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Effect of Forward Speed and Tuber Characteristics on Tuber Spacing Uniformity for a Cup-Belt Potato Planter

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Abstract: The present study has been conducted to evaluate the performance of an auto-feed cup-belt potato planter operated at three forward speeds (1.8, 2.25 and 3 km/h) and three tuber sizes (35-45, 45-55 and 55-65 mm). Also, Hermes and Sponta varieties were utilized to provide different tuber shapes (spherical and oblong, respectively). The performance of the planter was evaluated in terms of the mean tuber spacing (M), the coefficient of variation (CV), the multiple index (MULTI), the miss index (MISI) and the quality of feed index (QFI). The results revealed that the increase in the forward speed induced a significant increase in the mean tuber spacing and a significant reduction in the tuber spacing uniformity, as indicated by the values of the CV, MULTI and MISI indexes. Also, tuber size was observed to induce insignificant effects on the mean tuber spacing. But, the effect of tuber size on tuber spacing uniformity was found to be significant. Tuber size of 35-45 mm induced better tuber spacing uniformity than other tested tuber sizes. On the other hand, tuber shape (variety) exhibited significant effects on both the mean tuber spacing and tuber spacing uniformity.

Key words: Potato planter · Planter performance · Tuber size · Tuber shape

INTRODUCTION

Potato is ranked as one of the most important vegetable crops in the world. Potato occupies the second place in importance after seed crops [1]. In Saudi Arabia, potato crop is planted in an area of 17,665 hectares in season 2010 with a production of about 444,138 tons [2]. Potato planting is considered as a very crucial and critical operation because it directly affects the yield and the farming cost, as the price of potato tubers mounts to about 60% of the total potato production cost [3]. Improving uniformity of within row spacing is expected to decrease competition between plants and increase grain yield through more efficient use of available light, water and nutrients by the plants. The performance of several potato planters has been investigated by many researches and studies: Bader [4] evaluated three potato feeding systems (semi automatic chain, semi automatic tray and automatic cup) to determine the optimum operational requirements and to select the most effective system. Automatic cup planter was found to be the best. Wahby *et al.* [5] observed lower in-row spacing with cup-feeding planter than semi-automatic and finger-feed mechanism planters. However, Ghonimy and Rostom [3] observed higher coefficient of variation for tuber spacing with auto-feed cup planter than planters with either single- or multi-feed belts. Previous studies showed that there is a correlation between speed and performance of potato planters where the low performance of these machines may be due to the high of forward speed [6]. Altuntas [7] reported that seed distribution pattern in the row was disturbed as forward speed increased. Forward speed and release point on the metering mechanism was found to affect tuber spacing distribution in the furrow [8]. Khairy [9] reported that as the forward speed increased the mean tuber distance increased. He observed low uniformity when the forward speed was higher than 3.6 km/h. Adjusting planting speed in conjunction with

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uniform sized seed improved planter performance [10]. Buitinwerf *et al.* [11] observed more uniform deposition of potato tubers with higher cub-belt speed. Ismail [12] reported that when the planting speed increased, the percentage of tuber doubles and space uniformity were decreased. The seed spacing uniformity is affected by the tuber characteristics (size and shape) as well as machine's forward speeds Sieczka *et al.* [6]. Misener [13] reported that the performance of cup type planter is quite sensitive to tuber size and shape. To achieve optimum planter performance, Kepener *et al.* [14] recommended the selection of tubers of proper size and shape that best fit a given shape of cell. They also reported that smooth tubers approaching spherical tuber shape are the best for precision planting. Ismail [15] reported that the most suitable tuber size for cup-belt potato planter must be in the range of 30 - 50 g per hill. Gruczek [16] reported that higher planting precision can be achieved when exactly graded medium shaped tubers (4-5 cm) were used at a planter forward speed of 3.0 km/h. Hamad *et al.* [17] stated that the percentage of miss tubers of 10.76±5.95 %, 8.2±3.54% and 5.2±2.05% were obtained with tuber weights of 50, 40 and 30 g, respectively. The percentage of double tubers for 30 g tubers was higher than for other categories. Altuntas [7] observed that the small tubers caused better in row distribution pattern than big tubers. However, Buitenwerf *et al.* [11] reported that a regular potato shape did not result in higher planting accuracy. The mean spacing and the standard deviation of the seed spacing are useful but do not thoroughly characterize the distribution of seed spacing for single seed planters. In addition to the coefficient of variation of the seed spacing, the multiple index, the miss index and the quality of feed index should all be considered in the performance evaluation of a single seed planter [18].

