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Effects of seedling thickness on the production and quality of onion (*Allium cepa* L.) 'Santa Rita' in Arequipa, Peru

Efecto del grosor de las plántulas en la producción y calidad de la cebolla (*Allium cepa* L.) cv. Santa Rita en Arequipa, Perú

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Abstract

Onion crop begins with seedling preparation and finishes with transplanting. In some Peruvian onion-productive areas, it is assumed that seedling thickness is important to have a better yield. Four different seedling thickness of red onion (*Allium cepa* L.) were evaluated between February and June 2017 in Santa Rita de Siguas, Arequipa, Peru. The seedling thicknesses evaluated were very thin (2.00 mm – 3.49 mm), thin (3.50 mm – 4.99 mm), standard (5.00 mm – 6.49 mm) and thick (6.50 mm – 7.99 mm). The plant density was 340 000 plants ha^{-1}. The experimental design was a randomized complete block with four treatments and five replications. The variables evaluated were plant height (cm), leaf number, stemlike diameter (mm), bulb diameter (mm), total yield (t ha^{-1}), and marketable yield categories (t ha^{-1}). The leaf number, plant height, and stemlike diameter among treatments were significantly different, with higher values in the "standard" and "thick" treatments up to 60 days after transplanting. The harvest was earlier in the "standard" and "thick" treatments. The "very thin" and "thin" treatments needed more days to harvest than the others. The "thin" treatment showed the highest total yield. There were no significant differences between marketable yield categories in all treatments. It was concluded that seedling thickness upon transplanting influences the yield under the conditions in this study.

Keywords: *onion, seedling, thickness, yield, quality*

Resumen

El cultivo de la cebolla comienza con la preparación de las plántulas y termina con el trasplante. En algunas zonas peruanas productoras de cebolla, se asume que el grosor de las plántulas es importante para tener un mejor rendimiento. Se evaluaron cuatro diferentes espesores de plántulas de cebolla roja (*Allium cepa* L.) entre febrero y junio de 2017 en Santa Rita de Siguas, Arequipa, Perú. Los espesores de plántulas evaluados fueron muy fino (2.00 mm – 3.49 mm), fino (3.50 mm – 4.99 mm), estándar (5.00 mm – 6.49 mm) y grueso (6.50 mm – 7.99 mm). La densidad de plantas fue de 340 000 plantas ha^{-1}. El diseño experimental fue un bloque completo al azar con cuatro tratamientos y cinco repeticiones. Las variables evaluadas fueron altura de la planta (cm), número de hojas, diámetro del tallo (mm), diámetro del bulbo (mm), rendimiento total (t ha^{-1}) y categorías de rendimiento comercial (t ha^{-1}). El número de hojas, la altura de la planta y el diámetro del tallo entre los tratamientos fueron significativamente diferentes, con valores más altos en los tratamientos

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"estándar" y "grueso" hasta 60 días después del trasplante. La cosecha se adelantó en los tratamientos "estándar" y "grueso". Los tratamientos "muy fino" y "fino" necesitaron más días para la cosecha que los demás. El tratamiento "fino" mostró el mayor rendimiento total. No hubo diferencias significativas entre las categorías de rendimiento comercial en todos los tratamientos. Se concluyó que el grosor de la plántula al trasplantar influye en el rendimiento bajo las condiciones de este estudio.

Palabras clave: *cebolla, plántula, grosor, rendimiento, calidad*

Introduction

In Peru, various domesticated *Allium* species are cultivated, including *Allium cepa* L. This vegetable possibly originated from the mountainous regions of Central Asia, where inhabitants of some valleys would initiate the domestication process (Brewster, 2001). After many years, its arrival in Peru took place through the travel of European settlers. In Perú, Arequipa has the highest regional production and the largest onion cultivation area (Ministerio de Agricultura y Riego [MINAGRI], 2019).

The red onion *Allium cepa* 'Santa Rita' comes from the continuous mass selection of the 'Americana' variety. This led to an adaptation of the late onion plantings in Santa Rita de Siguas to adverse weather conditions. This cultivar allows onion production in an important commercial window for Arequipa (sales on April, May, and June), which is why this cultivar was used in this study.

