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Effect of Cup Size, Seed Characteristics and Angular Speed on the Performance of an Automatic Potato Planter under Laboratory Conditions

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ABSTRACT

The seed metering mechanism is the most important unit of potato planters. Accuracy of row plant spacing depends on the ability of the seed metering mechanism. The ability of the seed metering mechanism is directly associated with the constructive and operational variables of the planter. This study was conducted to evaluate the effects of different cups sizes (C1<C2<C3), different seed sizes (25 to 45 and 45 to 65 mm), different shapes (oblong and spherical), and angular speeds (0.9, 2.04 and 3.18 rad s^{-1}) on the seed metering mechanism in a full automatic potato planter. The cup, angular speed, seed size and shape have an important role on the efficiency of the seed metering mechanism. The seed spacing uniformity was determined including doubles and skips. The coefficient of variation (CV%) was used to determine the seed spacing uniformity. The values of CV% for cups were 29.24, 23.76 and 26.11% for C1, C2 and C3, respectively. C3 has the highest percent value of doubles and the lowest percent value of skips. The seed spacing uniformity of oblong potato seeds was better than that of spherical potato seeds. The percent value of doubles increased and percent value of skips decreased for oblong potato seeds, opposite to the spherical potato seeds. The seed size of 45-65 mm gave a better seed spacing uniformity than the other seed size. It was observed that the seed size of 25-45 mm had higher percent value of doubles. The seed spacing uniformity tended to increase as the angular speed reduced. The CV% values of angular speed were 22.83, 24.90 and 31.39% for 0.9, 2.04, 3.18 rad s^{-1}, respectively. As the angular speed increased, percent value of doubles decreased and percent value of skips increased.

Keywords: Seed metering mechanism; Seed spacing uniformity; Laser measurement system; Doubles; Skips

Laboratuvar Koşullarında Otomatik Bir Patates Dikim Makinasının Performansına Kepçe Büyüklüğünün, Tohum Karakteristiklerinin ve Açısal Hızın Etkisi

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ÖZET

Tohum dağıtma düzeni patates dikim makinalarının en temel kısmını oluşturmaktadır. Sıra üzeri tohum dağılım düzgünlüğündeki doğruluk, tohum dağıtma düzeninin kabiliyetine bağlıdır. Tohum dağıtma düzeninin bu kabiliyeti yapısal ve çalışma şartlarına direkt olarak bağlıdır. Bu çalışma, tam otomatik bir patates dikim makinasında farklı büyüklükte kepçelerin (C1<C2<C3), farklı büyüklükteki tohumların (25 ile 45 mm ve 45 ile 65 mm arası), farklı şekildeki tohumların (uzun ve küresel) ve farklı açısal hızların (0.9, 2.04 ve 3.18 rad s^{-1}) tohum dağıtma düzeni üzerine etkisini belirlemek için yürütülmüştür. Kepçelerin, açısal hızın, tohum büyüklüğünün ve şeklinin tohum dağıtma düzeni üzerine önemli bir etkiye sahip olduğu görülmüştür. Denemede, tohum dağılım düzgünlüğü, ikili atma ve boş bırakma belirlenmiştir. Tohum dağılım düzgünlüğünü belirlemede varyasyon katsayısı (% CV) kullanılmıştır. C1, C2 ve C3 kepçeleri için en büyük % CV değerleri sırayla % 29.24, 23.76 ve 26.11 olarak bulunmuştur. C3 kepçesiyle en büyük ikili atma ve en küçük boş bırakma değerleri elde edilmiştir. Uzun tohumlardan elde edilen tohum dağılım düzgünlüğünün küresel tohumlara göre daha iyi olduğu belirlenmiştir. Uzun tohumlarda ikili atmanın arttığı ve boş bırakmanın azaldığı görülmüştür. Küresel tohumlarda ise bunun tam aksi görülmüştür. 45-65 mm aralığındaki tohumlardan elde edilen % CV değerlerinin 25-45 mm aralığındaki tohumlardan elde edilen % CV değerinden daha düşük olduğu belirlenmiştir. 25-45 mm aralığındaki tohumların ikili atmayı artırdığı görülmüştür. Açısal hızdaki azalma tohum dağılım düzgünlüğünde iyileşmeye neden olmuştur. Farklı açısal hızlardan elde edilen % CV değerleri; 0.9, 2.04, 3.18 rad s^{-1} için sırasıyla % 22.83, 24.90 ve 31.39 olarak bulunmuştur. Açısal hızdaki artış ikili atmada azalışa ve boş bırakmada artışa neden olmuştur.