In the Kingdom of Saudi Arabia, the cup-belt prototype is the most commonly used machine for potato planting. However, a lack of a thorough knowledge exists in the details of the factors affecting the operation efficiency of this machine under different operation conditions. Therefore, the objective of this field study was to investigate the effects of forward speed and tuber characteristics (tuber size and shape) on seed spacing uniformity.

MATERIALS AND METHODS

Field experiments were conducted on an area of 2000 m^2 at the educational farm of the College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia. The soil was mainly sandy loam with bulk density of 1.60 - 1.65 g/cm^3. The field was prepared by using moldboard plow, disc harrow and a roller. Experiments were conducted under three forward speeds (1.8, 2.25 and 3.0 km/h), three tuber sizes (35 - 45, 45 - 55 and 55 - 65 mm) and two potato varieties (Hermes and Sponta). The main tuber characteristics of the two used varieties are given in Table 1. It should be noted that these characteristics were obtained prior to the grading process of tubers and the classification of the used tuber sizes.

Table 1: The mean tuber characteristics.

	Variety	
	Hermes	Sponta
Mean length, mm	65±6.7	74±4.8
Mean width, mm	56±7.62	46±7.26
Thickness, mm	48±3.44	37±5.67
Mean weight, g	66±8.73	64±6.87

Fig. 1: Tested potato planter.

Tubers shape index, calculated using Equation 2, was found to be 157.18 for Hermes and 321.74 for Sponta. Therefore, according to the International Organization for Standardization [19], the shape of Hermes tubers is characterized as 'spherical' and the shape of Sponta tubers as 'oblong'.

$$f = \frac{j^2 \times 100}{t \times h} \quad (1)$$

Where: f is the shape index, j is the maximum length (mm), h is the maximum width (mm) and t is the thickness (mm).

An automatic cup-belt potato planter (model: TEKYATAGANLI, Turkey), Fig. 1, mounted on a 74 kW - Volvo tractor was used as a test machine. This machine was specified to cover two rows with 64 cm spacing and equipped with a shoe furrow opener type. The size of cups is 76, 55 and 15 mm for outside diameter, inside diameter and depth respectively. The capacity of the machine hopper was specified at 300 kg with total machine weight of 550 kg. The rotational speed of the belt that carrying the cups is adjustable and dependent on the selected speed ratio. The planter was adjusted for a target tuber seed spacing of 23 cm. Different combinations of treatments were repeated three times (replicates) which produced 54 test runs. Each test run was conducted on a course of 15 m. Split-split plot design was adopted for the field experiment layout.

Seed spacing measurements were performed immediately after planting on a central 5 meters of the 15 m row length for both rows in each plot. Soil was carefully removed from above the seeds and seed spacing was then measured using a measuring tape. Seed tuber spacing uniformity has been evaluated in terms of the mean tuber spacing (M), the coefficient of variation (CV), the multiple index (MULTI), the miss index (MISI) and the quality of feed index (QFI,%).

(i) Coefficient of variation (CV,%) of tuber seed spacing was calculated as follows:

$$CV, \% = \frac{SD*100}{X_m} \qquad (2)$$

Where: SD is the standard deviation of tuber seed spacing. X_m is the mean tuber spacing, mm.