According to Guillén (2012), the methods used for sowing in Peru are direct sowing and transplantation. Direct sowing is minimal due to its high cost, so seedling or bulb transplantation are currently used. Plants grown from transplants show better performance compared to those grown via direct seeding. In Lincolnshire, transplanted onions produce uniform bulb yields of 45 t ha^{-1}, and these mature two weeks earlier than directly seeded plants, resulting in a higher production (Currah et al., 1990 cited by Brewster, 2001). Instituto Nacional de Investigaciones Agropecuarias (INIA, 2012) indicates that seedlings for transplanting have a minimum quality standard (<6.0 mm in diameter at the neck level). If this parameter is not met, there is a great disadvantage in achieving a rapid and vigorous recovery after transplanting.

Therefore, this study aimed to evaluate the yield, growth, development, and quality of the cultivar 'Santa Rita' based on the thickness of the seedlings before transplanting. We evaluated the effects of the seedling diameters between 20 and 80 days after transplanting on biometric parameters (height, number of leaves, diameter of false stem, bulb diameter, and bulbification index), yield, and production quality.

Materials and Methods

This study was done in Fundo America located in the district of Santa Rita de Siguas in Arequipa province. Plants ready for transplant were two months old. The definitive field period was from February to June 2017. The plant density was 10 cm between plants and 60 cm between lines.

a) *Treatments*

The four different levels of seedling thickness for transplanting were very thin (2.00 mm – 3.49 mm), thin (3.50 mm – 4.99 mm), standard (5.00 mm – 6.49 mm), and thick (6.50 mm – 7.99 mm). These sizes are normally used by farmers who grow onions using the seedling method.

b) *Experimental design*

A completely randomized block design was used, with four treatments and five blocks. The statistical tests performed were analysis of variance and Tukey's test at 5 % significance level for mean comparisons.

c) *Evaluations*

All samples were selected from the central lines of each experimental unit. Each sample consisted of five randomly chosen plants that were used for all the evaluations indicated below. Harvest in all plots was done 130 days after planting.

d) ***Morphological variables***

All data were collected 80 days after transplanting.

Plant height: Plant height was measured starting from the neck of the plant to the apex of the largest leaf.

Number of leaves: Photosynthetically active leaves were counted. Photosynthetically active leaves are those that did not have any damaged tissues due to a plague, disease, or senescence.

False stem diameter: This was evaluated by measuring the base diameter of the false stem.

Bulb diameter: This was evaluated by measuring the equatorial diameter of the bulb.

Bulbification index: The bulb diameter/false stem diameter relationship was calculated, which is an index that indicates the beginning and development of the bulb.

e) ***Production and commercial quality.***

Total yield: All bulbs from the central lines of each plot were harvested. The total yield represented the total weight of the bulbs after neck cutting and curing.

Grade 1: bulbs that are healthy, compact, and dry, with thin necks and an equatorial diameter of 7 cm to 10 cm.

Grade 2: bulbs with similar characteristics as the first ones, but with an equatorial diameter between 5 cm to 7 cm.

Discard: diseased, elongated, split, or double bulbs.

Results and Discussion

Plant height

Table 1 shows the height of each transplanted seedlings from 20 to 80 days after transplanting. The "standard" and "thick" treatments had the tallest height in 40 days after transplanting, but only the "standard" treatment continued to lengthen until 80 days; then, the "very thin" and "thin" treatments surpassed it. The "very thin" treatment was shorter until 50 days after transplanting; however, after 70 days, it was superior to all the others, with the highest plant

Table 1. Onion (*A. cepa*) plant height (cm) cv. 'Santa Rita' using seedlings with four different thicknesses

Treatment	20 DAT		30 DAT		40 DAT		50 DAT		60 DAT		70 DAT		80 DAT	
Very Thin	13.40	b	19.43	b	36.73	b	48.13	c	62.42	ab	66.05	a	70.88	a
Thin	15.34	a	23.56	ab	41.90	a	52.69	b	62.09	ab	67.31	a	67.94	ab
Standard	16.93	a	26.44	a	44.47	a	58.05	a	64.63	a	66.25	a	65.72	b
Thick	16.51	a	26.38	a	42.61	a	54.54	b	60.42	b	61.96	b	64.07	b
CV (%)	10.77 %		14.97 %		8.25 %		7.35 %		4.07 %		4.29 %		4.92 %	
Statistical SIG	*		*		*		*		*		*		*	