Anahtar Kelimeler: Tohum dağıtma düzeni; Tohum dağılım düzgünlüğü; Lazer ölçüm sistemi; İkizlenme; Boş bırakma

1. Introduction

Potato is an important food crop for humans and animals due to its desirable starch, protein and vitamins contents. The potato is used as a versatile vegetable and in the industry. The potato is grown in many countries around the world and in different climates (Taheri & Shamabadi 2013; Potato 2015). The potato acreage in Turkey is 125030 ha resulting in a harvest of 3.9 million tonnes of tubers and yield is 31.6 tons per ha for the year 2013 (FAO 2015). The most common potato varieties in Turkey have yellow flesh are Marabel, Marfona, Granola, Latona, Adora, Atlas, Fabula, Lady Rosetta, Lady Claire, Russet Burbank, Shepody, Agria and Van Gogh. According to regional conditions in Turkey, traditional and modern methods are used in the potato production. Traditional potato production is difficult, time consuming and labor intensive. Therefore, most of the farming operation for this crop has been mechanized to reduce the cost of production. There are three main stages in potato production: planting, cultivating, and harvesting. Planting has an important effect on the potato yield. Planting is performed by hand, semi-automatic planters, and fully automatic planters. Planting done by hand is time-consuming and requires a great deal of labor. Semi-automatic potato planters have a suitable performance and low labor and less time-consuming compared to planting by hand. Labor and time-consuming in fully automatic potato planters are the lowest level. Results achieved in potato planting by machine depend on complex relationships between the technical quality of machine performance and the ability to work fast with a minimum demand for labour (Culpin 1992; Steele et al 2010). The fully automatic potato planters release potato seeds in furrows at desired certain spacing and depth. A potato planting machine has many different parts such as frame, wheels, seed metering mechanism, furrow openers, covering discs, and the seed spacing adjustment gear. Among these parts, the seed metering mechanism is a crucial one. Accuracy of in-row seed spacing is the main parameter of the seed metering mechanism. Because, improvement of plant spacing uniformity leads to high yield, and to facilitate harvesting and post-harvest operations (McPhee et al 1996; Pavek & Thornton 2003). The plant uniformity affects development, yield and seed quality of plant (Bussan et al 2007; Güllüoglu & Arioglu 2009). Seed spacing uniformity has very important role for evaluating a potato planter performance (Zoraki & Acar 2000; Seyedbagheri 2006). To increase yield and quality of potato, uniform seed spacing is required (Klassen 1974; Klassen 1975). Rupp & Thornton (1992) found that a 10% decrease or increase in the optimum plant number leads to reduce yield from 2% to 12%. Furthermore, they said that increasing skips and doubles reduced economic return compared with uniform seed spacing. Deep planting and diseased seed can cause skips to increase (Cross & Ohms 1967; James at al 1973). However, James et al (1975) determined that 88% of skips were due to the lack of seed. Some researchers found that the skips were mainly caused by mechanical deficiencies of the potato planter (Misener 1979). James et al (1973) found that 10, 20 and 30% of skips led to 0, 5.6 and 11.1% average yield loss, respectively. However, potato yield is a good criterion along with the market value of tubers in the proto production. Therefore, the physical properties of potato tubers also have an important role in appearance at markets. Tuber size is more important indication of marketable yield than the total tuber yield. Some researchers have showed that seed spacing uniformity plays a major impact on marketable yield (Schotzko et al 1983; Thornton et al 1983; Rex et al 1987; Rupp & Thornton 1992; Creamer et al 1999; Love & Thompson-Johns 1999). Getachew et al (2012) determined the effect of seed spacing on total yield and marketable yield of potato in Ethiopia. They found the highest total tuber yield at seed spacing of 10 cm whereas marketable tuber yield at seed spacing of 10 cm had the lowest value. Similarly, Love & Thompson-Johns (1999) determined that seed planted at seed spacing of 8 cm resulted in more potato yields than those of seed planted at spacing from 15 to 91 cm. But, they said that the market value decreased due to increasing percent of small potatoes. Naturally, accuracy of seed spacing changes depending on the size and shape of cups. However, although many works were done on potato planters, studies on the effect of cups on seed spacing uniformity are limited. Buitenwerf et al (2006) studied on cup-belt planter and stated that the geometry of cups should be focused. In addition, previous research (Khairy 1997; Altuntas 2005; Al-Gaadi & Marey 2011) showed that there was an effect of ground speed, and different seed sizes and shapes on seed spacing uniformity. Altuntas (2005) reported that in-row spacing uniformity decreased as ground speed increased. Khairy (1997) found that when the ground speed was higher than 3.6 km h^{-1}, seed spacing uniformity became worse. Similarly, Al-Gaadi & Marey (2011) determined that the lowest and the highest mean values of CV% were 28.73 and 54.53% for ground speed of 1.80 and 3 km h^{-1}, respectively. Sieczka et al (1986) stated that high planting speeds reduced performance of potato planter. Buitenwerf et al (2006) determined that potato shape had an important effect on seed spacing uniformity.