The standard deviation was calculated according to Equation 3.

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(X_i - X_m)}{N-1}} \qquad (3)$$

Where: X_i is a specified tuber spacing, mm. N is the total number of tuber spacings.

(ii) Multiple index (MULTI, %) is the percentage of spacings that are less than or equal to half the theoretical spacing. Multiple index (MULTI, %) was calculated as follows:

$$MULTI, \% = \frac{N_1 \times 100}{N} \qquad (4)$$

Where: N_1 is the number of spacings that are less or equal to half the theoretical spacing.

(iii) Miss index (MISI, %) is the percentage of spacings greater than 1.5 times the theoretical spacing. The percentage of tuber miss index (MISI, %) was calculated as follows:

$$MISI, \% = \frac{N_2 \times 100}{N} \qquad (5)$$

Where:
N_2 is the number of spacings that are greater than 1.5 times the theoretical spacing.

(iv) Quality of feed index (QFI) is the percentage of spacings that are more than half but not more than 1.5 times the theoretical spacing. This is a measure of how close the spacings are to the theoretical spacing. The quality of feed index (QFI) was calculated as follows:

$$QFI, \% = 100 - (MULTI + MISI) \qquad (6)$$

RESULTS AND DISCUSSIONS

Table 2 summarizes the analysis of variance (p values) of the effects of the forward speed and tuber characteristics (tuber size and shape) on tuber spacing uniformity. Tuber spacing uniformity in terms of the tested parameters will be discussed in the following sections.

Effect of the Forward Speed: The effect of the forward speed on tuber spacing uniformity is characterized by the results presented in Table 3 and Fig. 2. The results indicated that the forward speed was significantly affected both mean tuber spacing and tuber spacing uniformity. It was observed that the mean tuber spacing increased with the increase in the forward speed. Also, tuber spacing uniformity is the best under low forward speed as indicated by CV values. This was also confirmed by the values of the multiple index (MULTI), the miss index (MISI) and the quality of feed index (QFI) given in Table 3, that the best values of these indexes were observed at low forward speed. It was also observed that there were no significant differences between the performance of the tested planter when operated at 1.8 km/h or 2.25 km/h as indicated by the MULTI, MISI and the QFI (Table 3). According to these results, the tested planter could be efficiently operated at a forward speed of 2.25 km/h to get high field capacity (compared to 1.8 km/h), while not affecting seed tuber uniformity.

Effect of Tuber Size: The results of tuber spacing uniformity as affected by tuber size are presented in Table 4 and Fig. 3. The increase in tuber size caused slight increase in the mean tuber spacing as presented in Table 2 and there were no significant differences observed in the mean tuber spacing as a result of tuber size. While, the influence of tuber size on tuber spacing uniformity was found to be significant as indicated by the values of CV, MULTI and MISI indexes. The 35 - 45 mm tuber size induced higher MULTI values than other sizes. These results agreed with the result reported by Altuntas [7]. Also it was observed that there are significant differences between the MULTI values when using tuber size of 35 - 45 mm and 55 - 65 mm. The MISI value increased by 20.43 and 40.66% when the tuber size of 35-45 mm was used instead of 45-55 mm and 55-65 mm respectively. For all test parameters, the lowest values of the CV of tuber spacing were observed for the smallest tuber size (35-45 mm). Therefore based on the seed spacing uniformity data, the performance of the tested cup-belt potato planter is the best when small tuber size (35-45 mm) was used.

Effect of Tuber Shape: The results of the effect of tuber shape (tuber variety) as well as the results of the statistical analysis are given in Fig. 4 and Table 5. The results indicated that tuber variety effects on the mean tuber spacing were statistically significant. Hermes variety (spherical shape) induced significantly lower mean tuber spacing than Sponta variety (oblong shape). Regarding tuber spacing uniformity, it was observed that tuber shape induced a significant differences between the values of CV and MISI. While the effect of tuber shape on the MULTI and QFI indexes was not significant. These observation could be attributed to that the flow of tuber from the tank to the feeding cups is expected to be better with Hermes variety than for Sponta as a result of the uniform shape of Hermes variety and that will enhance the possibility for the cups to be filled by tubers. Obviously, the use of spherical shape for seed tuber will improve the uniformity of seed spacing.

