 min^{-1}) at conveying inclination (°)			
		0	10	20	30
15.5	200	33.10 (4.29)	30.34 (3.97)	24.21 (5.24)	18.62 (3.93)
	300	26.91 (5.38)	25.67 (3.92)	21.43 (3.36)	15.94 (3.77)
	400	22.35 (3.41)	21.66 (2.99)	18.23 (1.86)	14.06 (2.34)
	500	17.98 (1.82)	17.18 (2.75)	14.04 (2.41)	11.77 (1.29)
	600	14.40 (0.75)	12.96 (2.06)	10.45 (0.99)	8.55 (1.41)
20	200	34.12 (2.47)	32.09 (2.14)	27.03 (3.31)	22.89 (2.87)
	300	26.97 (1.15)	26.64 (1.15)	22.37 (1.41)	18.29 (1.91)
	400	22.82 (1.84)	22.11 (1.64)	20.19 (1.51)	15.30 (1.23)
	500	18.04 (0.97)	17.02 (1.04)	16.05 (1.06)	12.06 (0.76)
	600	14.60 (0.88)	13.42 (0.82)	12.13 (0.86)	9.35 (0.84)
25	200	33.44 (0.92)	32.63 (1.97)	30.13 (1.55)	25.91 (1.21)
	300	26.13 (0.88)	24.83 (1.41)	22.41 (1.61)	19.49 (0.74)
	400	20.88 (0.79)	20.41 (1.33)	18.71 (0.83)	15.83 (0.44)
	500	16.96 (0.84)	16.58 (0.98)	15.41 (0.71)	12.84 (0.69)
	600	13.83 (0.64)	13.04 (0.71)	12.36 (0.87)	10.25 (0.61)

Table 3. Relationships between the volumetric efficiency (E_v) and screw rotational speed (N_S) at different conveyor dimensions and conveying inclinations (R^2 are in parentheses)

Conveying inclination (°)	Conveyor diameter (cm)		
	15.5	20	25
0	E_v = -463E-4N_S+ 41.48 (0.989)	E_v = -480E-4N_S+ 42.99 (0.983)	E_v = -484E-4N_S+ 41.61 (0.972)
10	E_v = -433E-4N_S+ 38.86 (0.998)	E_v = -471E-4N_S+ 41.04 (0.996)	E_v = -476E-4N_S+ 40.67 (0.967)
20	E_v = -349E-4N_S+ 31.64 (0.994)	E_v = -361E-4N_S+ 34.01 (0.991)	E_v = -425E-4N_S+ 36.81 (0.965)
30	E_v = -243E-4N_S+ 23.51 (0.992)	E_v = -333E-4N_S+ 28.91 (0.990)	E_v = -380E-4N_S+ 32.05 (0.963)

that with increasing the screw rotational speed, the power needed for auger rotation and also the mass of the materials being conveyed increases. The results confirms Srivastava *et al*. (2006) conclusion that the power requirements of an auger increases with increasing the auger rotational speed. Chang and Steele (1997) reported that with increasing the screw rotational speed from 413 to 690 r.p.m., the average power requirements for the inlet section of a 15.2 cm conveyor increased from 189 to 338 W and 209 to 350 W, respectively, for two corn lots evaluated. They concluded that the power requirements for the inlet section tested were about 28 to 33% of the total power requirements for the 3 m long 15.2 cm diameter screw conveyor reported by White *et al*. (1962). Nicolai *et al*. (2004) determined the power requirements of large portable augers operating in a speed range of 250 to 1100 r.p.m. at inclination angles of 13, 20, and 30°. They reported that for every 100 r.p.m. increase in screw speed for a 25 cm conveyor an increased power of 0.8 kW was needed for inclination angles greater than 20°. The power requirement was reduced to 0.5 kW for each 100 r.p.m. increase at the transport position of 13° inclination. The results also revealed that the power requirements of the screw augers increase with increasing the conveying inclination (Fig. 4). This can be explained by an increase in the value of frictional forces between the conveying grains and the augers housing wall at higher levels of conveying