The objective of this study was to determine the effect of three various size cups, three different angular speeds, and two several seed size and shape on the seed spacing uniformity, skips and doubles; and then to develop a measurement system suitable for laboratory and field studies.

2. Material and Methods

2.1. Potato planter, cups, and angular speeds

The experiments were conducted at the laboratory of Agricultural Farm Machinery Department, Ataturk University, Erzurum, Turkey. The laboratory temperature and relative humidity were measured as 9 ^{0}C and 25%, respectively. A full automatic potato planter (Model: YN-08 Kenan Ertugrul, Nevsehir, Turkey) (Figure 1) was used in the experiments.

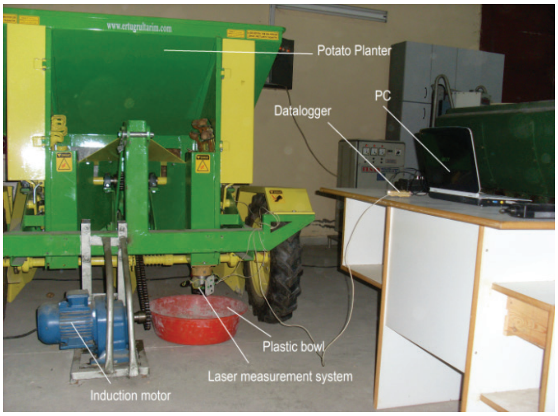

Figure 1- Potato planter and test rig

Şekil 1- Patates dikim makinası ve deney düzeneği

The potato planter consists of two rows. The seed metering mechanisms are placed under the hopper, and driven by ground wheels. The seed metering mechanism consists of a vertical disc, cups, holding pins, and torsion springs. The 14 cups, 14 holding pins, and 14 torsion springs are attached with equal angles to the vertical disc.

The seed metering mechanism works like a water mill. The cups, attached to vertical disc, clutch potato seeds in the bottom of seed hopper while the vertical disc rotates. Then, seed entering into the cup is kept by the holding pin, and transferred out of the seed hopper. After vertical disc revolves 190^0, the holding pin is opened by the pin-position cam. So, potato seed drops into furrow (Figure 4). The force exerted by helical spring was 11.96±0.96 N. The cups with three different sizes (Figure 2) (small, middle and big is C1, C2 and C3, respectively) were used in the experiment. All cups were made of cast iron. The dimensions of these cups are presented in Table 1 and Figure 3. Three angular speeds for the seed metering mechanism were determined by taking into account the maximum and minimum forward speeds and seed rates of the potato planter, because while the ground speed and seed rates change, the angular speeds of the seed metering mechanism change. So, the angular speeds of the seed metering mechanism were selected as 0.9, 2.04 and 3.18 rad s^{-1}. The seed rates were 120, 273 and 425 seed min^{-1} for these angular speeds, respectively. These angular speeds were provided by an AC three phase inverter which changed the rpm of the three-phase electric motor attached by a roller chain to the axle of the vertical disc.

Figure 2- Cups used in the experiment

Şekil 2- Denemede kullanılan kepçeler

Table 1- Selected dimensions of the cups

Çizelge 1- Kepçelerin seçilmiş boyutları

Cups	*A, mm*	*B, mm*	*C, mm*	*D, mm*	*E, mm*
C1	50	40	50	45	15
C2	64	54	64	54	21
C3	76	65	76	65	25