DAT: days after transplanting

Table 2. Number of leaves of onion 'Santa Rita' seedlings with four different thicknesses

Treatment	20 DAT		30 DAT		40 DAT		50 DAT		60 DAT		70 DAT		80 DAT	
Very Thin	3.44	b	4.88	b	6.52	c	7.68	b	9.04	b	9.96	a	10.72	a
Thin	3.72	ab	5.72	a	7.60	b	8.32	b	9.60	ab	10.44	a	10.68	a
Standard	3.84	a	6.16	a	8.24	a	9.60	a	10.20	a	10.44	a	10.60	a
Thick	4.04	a	5.96	a	8.08	ab	9.04	a	9.92	a	10.24	a	10.40	a
CV (%)	8.20 %		10.05 %		9.74 %		9.58 %		5.82 %		4.95 %		7.72 %	
Statistical SIG	*		*		*		*		*		n.s.		n.s.	

DAT: days after transplanting

height of 70.88 cm after transplanting. Guzmán, cited by Chimborazo (2015), indicates that the length of the leaves ranges from 40 cm to 65 cm, which is similar to the results obtained in this study. The results are also similar to those obtained in national studies, such as Amaya (2011) in which the cultivar 'Roja Arequipeña' reached 50 cm at 90 days after transplanting under Laredo conditions. On the other hand, under conditions similar to this study, Poma (2013) described the 60-cm heights of the cultivar 'Roja de Camaná' at 70 days after transplanting in Majes Irrigation. As shown in Table 1, the trend of the height increase in all treatments was similar, and the "very thin" treatment had the lowest height until 60 days after transplanting. When the growth in other treatments decelerated, this growth of this one continued to accelerate. According to Brewster (2001), the height variable is determined by cultivar factors, planting density, and climate. Based on the experiment, seedling thickness should also be considered.

Number of leaves

Table 2 shows the number of leaves in each treatment 20 to 80 days after transplanting (DAT). Based on the results of the analysis of variance in each evaluation date, there are significant differences in the number of leaves up to 60 DAT based on the seedling thickness factor; there were no significant differences between the thickness of the seedlings afterwards. The "standard" treatment had more leaves up to 60 DAT, however all treatments were similar in this characteristic after 70 DAT. The "very thin" and "thin" treatments had fewer leaves on average (except at 30 days after transplanting, where the "thin" treatment was similar to the "standard" and "thick" treatments). Despite these differences, 70 days after transplanting, there were no significant differences in the number of leaves. Poma (2013) evaluated the number of leaves of the cultivar 'Roja de Camaná' according to the level of fertilization and planting system, obtaining plants with eight leaves on average at 71 days after transplanting under the conditions in Majes Irrigation. This indicates that the average number of leaves in the different treatments was within the range and was even higher. According to Guzmán, cited by Chimborazo (2015), a foliage grows until the external conditions favor bulb formation. These conditions are usually the decrease in temperature and the change in photoperiod. These conditions varied during April, having a different impact on each treatment, starting with the "standard" and "thick" treatments.

False stem diameter

Table 3 shows the results of the false stem diameter variable from 20 to 80 days after transplanting. The analysis of variance shows that the seedling thickness factor generated significant differences in the diameter of the false stem throughout the experiment, except at 60 days after transplanting. The "standard" and "thick" treatments had a similar behavior; however, the "standard" treatment stood out, with a higher false stem diameter up to 60 days after transplanting. At 60 days after transplanting, the "very thin" and "thin" treatments were not significantly different from the "standard" and "thick" treatments because the false stem diameter at this growth stage coincides. The "very thin" treatment obtained the largest false stem diameter at 80 days after transplanting, with a measurement of 17.43 mm. According to Brewster (2001), the necks lose turgor and soften due to senescence. This indicates the final stage of the growth of

Table 3. False stem diameter (mm) of onion 'Santa Rita' seedlings with four different thicknesses

