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Research Article

INFLUENCE OF SET SIZE ON YIELD AND QUALITY IN OFF-SEASON ONION PRODUCTION

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ABSTRACT

Off-season onion production requires optimal set size to achieve a delicate balance of high yield and good quality. This study investigates the effect of different set sizes on onion production and quality. The experiments were conducted on Pulkara onion variety at Agricultural Research Institute Mingora, Swat, during 2021 and 2022. Five set sizes (9-12 mm, 13-16 mm, 17-20 mm, 21-24 mm, and 25-28 mm) were selected based on previous literature and preparation of classes. Each set were replicated three times in a randomized complete block design. Significant differences ($P \leq 0.01$) were observed among the treatments for most of the studied traits, except plant height across the years. Bolting and splitting percentage increased with increased set size, while plant height, leaf number, bulb diameter, and single bulb weight increased with increased sets size. This study concludes that sets having diameter range 17-20 mm produced maximum bulb yield. Selecting the appropriate set size is crucial for balancing yield and quality in off-season onion production, as bolting, splitting, bulb diameter, and white rot disease have complex correlations with yield, increasing both productivity and disease risk.

Keywords: Onion autumn crop, Off-season, Set size, Yield Bulb Quality and Correlation

INTRODUCTION

Onion (*Allium cepa* L.) is a bulbous vegetable belong to family Alliaceae which is widely used for its flavorful bulbs and leaves (Teshika et al., 2019). Globally, onion is grown in 175 countries with total production of more than 100 million metric tons. Pakistan ranked 7th in production and 8th in onion exporting countries (FAO, 2020). In Pakistan it is grown on 140,839 hectares with total production exceeding 2 million tons (Fruit, Vegetable & Condiment Statistics of Pakistan, 2021-22).

The supply period of onion in Pakistan is from May-August and the prices are low during this period. Supply of onion starts decreasing from December-January and prices in the market escalates almost five times than the normal season. Autumn crop which is harvested in this lean period can augment supply and stabilize market prices. Autumn crop is planted from mid-August to mid-September. At that time the concurrent high temperatures and monsoon rains make it difficult to establish and maintain nursery and ensure survival of the transplant (Khokhar, 2018). This issue can be solved by planting autumn crop through sets to eliminate nursery raising step. Sets are small matured bulbs weighing 2-3 gram when fresh and less than 25 mm in size. (Brewster, 2008). Sets are equipped with reserves food and can withstand harsh weather conditions. It is produced in one season, stored, and replanted in next season. Sets are easy to handle and have the advantage of producing robust plants after sprouting as compared to emergence from seeds. Sets have shorter growing season and mature early than plants produced from seeds although, large sets have the tendency of bolting and splitting (Khokhar et al. 2002a).

Set size have significant effect on marketable yield, bolting percentage and splitting of bulbs (Khokhar et al. 2002). In this study the effect of different set size on yield and quality in onion autumn crop were investigated.

MATERIALS AND METHODS

The experiments were carried out on Pulkara onion variety at Agricultural Research Institute (ARI), Mingora, Swat during 2021 and 2022 to standardize set size in autumn onion crop for better quality and high yield. The soil of ARI is calcareous in nature with

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low organic matter content. Treatments were designed to test the effect of five classes of set sizes in diameter 09-12 mm, 13-16 mm, 17-20 mm, 21-24 mm & 25-28 mm(Figure 1, A and B). Sets were planted on both sides of the ridges in $9m^2$ plots with 30 cm distance between rows and plant to plant space was kept 10 cm (Figure 1C). Ammonium sulphate and NPK fertilizer were applied in two split doses after one and two months of sowing, respectively. Standard agronomic practices were carried out during the crop growing season. The crop was harvested when optimum bulb size was attained. Data were recorded on plant height (cm) and number of leaves plant^{-1}, bolting %, splitting percentage (%) before attaining physiological maturity, bulb diameter (mm), single bulb weight (g) and bulbs yield tons ha^{-1} after harvesting of the crop. After compilation the collected data were statistically analyzed according to steel et al. (1997).