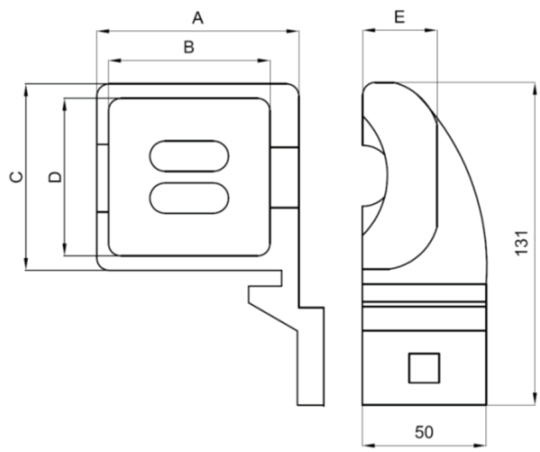

Figure 3- Dimensions of the cups

Şekil 3- Kepçelerin boyutları

2.2. Seed material

Agria and Marfona cultivars were used as seed materials in the experiments. These cultivars had different shapes from each other. Until the experiments were conducted, the potato seeds were stored in a warehouse under appropriate conditions. The potato seeds were separated into two groups. The first group was between 25-45 mm seed size, and the second group was between 45-65 mm seed size. Some physical properties of seeds were presented in Table 2.

Shape factor (*Sf*) was determined with Equation 1 (Buitenwerf et al 2006).

$$S_f = \frac{a^2}{bc} x100\% \quad (1)$$

Where; *a*, *b* and *c*, length, width and height of the seed as mm, respectively. The *a*, *b* and *c* dimensions have a relationship of c<b<a (Mohsenin 1986).

Table 2- Some physical properties of Marfona and Agria*

*Çizelge 2- Marfona ve Agria'nın bazı fiziksel özellikleri**

	Agria		*Marfona*	
	25-45 mm	*45-65 mm*	*25-45 mm*	*45-65 mm*
a, mm	60.97±4.02	70.88±3.53	50.18±3.43	56.94±5.68
b, mm	43.10±1.56	49.42±3.42	43.89±3.51	51.65±2.61
c, mm	36.07±2.58	41.54±2.93	41.57±2.52	44.41±2.06
D_p, mm	45.54±1.39	52.55±2.35	45.02±2.28	50.69±2.61
Mass, g	54.53±3.40	83.58±12.29	53.43±4.94	74.91±11.16
Shape factor	242.33±44.57	246.70±27.65	138.92±16.80	142.08±23.30
Percent sphericity	75±4.00	74±3.00	90±3.00	89±5.00

*, values are presented as mean±standard deviation; *a*, *b* and *c*, dimensions of the principle axes; D_p, geometric mean diameter

Sphericity (S_p) and geometric mean diameter (D_p) were determined by Equation 2 and 3 (Mohsenin 1986).

$$S_p = \frac{(abc)^{1/3}}{a} x100\% \quad (2)$$

$$D_{p=(abc)^{1/3}} \quad (3)$$

2.3. Measurement system

The measuring system was composed of two main parts: 1) Laser measuring unit used to determine the seed spacing uniformity, doubles, and skips, and 2) angular speed measuring unit (Figure 4).

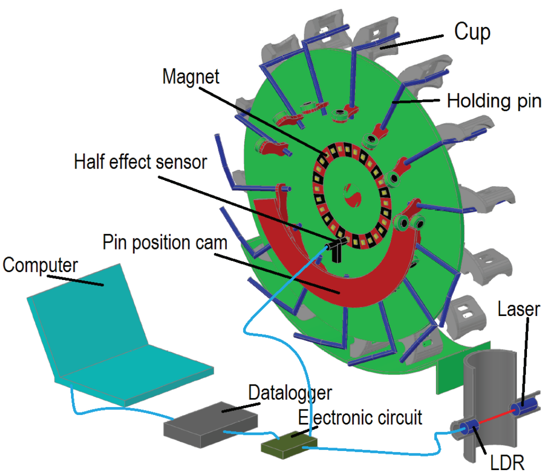

Figure 4- Measurement system

Şekil 4- Ölçüm sistemi

The laser measurement unit consists of a light dependent resistor (LDR), a laser pointer, a pipe of 80 mm diameter, and an electronic circuit. The laser measurement unit was attached under the cups. The unit measures time intervals between seeds falling down from cups (Boydas & Uygan 2012). Seeds passed through the pipe create a signal, and this signal is sent to the electronic circuit, then to the digital port of datalogger. So, a square wave is obtained from the unit. The time interval between two peaks of a square wave is used to determine seed spacing uniformity, percent value of skips, and percent value of doubles (Figure 5).