Treatment	20 DAT		30 DAT		40 DAT		50 DAT		60 DAT		70 DAT		80 DAT	
Very Thin	3.33	b	4.92	c	8.41	c	11.61	c	15.97	a	16.99	a	17.43	a
Thin	4.22	a	6.48	b	10.24	b	12.68	bc	15.71	a	16.91	a	16.36	ab
Standard	4.60	a	7.49	a	11.44	a	14.85	a	15.84	a	15.22	ab	14.76	b
Thick	4.59	a	7.38	ab	11.06	ab	13.78	ab	14.93	a	14.42	b	14.70	b
CV (%)	14.73 %		17.41 %		12.96 %		10.55 %		5.78 %		10.06 %		11.09 %	
Statistical SIG	*		*		*		*		n.s.		*		*	

DAT: days after transplanting

Table 4. Bulb diameter (mm) and bulb index of onion 'Santa Rita' seedlings with four different thicknesses

Treatment	Bulb diameter						Bulb index					
	60 DAT		70 DAT		80 DAT		60 DAT		70 DAT		80 DAT	
Very Thin	32.48	c	46.49	c	63.62	b	2.05	c	2.79	b	3.7	b
Thin	38.33	b	53.44	b	65.59	ab	2.45	b	3.25	b	4.15	ab
Standard	46.85	a	59.99	a	71.54	a	2.99	a	4.02	a	4.97	ab
Thick	48.68	a	59.03	a	68.69	ab	3.32	a	4.19	a	4.74	a
CV (%)	16.95 %		11.10 %		6.85 %		19.89 %		18.39 %		16.25 %	
Statistical SIG	*		*		*		*		*		*	

DAT: days after transplanting

bulbs, concluding with the fall of aerial parts. The "standard" and "thick" treatments showed this characteristic at 60 days after transplanting when they reached their maximum false stem diameter, which coincided with their slow growth (height and number of leaves). The "thin" treatment reached the maximum false neck diameter first at 70 days after transplanting, followed by the "very thin" treatment at 80 days. The differences between each treatment were related to the days to harvest.

Bulb diameter

The bulb diameters in each treatment 60, 70, and 80 days after transplanting are shown in Table 4. The bulb diameters of the "standard" and "thick" treatments were statistically higher up to 70 days after transplanting. After 80 days, the "thick" and "thin" treatments did not have significant differences, while the standard treatment had the highest bulb diameter. The "very thin" treatment had the lowest bulb diameter in all evaluations.

Bulb index

Table 4 shows the bulb indices in all treatments 60, 70, and 80 days after transplanting. Since the false stem diameter and bulb diameter are inversely proportional during bulb formation, this relationship allows a more precise identification of the time of harvest. This parameter determines the start of bulb formation when the ratio is 2. During the evaluations, all values were >2, which indicates that all treatments started bulb formation.

Yield

Table 5 summarizes the total yield (t ha^{-1}), their qualities (t ha^{-1}), and the percentage (%) that each one represents with respect to the total yield. The analysis of variance showed that the thickness of the seedlings generates significant differences in the total yield and on Grade 1 onions. The analysis of variance of the other qualities were not significantly different, including the percentage that each represents with respect to the total yield. According to the Tukey's test, the highest yield was obtained by the "thin" treatment (29.24 t ha^{-1}), while the lowest yield was obtained by the "thick" treatment (25.01 t ha^{-1}). The yield in the "very thin" and "standard" treatments was not significantly different, but it was significantly higher than that of the "thick" treatment. These yields were lower than those reported by Gonzáles (2003), Poma (2013), León (2015), and MINAGRI (2019) because this study was initiated at the beginning of the year, when the conditions accelerate onion development, preventing the yields from reaching their peaks. In addition, the atypical rains caused by the "Niño Costero" phenomenon, which favored the development of fusarium, reduced the initial transplanted population.