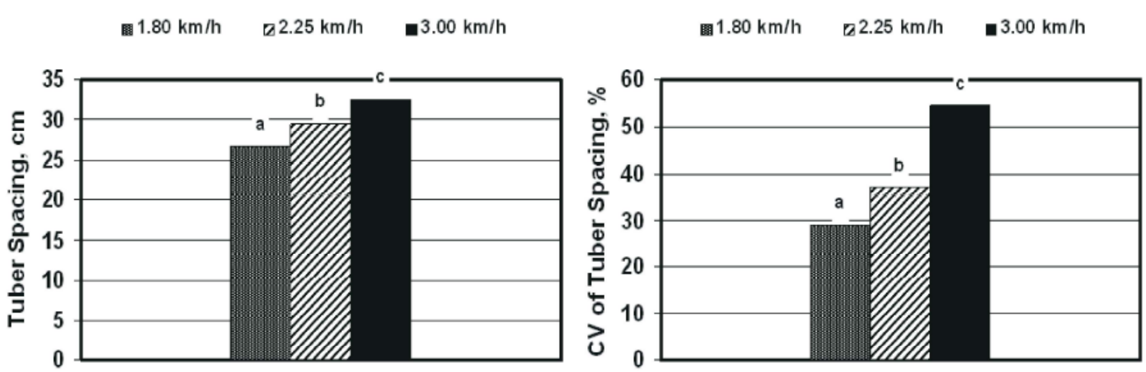

Fig. 2: Tuber spacing uniformity as affected by the forward speed.

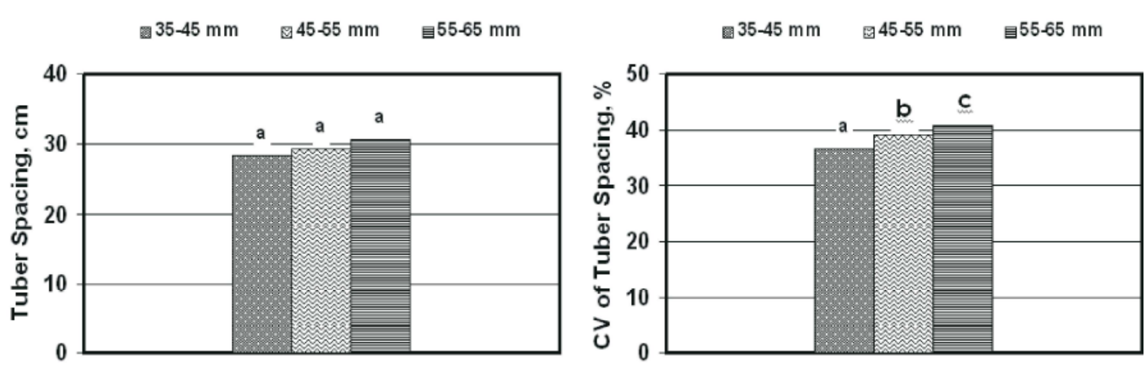

Fig. 3: Tuber spacing uniformity as affected by tuber size.