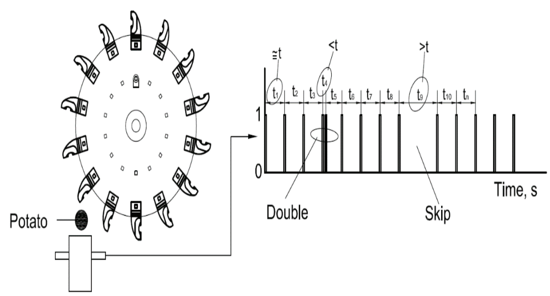

Figure 5- The square wave obtained from falling seeds

Şekil 5- Düşen tohumlardan elde edilen kare dalga

Angular speed measuring unit consists of a half effect sensor, neodymium magnets, and an electronic circuit. The magnets were positioned in the circumference of the vertical disc. The half effect sensor was placed exactly in front of the magnets (Figure 6). While the vertical disc rotated, a square wave was obtained from the half effect sensor. This signal was sent to the electronic circuit (Figure 7). The rpm of the seed metering mechanism and two threshold values giving doubles and skips were determined with the help of the half effect sensor. The time between two square waves was shown with "t" (Figure 7). The value of t changed depending on the change in angular velocity of the seed metering mechanism. The value of t was calculated with a program written in MATLAB.

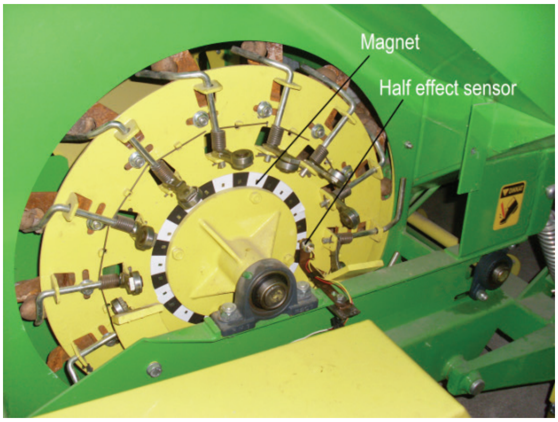

Figure 6- Half effect sensor, and magnets ranked the circumference of the seed metering mechanism

Şekil 6- Half effect sensor ve tohum dağıtma düzeni etrafına dizili mıknatıslar

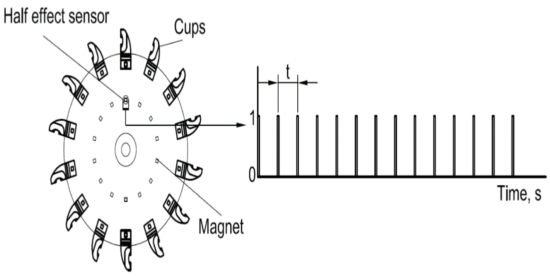

Figure 7- The square wave obtained from half effect sensor

Şekil 7- Hallf effect sensörden elde edilen kare dalga

Time intervals obtained from the laser measurement system and time intervals obtained from the half effect sensor should be equal, theoretically. However, it is not possible in practice, and time intervals obtained from the laser measurement system change due to skips, doubles and irregular drops (Figure 5). To find the percent value of doubles and skips, two threshold values, named as t_d and t_s, were used. The t_d and t_s were determined by using the Equation 4 and 5.

$$t_d \leq t \text{ x } 0.7 \tag{4}$$

$$t_s \geq t \text{ x } 1.5 \tag{5}$$

If the time interval obtained from the laser measurement system is less than the t_d, there is doubles. If the time interval obtained from the laser measurement system is higher than the t_s, there is skips. Therefore, the values of 0.7 and 1.5 were chosen for safety. For example, the time interval obtained from the half effect sensor is 5 s (t= 5 s), the time intervals obtained from the laser measurement system are 7, 12, 3, 17, 8, and 2 s, respectively. To find skips and doubles, these values were divided by the t value. It gets 7/5= 1.4, 12/5= 2.4, 3/5= 0.6, 17/5= 3.4, 8/5= 1.6, and 2/5= 0.4. The value of 1.4 is between 0.7 and 1.5, then there are no skips and doubles in this time interval. When we consider the value of 2.4, we see the two skips. For the value of 0.6 is smaller than 0.7, there is one doubles (Equation 6).

$$Percent\ value\ of\ doubles = \frac{N_{d.}100}{N} \tag{6}$$

Where; N_d, total number of doubles and N, total number of time intervals obtained from half effect sensor (Equation 7).

$$Percent\ value\ of\ skips = \frac{N_{s.}100}{N} \tag{7}$$

Where; N_s, total number of skips.