RESULTS AND DISCUSSION

Plant Height (cm) and Number of Leaves Plant^{-1}

In onions, plant height and number of leaves are crucial indicators of bulbs growth and yield potential. Non-significant differences were observed among the treatment under both years and year × treatment interaction for plant height which shows stability in plant height among and across the years. In contrast, number of leaves plant^{-1} varied significantly among the treatments and year × treatment interactions (Table 1A and 2). Minimum plant height (58.1 cm & 69.7 cm) in set size 09-12 mm and 13-16 mm while maximum 64.2 & 76.1 cm were recorded in large set size 25-28 mm during 2021 and 2022, respectively (Table 3A). Similarly, minimum number of leaves plant^{-1} (9.3 & 10.1) were observed in set size (09 mm-12 mm) and maximum (10.2 & 12.8) no of leaves were recorded in large set size (25 mm- 28 mm) and (21 mm-24 mm) during 2021 and 2022 respectively (Table 3A). Overall, results indicate that larger sets produced taller and more vigorous plants which is the confirmation of Singh and Singh (2003). They reported that due to more reserve food larger set produce vigorous plant having more leaves at earlier stage. Similarly, Khan et al. 2024 also stated that taller plants with more leaves plant^{-1} provide larger surface area for photosynthesis and ultimately contribute to bulb yield. Large sets produce robust plants with greater leaf area index at emergence. This enables plant to convert more intercepted light into dry matter. Small sets, however, have limited light interception due to their smaller plant canopy. Consequently, they produce smaller plants. The outcomes of this study support Khan et al. (2021) findings of direct linear relation between set size and number of leaves plant^{-1}. Similarly, Cramer (2003) also concluded that mature onion bulbs produce superior plants with more leaves compared to smaller onions sets.

Correlation analysis results showed that number of leaves exhibited significant positive correlation with plant height (r = 0.740) and splitting percentage (r = 0.590) (Table 4). This indicates that plant height and splitting also tend to increase with increase in number of leaves. This positive correlation attributed to the fact that leaves are responsible for photosynthesis, which provides necessary energy for plant growth and development. Similar findings of significant positive correlation were also published by Mane et al. 2024.

Bolting Percentage (%)

Bolting or premature formation of flower stalk in onion, develops a hard, less desirable and unpalatable center which decrease bulb yield, because the plant divert energy to initiate reproductive phase (Boyhan et al., 2009 and Khan et al., 2020). Bolting percentage indicate significant differences between treatments and years, showing variability in treatment across the years (Table 1A and 2). Mean values showed that minimum bolting (0.95 & 1.97%) was recorded in set size (09-12 mm) and (13-16 mm) while maximum (25.32 % & 24.31 %) was observed in large set size (25-28 mm) during 2021 and 2022, respectively (Table 3A). In offseason onion production, set size plays crucial role to determine bolting risk. Bolting reduces storage life and lower bulb weight (Cramer, 2003 and Khan et al., 2019). Larger sets are close to their final growing stage which is looking attractive but perform poorly due to early maturity, more reserve food, and quick response to cold temperature, which enhance chances of bolting as compare to smaller sets (Khan et al. 2024). Larger sets enable plants to attain optimal vegetative growth and complete juvenile period earlier and the plants become sensitive to low vernalizing temperature (Khan et al., 2021). The relative rate of vernalization increases with increase in bulb size or weight. This is the reason that large set size produced higher percentage of bolting than medium or small sets (Khokhar, 2002). In general, smaller sets are less prone to bolting. Although, Khan (2017) and Boyhan et al. (2009) reported that seedling age and temperature also affect bolting percentage. Large sets either be stored at high temperature at 28C^{o} to minimize bolting (Teshika et al., 2019) or be sown earlier in the season so that the crops should be harvested before the approaching winter to minimize plant exposure to low vernalizing temperature and escape bolting (Cramer,2003). Although, Ansari et al. (2009) published contrary results of no effect of set size on bolting incidence.

Correlation data showed that bolting exhibited a significant and positive correlation with splitting (r = 0.889), bulb diameter (r = 0.666), bulb weight (r = 0.925), white rot (r = 0.707), and yield (r = 0.717) (Table 4). This suggests that increasing incidence of bolting, also promote corresponding increase in splitting, bulb diameter, bulb weight, white rot, and yield. And these parameters are linked with one another because splitting increase bulb diameter, weight and finally yield but that may not be included in marketable yield which decrease final yield. This positive correlation is attributed to the fact that bolting is often associated with changes in plant morphology and physiology, which can also lead to increased susceptibility to splitting, white rot, and other diseases.