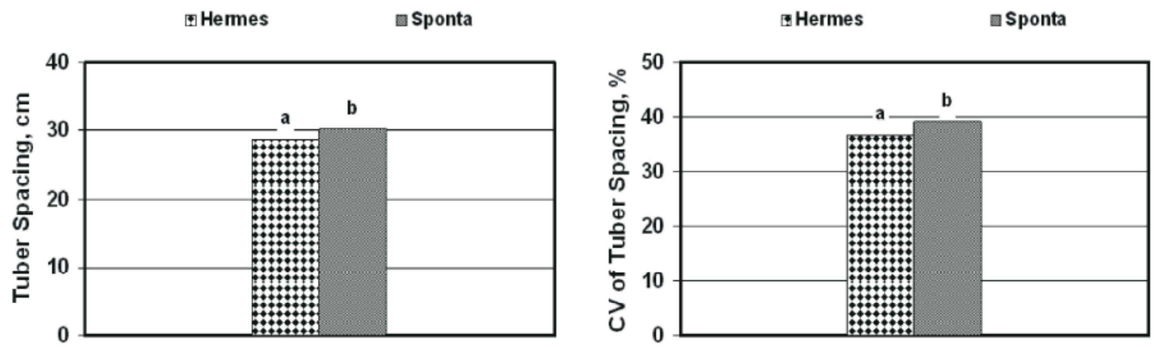

Fig. 4: Tuber spacing uniformity as affected by tuber shape (variety).

Table 2: Analysis of variance (P values) for tuber spacing.

Source	DF	Mean Spacing	CV	MULTI	MISI	QFI
Tuber size (Z)	2	0.265	0.034	0.022	0.005	0.649
Forward speed (S)	2	0	0	0.001	0.004	0.666
Variety (V)	1	0.021	0	0.385	0.003	0.178
S × Z	4	0.999	0.64	0.787	0.998	0.999
Z × V	2	0.534	0.696	0.997	0.772	0.949
S× V	2	0.845	0.736	0.772	0.902	0.971
Z × S × V	4	0.999	0.966	0.989	0.98	0.985

Table 3: Effect of the forward speed on tuber spacing uniformity.

Forward Speed km/h	Mean Spacing (M) cm	CV %	MULTI%	MISI %	QFI %
1.80	26.65 a*	28.73 a	5.93 a	3.91 a	90.16 a
2.25	29.42 b	37.10 b	4.62 a	5.74 a	89.81 a
3.00	32.48 c	54.53 c	2.29 b	9.11 b	88.91 a

* Values followed by the same letter are not significantly different

Table 4: Effect of tuber size on seed spacing uniformity (mean comparisons).

Tuber Size mm	Mean Spacing (M) cm	CV %	MULTI %	MISI %	QFI %
35 - 45	28.34 a	36.73 a	5.35 a	5.19 a	90.00 a
45 - 55	29.51 a	39.07 b	4.18 ab	6.25 b	89.57 a
55 - 65	30.70 a	40.70 c	3.31 b	7.30 c	89.31 a

Table 5: Effect of tuber variety on seed spacing uniformity (mean comparisons).

Tuber Size mm	Mean Spacing (M) cm	CV %	MULTI%	MISI %	QFI %
Hermes	28.85 a	38.36 a	4.61 a	5.24 a	90.30 a
Sponta	30.18 b	41.98 b	3.95 a	7.27 b	88.95 a

CONCLUSIONS

A cup-belt potato planter was field tested at different forward speeds, tuber sizes and two different tuber shapes (two varieties: Hermes and Sponta). The specific conclusions of the study include the following:

- The forward speed influenced the mean tuber spacing significantly. The increase in the forward speed caused an increase in the mean tuber spacing. Also the forward speed affected tuber spacing uniformity significantly as indicated by the CV, MULTI, MISI and QFI indexes.
- Tuber size induced slight effects on the mean tuber spacing. While the effect of tuber size was found to be significant on tuber spacing uniformity as indicated by the values of CV, MULTI and MISI indexes. Tuber size of 35-45 mm

induced better tuber spacing uniformity than other tested sizes.

- Potato variety exhibited significant effects on both mean tuber spacing and tuber spacing uniformity.
- From the results of this study, a forward speed in the range of 2.25 km/h, tuber size of 35-45 mm and spherical tuber shape could be recommended for the cup-belt potato planter.

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