The t_d, t_s, N_d, and N_s values were determined with the aid of a program written in MATLAB (Mathworks 2011).

To determine coefficient of variation of seed spacing or irregularity in the time interval, coefficient of variation (CV%) was used, and calculated as shown in Equation 8.

$$CV\% = \frac{SD.100}{X_m} \quad (8)$$

Where; *SD*, standard deviation of time intervals obtained from the laser measurement system; X_m, mean of time intervals obtained from the laser measurement system.

The values obtained from the measuring systems were sent as digital data to the computer via a datalogger. The measuring system had an accuracy of 0.01 seconds.

2.4. Statistical analysis

This study was a factorial design consisting of three levels of cup, three levels of angular speed, two levels of variety, and two levels of seed size with three replications. As stated above, the coefficient of variation of seed spacing, percent value of doubles and skips were calculated. For each replication, the seed metering mechanism was rotated 10 times. The data was analyzed using analyses of variance (ANOVA) and comparison of means was made with Duncan's Multiple Range Test.

3. Results and Discussion

Table 3 shows the effects of the cups, angular speeds, varieties, and sizes on the values of CV%, percent value of doubles and skips. According to results of the ANOVA, the variety, the cup, the size and the angular speed, and two way interactions of cup x angular speed (C x A) had significant effect on the values of CV%. In addition, the cup, variety, size, and angular speed affected the percent value of doubles and skips. There were no significant interactions for the percent value of doubles and skips. On the other hand, as seen from Table 3, the interactions other than C x A were not significant, therefore they were not taken into considerations.

Table 3- Analysis of variance of cup, seed variety, seed size, and angular speed on values of CV%, and the percent value of skips and doubles

Çizelge 3- % CV, ikili atma ve boş bırakma üzerine kepçe, tohum çeşidi, tohum büyüklüğü ve açışal hızın varyans analizi

		CV, %		*Doubles, %*		*Skips, %*	
Variation sources	*DF*	*MS*	*P*	*MS*	*P*	*MS*	*P*
Cup (C)	2	271.967	0.000[a]	127.708	0.000[a]	63.851	0.000[a]
Variety (V)	1	425.667	0.000[a]	6.211	0.001[a]	88.408	0.000[a]
Size (S)	1	141.587	0.000[a]	323.837	0.000[a]	15.177	0.000[a]
Angular speed (A)	2	718.372	0.000[a]	4.980	0.000[a]	9.354	0.000[a]
Replication	2	1.648	0.795	1.050	0.129	0.046	0.953
C x V	2	10.517	0.238	0.141	0.754	0.203	0.810
C x S	2	12.983	0.171	0.131	0.770	1.169	0.301
C x A	4	30.141	0.004[a]	0.366	0.572	0.667	0.597
V x S	1	0.016	0.963	0.002	0.946	0.019	0.889
V x A	2	10.276	0.245	0.298	0.553	0.042	0.957
S x A	2	18.761	0.080	0.117	0.791	0.017	0.983
C x V x S	2	6.899	0.387	0.719	0.243	0.351	0.694
C x V x A	4	2.638	0.831	0.049	0.983	0.012	1.000
C x S x A	4	4.598	0.635	0.355	0.587	0.285	0.878
V x S x A	2	4.062	0.570	0.243	0.616	0.739	0.466
Error	74	7.178		0.499		0.958	
Total	107						

[a], significant at 1% level of probability; DF, degrees of freedom; MS, mean square

3.1. Effect of the cups on the seed spacing uniformity, doubles and skips

The effect of cups on value of CV%, percent value of doubles and skips was statistically significant (P<0.01). The highest value of CV% was determined as 29.24% for C1 (Table 4). The lowest value of CV% was determined as 23.76% for C2. The small cup showed more variability of spacing than the big cup. So, it can be said that C2 for potato seeds in the range of 25 to 65 seed size would be appropriate. The doubles and skips were observed as the main source of deterioration of the seed spacing uniformity, the highest percent value of doubles was determined as 6.90% for C3. The lowest percent value of doubles was determined as 3.13% for C1. However, when looking at percent value of skips, the highest percent value of skips was determined as 5.07% for C1. There was no statistically significant difference between C2 and C3 for percent value of skips. As the highest percent value of doubles was 6.90% for C3, the highest percent value of skips was 5.07% for C1. It was shown that the effect of the skips was greater than that of doubles on value of CV%.