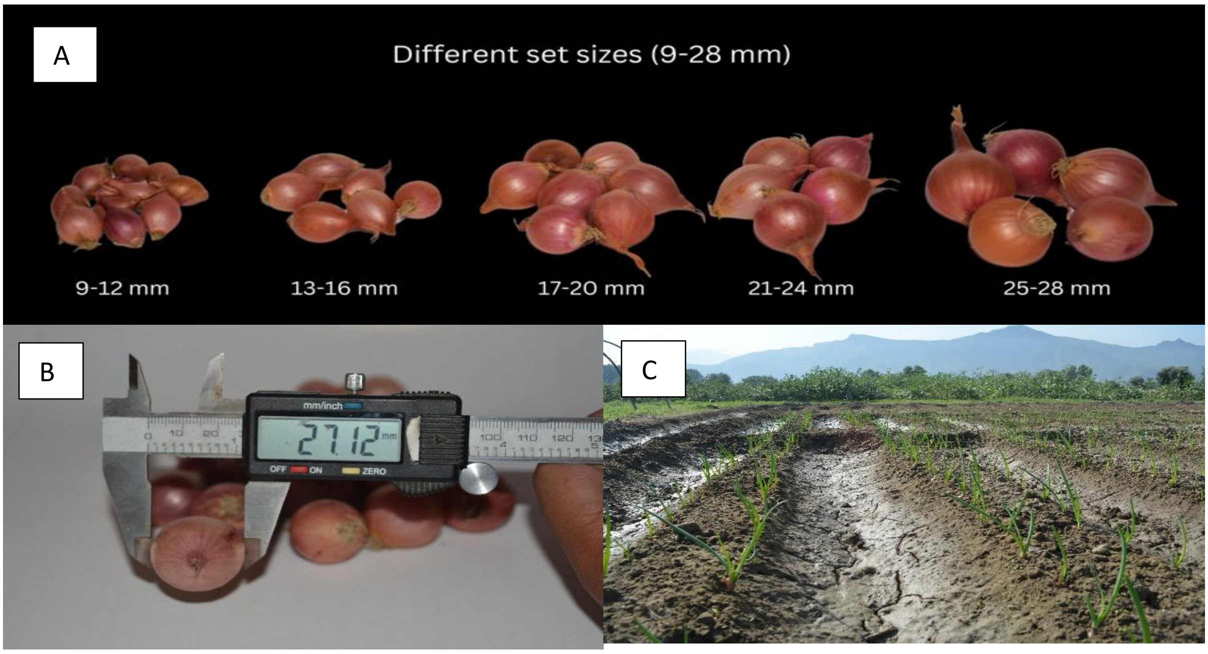

Figure 1A. Different Set sizes. B. measuring diameter of set sizes through vernier caliper C. sets sprouted sown on ridges

Table-1A. Mean squares values for various traits in offseason onion crop at ARI Mingora Swat during 2021 and 2022.

SOV	DF	Plant height (cm)	No. of leaves plant^{-1}		Bolting %		Splitting %	
		2021	2022	2022	2021	2022	2021	2022
Reps	2	4.96	29.04	0.316	0.218	0.94	0.015	0.084
Treatment	4	17.84^{NS}	17.62^{NS}	3.08**	307.3**	273.2**	37.80**	88.9**
Error	8	6.87	13.29	0.19	0.498	0.499	0.16	0.56
CV		4.3	5.03	3.83	9.1	9.12	16.7	14.67

Table-1B. Mean squares values for various traits in offseason onion crop at ARI Mingora Swat during 2021 and 2022.

SOV.	DF	Bulb diameter (mm)		Bulb weight (g)		White rot (%)		Yield (ton ha^{-1})	
		2021	2022	2021	2022	2021	2022	2021	2022
Reps	2	6.3	7.24	4.07	0.87	1.12	0.76	4.059	2.07
Treatment	4	111.1**	12.73**	2886.4**	2467.5**	44.7**	10.05**	297.6**	297.3**
Error	8	9.6	24.45	43.46	19.37	1.76	0.75	8.006	3.82
CV		4.3	6.64	4.4	2.95	15.27	14.22	9.7	6.86

Table-2. Mean squares values for various traits across the year in off season onion crop at ARI Mingora Swat, during 2021 and 2022.