Table 4. Mean values of power requirements for the three evaluated screw augers at different screw rotational speeds and conveying inclinations (standard deviations are in parentheses)

Conveyor diameter (cm)	Screw speed (r.p.m.)	Power requirements (W) at conveying inclination (°)			
		0	10	20	30
15.5	200	50.28 (3.27)	52.78 (2.29)	52.19 (4.43)	54.22 (4.31)
	300	77.65 (5.64)	84.14 (6.43)	86.63 (5.93)	90.49 (6.41)
	400	109.62 (6.43)	118.71 (6.55)	126.39 (4.41)	132.96 (6.88)
	500	128.5 (6.54)	142.86 (8.84)	147.92 (8.27)	159.51 (8.92)
	600	148.95 (4.69)	162.95 (6.31)	168.89 (7.13)	180.37 (6.93)
20	200	112.09 (7.12)	110.26 (7.84)	120.52 (4.21)	125.90 (4.67)
	300	159.07 (8.18)	168.80 (3.74)	186.53 (5.23)	199.70 (5.25)
	400	213.68 (7.02)	239.88 (5.93)	264.96 (7.02)	288.65 (6.34)
	500	289.36 (8.54)	308.95 (7.48)	324.41 (4.99)	357.54 (8.46)
	600	328.71 (6.72)	341.23 (8.35)	360.93 (4.77)	374.53 (6.35)
25	200	182.11 (4.04)	187.86 (4.74)	188.45 (6.18)	200.73 (4.05)
	300	238.39 (3.53)	258.22 (8.96)	262.25 (7.37)	275.84 (7.77)
	400	284.53 (4.36)	297.67 (3.52)	314.21 (8.73)	333.07 (7.01)
	500	331.39 (5.40)	373.23 (6.61)	395.73 (6.75)	411.36 (5.55)
	600	400.79 (4.45)	443.12 (8.12)	465.15 (7.48)	489.06(5.59)

Table 5. Relationship between the screw augers power requirements (P_t) and screw rotational speed (N_S) at different conveyor dimensions and conveying inclinations (R^2 are in parentheses)

Conveying inclination (°)	Conveyor diameter (cm)		
	15.5	20	25
0	P_r = 2422E-4N_S + 5.52 (0.984)	P_r == 5635E-4N_S + 4.83 (0.992)	P_r == 5304E-4N_S + 75.29 (0.994)
10	P_r = 2791E-4N_S + 1.66 (0.989)	P_r == 6021E-4N_S + 7.02 (0.987)	P_r == 6255E-4N_S + 61.81 (0.992)
20	P_r = 2947E-4N_S + 1.27 (0.980)	P_r == 6187E-4N_S + 3.99 (0.986)	P_r == 6869E-4N_S + 50.39 (0.996)
30	P_r = 3213E-4N_S + 5.02 (0.982)	P_r == 6371E-4N_S + 10.82 (0.973)	P_r == 7122E-4N_S + 57.14 (0.997)

inclination. The power requirements of the 15.5, 20 and 25 cm augers at horizontal transporting were respectively 83.39, 81.92, and 84.04% of their power requirements at the conveying angle of 30°. Nicolai *et al*., (2006) reported that the power requirements for large portable bottom-drive swing augers were over twice the requirements of a top drive. They also indicated that each auger required an additional 2.89 kW power when the inclination angle was increased from transport position (13°) to 20°. An additional 3.73 to 4.47 kW power was required when the inclination angle was increased from 20 to 30°. The equations representing relationship between the power requirements of screw augers with respect to the augers rotational speed for the three conveyors evaluated at different conveying inclinations with their coefficient of determination (R^2) are presented in Table 5.

CONCLUSIONS

1. For all of the tested augers, increasing the screw speed increased the volumetric output up to a maximum value and further increases in speed caused a decrease in output.

2. The screw speed for the maximum volumetric output of the augers was in the speed range of 400 to 500 r.p.m. This range of the conveyors speed for maximum output was independent of the conveyors dimension and also the angle of inclination.