Table 4- Effects of cups, seed varieties, seed sizes and angular speeds on values of CV%, percent values of skips and doubles

Table 4- % CV, ikili atma ve boş bırakma üzerine kepçe, tohum çeşidi, tohum büyüklüğü ve açısal hızın etkisi

Treatments		*CV, %*	*Doubles, %*	*Skips, %*
Cups	C1	29.24 a*	3.13 c	5.07 a
	C2	23.76 c	4.95 b	2.94 b
	C3	26.11 b	6.90 a	2.62 b
	LSD	1.26	0.33	0.46
Potato varieties	Agria	24.39 b	5.23 a	2.64 b
	Marfona	28.36 a	4.75 b	4.45 a
Potato sizes, mm	25-45	27.52 a	6.73 a	3.17 b
	45-65	25.23 b	3.26 b	3.92 a
Angular speeds, rad s^{-1}	0.9	22.83 c	5.35 a	3.06 b
	2.04	24.90 b	5.02 a	3.51 b
	3.18	31.39 a	4.61 b	4.08 a
	LSD	1.26	0.33	0.46

*, means in a single column without the same letter are significantly different at the 5% level using the LSD test

3.2. Effect of potato shape on the seed spacing uniformity, doubles and skips

The results of the effect of seed shape on value of CV%, percent value of doubles and skips are given in Table 4. The statistical results show that the seed shape affected the seed spacing uniformity, doubles and skips. The highest value of CV% was determined as 28.36% for Marfona, while the lowest value of CV% was determined as 24.39% for Agria. Oblong shaped Agria had less variability of seed spacing than spherical shape Marfona. Similarly, Buitenverf et al (2006) showed that the standard deviation of round balls was higher than oblong seeds. In contrast, Al-Gaadi & Marey (2011) found that Hermes variety of potato with spherical shape indicated significantly lower value of CV% than oblong shape Sponta variety of potato. The percent values of doubles were 5.23% and 4.75% for Agria and Marfona, respectively. The difference between Agria and Marfona was 0.48% for doubles. The percent values of skips were 2.64% and 4.45% for Agria and Marfona, respectively. The difference between Agria and Marfona was 1.81% for skips. Skips were the main source of disturbance of the seed spacing uniformity. It was observed in experiments that it was more difficult to keep spherical potato seeds on the cup than oblong potato seeds, because, the spherical potato seeds could fall down easier than oblong potato seeds. In addition, this showed that oblong seeds were clutched by holding pins better than spherical seed, and most probably, oblong seeds were grabbed by cups better than spherical seeds.

3.3. Effect of potato size on the seed spacing uniformity, doubles and skips

It was determined that seed size was an important parameter on the seed spacing uniformity. The results of values of CV%, and percent values of doubles and skips affected by seed size are shown in Table 4. As the seed size increased, the seed spacing uniformity increased. The highest value of CV% was determined as 27.52% for 25-45 mm seed size. The lowest value of CV% was determined as 25.23% for 45-65 mm seed size. Misener (1982) found that as the seed size increased, the accuracy of seed spacing increased. The highest percent value of doubles was obtained from 25-45 mm seed size with 6.73%. The lowest percent value of doubles was obtained from 45-65 mm seed size with 3.26%. These results agree with the results reported by Al-Gaadi & Marey (2011). They found that percent value of doubles were 5.35, 4.18 and 3.31% for 35-45, 45-55 and 55-65 mm seed size, respectively. As potato size increased, percent value of skips increased. The highest percent value of skips obtained from 45-65 mm seed size was 3.92%. The lowest percent value of skips obtained from 25-45 mm seed size was 3.17%. These results were supported by Al-Gaadi & Marey (2011). They determined that percent value of skips had a range from 5.19 to 7.30%. Misener (1982) compared the cup type and pick type potato planters in terms of various seed size. He showed that percent values of skips and doubles ranged from 3.8 to 9.2 and from 6.6 to 23.7, respectively. Misener (1982) and Altuntas et al (2004) determined that as the size of seed increased, the number of skips increased. In addition, they found that small seeds increased the number of doubles.