The results of this study were similar to those of Riekels et al. (1976), who reported that the purpose of producing seedlings is to obtain seedlings with a thickness of 3.5 mm to guarantee good yields. However, INIA (2012) mentioned that thicknesses >6 mm are recommended to obtain a better exportable onion performance

Table 5. Total yield (t ha^{-1}) and quality (%) of onion 'Santa Rita' seedlings with four different thicknesses

Treatment	Total Yield t ha^{-1}		1 Grade				2 Grade				Discard			
			t ha^{-1}		%		t ha^{-1}		%		t ha^{-1}		%	
Very Thin (2.00–3.49 mm)	26.16	ab	14.48	a	55.36	a	9.03	a	34.54	a	2.64	a	10.10	a
Thin (3.50–4.99 mm)	29.24	a	15.80	a	54.04	a	11.03	a	37.73	a	2.41	a	8.23	a
Standard (5.00–6.49 mm)	27.05	ab	15.82	a	58.48	a	9.25	a	34.21	a	1.98	a	7.31	a
Thick (6.50–7.99 mm)	25.01	b	11.87	a	47.47	a	10.41	a	41.64	a	2.73	a	10.90	a
C.V (%)	9.69 %		22.06 %		18.46 %		22.77 %		22.77 %		33.71%		33.71 %	
Statistical SIG	*		*		n.s.		n.s.		n.s.		n.s.		n.s.	

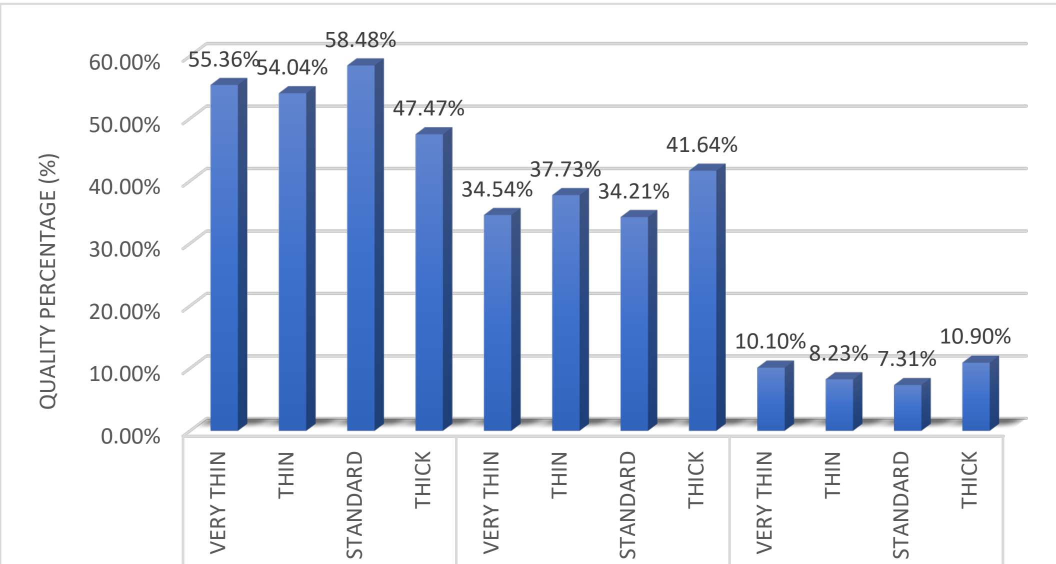

Figure 1. Quality (%) of onion 'Santa Rita' seedlings with four different thicknesses with respect to the total yield

under the conditions in Chile. This was different from the results obtained in this study because thicker plants had a lower performance.

Figure 1 shows that the "standard" treatment had the highest first-grade quality (58.48 %), while the "thick" treatment had the lowest percentage (47.47 %). Regarding the second-grade quality, the "thick" treatment had the highest percentage (41.64 %), while the "standard" treatment had the lowest percentage (34.21 %). The discard quality was the highest in the "thick" treatment (10.90 %), while the "standard" treatment had the lowest. Based on the descriptive statistics, it is evident that the "thick" treatment had the lowest first-grade quality, with an increased second-grade and discard qualities. This suggests that it is the least recommended thickness. According to the graph, it can also be seen that the most recommended treatment is the one with the highest first-grade quality and with the lowest second-grade and discard qualities. These observations were not valid based on analytical statistics.

Conclusions

Seedling thickness significantly affected the height, number of leaves, false stem diameter, and bulb diameter of onion 'Santa Rita.' It also significantly affected the bulbification, as those with seedling thicknesses of ≤ 4.99 mm had a greater bulbification. It also significantly affected the total yield, where the "thin" treatment (3.50 mm – 4.99 mm) had the highest performance under the test conditions. However, the seedling thickness did not significantly affect the grade 1, grade 2, and discard quality of onion 'Santa Rita.'

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