3. As the rotational speed and conveying inclination of the augers increased, the volumetric efficiency decreased significantly.

4. The power requirements of the screw augers increased with increasing the screw rotational speed and conveying inclination.

5. Comparing the results obtained in this study with the results had been previously reported for other cereal grains, it became evident that the performance characteristics of screw augers can be affected by the properties of materials being conveyed.

REFERENCES

ASABE Standards, **2006.** ASAE S374 MAR1975. Terminology and Specification Definitions for Agricultural Auger Conveying Equipment. ASABE Press, St. Joseph, MI, USA.

Asghari A., Alimardani R., Akram A., and Karparvar H., 2008. Effect of auger speed and air flow on discharge rate of bagasse. Am.-Eur. J. Agric. Environ. Sci., 3(5), 743-747.

Bloome P., Harp S., and Brusewitz G., 1996. Auger Conveyors. OSU Extension Facts No. 1105. Oklahoma State Univ. Stillwater, OK, USA.

Burr M.S., Kocher M.F., and Jones D.D., 1998. Design of tapered augers for uniform unloading particulate materials from rectangular cross-section containers. Trans. ASAE., 41(5), 1415-1421.

Chang C.S. and Steele J.L., 1997. Performance characteristics of the inlet section of a screw auger. Appl. Eng. Agric., 13(5), 627-630.

Dai J. and Grace J.R., 2008. A model for biomass screw feeding. Powder Techn., 186, 40-55.

Konig A. and Riemann U., 1990. Untersuchungen am Senkrechten chneckenforderer. Landtechn. Forschung., 10(2), 45-51.

Maleki M.R., Jafari J.F., Raufat M.H., Mouazen A.M., and Baerdemaeker J.D., 2006. Distribution uniformity of a multi-flight auger as a grain drill metering device. Biosys. Eng., 94(4), 535-543.

Moysey P.A. and Thompson M.R., 2005. Modelling the solids inflow and solids conveying of single-screw extruders using the discrete element method. Powder Techn., 153, 95-107.

Nicolai R., Dittbenner A., and Pasikanti S., 2006. Large portable auger throughput analysis. Proc. ASABE Ann. Int. Meeting, July 9-12, Portland, OR, USA.

Nicolai R., Ollerich J., and Kelley J., 2004. Screw auger power and throughput analysis. Proc. ASAE/CSAE Ann. Int. Meeting, August 1-4, Ottawa, Ontario, Canada.

Pan Z., Khir R., Godfrey L.D., Lewis R., Thompson J.F., and Salim A., 2008. Feasibility of simultaneous rough rice drying and disinfestations by infrared radiation heating and rice milling quality. J. Food Eng., 84, 469-479.

Roberts A.W., 1999. The influence of granular vortex motion on the volumetric performance of enclosed screw conveyors. Powder Techn., 104, 56-67.

Roohi G.R., 2003. Study of energy consumption in the hulling and whitening of three paddy varieties in Guilan, Iran. MSc. Thesis, Tehran Univ., Tehran, Iran.

Roohi G.R., Minaei S., and Payman M., 2005. Designing, manufacturing and evaluation of a power meter with the capability of data monitoring. Proc. 3rd Nat. Conf. Agricultural Machinery Engineering and Mechanization in Iran, September 11-15, Kerman, Iran.

Srivastava A.K., Goering C.E., Rohrbach R.P., and Buckmaster D.R., 2006. Engineering Principles of Agricultural Machines. ASABE Press, Detroit, MI, USA.

White G.M., Schaper L.A., Ross I.J., and Isaacs G.W., 1962. Performance characteristics of enclosed screw conveyors handling shelled corn and soybeans. Res. Bull. No. 740. Indiana Agric. Exp. Station, Purdue University, Lafayette, IN, USA.

Zareiforoush H., Komarizadeh M.H., and Alizadeh M.R., 2009. Effect of moisture content on some physical properties of paddy grains. Res. J. Appl. Sci. Eng. Techn., 1(3), 132-139.