3.4. Effect of angular speed on the seed spacing uniformity, doubles and skips

The accuracy of the seed spacing uniformity tended to increase as the angular speed reduced. The value of CV% ranged from 22.83 to 31.39% (Table 4). The highest value of CV% was found as 31.39% for the angular speed of 3.18 rad s^{-1}. The lowest value of CV% was found as 22.83% for the angular speed of 0.9 rad s^{-1}. The seed spacing uniformity was the best in lower angular speed as indicated by the seed spacing uniformity values. Research results of Misener (1979), Altuntas (2005) and Al-Gaadi & Marey (2011) agree with these results. However, Buitenwerf et al (2006) and Sieczka et al (1986) stated that as the speed increased, the accuracy of seed spacing became better. Al-Gaadi & Marey (2011) determined that the values of CV% were 28.73, 37.10, and 54.53% for the ground speeds of 1.80, 2.25, and 3.00 km h^{-1}, respectively. Entz & LaCroix (1984), Sieczka et al (1986) and Misener (1982) stated that the coefficient of variation of seed spacing obtained from different potato planters ranged from 20% to 80%. Misener (1979) stated that the values of CV% for the pick type potato planter ranged from 55.3 to 68.7% while the values of CV% for the cup type potato planter ranged from 59.2 to 87.1%. The change of angular speed was significantly affected the percent value of doubles and skips. The highest percent value of doubles for the angular speed of 0.9 rad s^{-1} was determined as 5.35%. The lowest percent value of doubles for the angular speed of 3.18 rad s^{-1} was found as 4.61%. As the angular speed increased, percent value of doubles decreased. The highest percent value of skips for the angular speed of 3.18 rad s^{-1} was determined as 4.08%. The lowest percent value of skips for the angular speed of 0.9 rad s^{-1} was obtained as 3.06%. Increase of the angular speed caused the percent value of skips to increase. Misener (1979) found that the pick type planter gave fewer doubles at the lower ground speeds. He also stated that, except two planters, all the other planters operating in the ground speed range of 5.6 to 7.2 km h^{-1} produced doubles more than skips. Al-Gaadi & Marey (2011) determined that percent value of doubles and skips were 5.93, 4.62 and 2.29%, and 3.91, 5.74 and 9.11% for the ground speed of 1.80, 2.25, and 3.00 km h^{-1}, respectively. These results agree with our results. The effect of C x A interaction on CV% was significant. Plot of this interaction is presented in Figure 8. From this figure, it can be seen that CV% value of C2 was lower than those of the other cups for the angular speed of 0.9 rad s^{-1}.

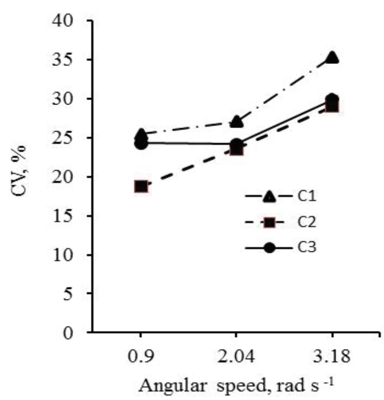

Figure 8- Plot of C x A interaction on CV, % value of angular speed

Şekil 8- Açısal hızın % CV üzerine C x A interaksiyon grafiği

4. Conclusions

A full automatic potato planter with the seed metering mechanism with the vertical disc was tested at different cups, angular speeds, seed sizes and shapes in laboratory. The laboratory tests showed that the cup, the angular speed, potato sizes and potato shapes have significant effect on the seed metering mechanism. The best seed spacing uniformity was obtained from C2. Both small and large cups disturbed the seed spacing uniformity. As cup size increased, percent value of doubles increased, although percent value of skips decreased. The effects of seed shapes and seed sizes on the seed spacing uniformity, and percent values of doubles and skips were significant. The seed spacing uniformity of oblong potato seeds was better than that of spherical potato seeds. Skips value of oblong potato seeds was lower than that of spherical potato seeds. Nevertheless, the percent value of doubles obtained from oblong potato seeds was slightly higher than that of spherical potato seeds. Small potato seeds led to an increase in the value of CV%. The reason for this was the doubles. The angular speed influenced seed spacing uniformity significantly. Increasing the angular speed decreased the seed spacing uniformity. As the angular speed increased, percent value of doubles decreased and percent value of skips increased.

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Abbreviations and Symbols	
a, b, c	Dimensions of seed, mm
ANOVA	Analysis of variance
CV	Coefficient of variation, %
D_p	Geometric mean diameter, mm
LDR	Light dependent resistor
N	Total number of spacing
N_d	Number of t_d
N_s	Number of t_s
SD	Standard deviation
S_p	Sphericity, %
S_f	Shape factor, %
t, t_d, t_s	Time, s
X_m	Mean of time intervals, s

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