Source of variation	DF	Plant height	No of leaves	Bolting	Splitting	Bulb Diameter	Bulb weight	White rot	Yield
Reps W/E	2	6.45	0.226	0.145	0.077	7.44	3.03	0.02	5.93
Treat (T)	4	20.63^{NS}	2.53**	577.2**	116.25**	95.2**	5325**	47.47**	593.8**
Year (Y)	1	1017.45**	28.63**	0.02^{NS}	54.19**	24.49^{NS}	5.62NS	59.08**	4.76^{NS}

Treat×Env. (T×Y)	4	14.85^{NS}	0.95^{**}	3.3^{**}	10.43^{**}	28.58^{NS}	28.9^{NS}	7.94^{**}	1.01^{NS}
Error	18	12.03	0.32	0.556	0.32	15.84	28.14	1.48	5.28
CV		5.2	3.72	9.6	15.1	5.41	3.55	16.12	7.95

Table-3A. Mean values for various traits in offseason onion crop at ARI Mingora Swat, during 2021 and 2022.

Treat.	**Plant height (cm)**			**No of leaves**			**Bolting (%)**			**Splitting (%)**		
Set size	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
09-12	58.1	71.3	65.7	9.3	10.1	9.8	0.95	2.55	1.75	0.06	1.45	0.76
13-16	58.8	73.2	64.3	9.7	10.9	10.3	1.14	1.97	1.56	1.01	1.02	1.02
17-20	61.4	69.7	66.4	9.4	11.9	10.7	4.38	2.29	3.34	0.93	2.02	1.47
21-24	61.6	72.0	68.9	10.0	12.8	11.4	7.24	7.63	7.43	1.48	7.54	4.51
25-28	64.2	76.1	68.1	10.2	12.3	11.2	25.32	24.32	24.82	8.73	13.65	11.19
LSD $_{(5\%)}$	4.9	6.8	--	0.68	0.8	--	1.32	1.3	--	0.78	1.4	--

Table-3B. Mean values for various traits in offseason onion crop at ARI Mingora Swat during 2021 and 2022.

	Bulb diameter (mm)			**Single bulb weight (g)**			**White rot (%)**			**Yield (ton ha^{-1})**		
Set size	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
09-12	70.2	74.2	72.2	120.0	120.3	120.2	4.06	4.59	4.33	16.97	15.50	16.23
13-16	66.6	73.7	70.1	129.8	127.0	128.4	8.05	5.31	6.68	20.54	20.87	20.70
17-20	71.7	73.3	72.5	151.1	151.3	151.2	6.14	4.57	5.35	34.30	33.45	33.88
21-24	72.1	73.1	72.6	147.8	152.7	150.2	12.01	7.59	9.80	34.63	32.96	33.80
25-28	82.9	78.1	80.5	200.3	193.3	196.8	13.20	8.53	10.86	40.00	39.67	39.83
LSD $_{(5\%)}$	5.85	9.3	--	12.41	8.2	--	2.49	1.64	--	5.32	3.6	--

Table 4. Correlation coefficients of various parameters studied in offseason onion crop at ARI Mingora Swat during 2021 and 2022.

	Plant height	**No of leaves**	**Bolting**	**Splitting**	**Bulb diameter**	**Bulb weight**	**White rot**
No. of leaves	0.740^{**}						
Bolting	0.170^{NS}	0.289^{NS}					
Splitting	0.410^{NS}	0.590^{**}	0.889^{**}				
Bulb diameter	0.226^{NS}	0.238^{NS}	0.666^{**}	0.589^{**}			
Bulb weight	0.156^{NS}	0.329^{NS}	0.925^{**}	0.844^{**}	0.662^{**}		
White rot	-0.157^{NS}	-0.0854^{NS}	0.707^{**}	0.447^{NS}	0.470^{**}	0.728^{**}	
Yield	0.134^{NS}	0.3784^{NS}	0.717^{**}	0.657^{**}	0.444^{**}	0.875^{**}	0.719^{**}

Splitting Percentage (%)

Onion bulbs comprise of a short underground stem surrounded by fleshy scale leaves and a central bud, from which lateral buds develop into multi-hearted bulbs that may split into two or more irregular shaped bulbs (Khokhar et al. 2002). Our two-year study revealed significant differences in splitting percentage among treatments, as well as year × treatment interaction. This indicates that treatment performance varied inconsistently across the years and treatments, highlighting the complexity of controlling onion splitting (Table 1A and 2). Mean values showed that minimum splitting (0.06 & 1.02 %) was observed in set size (09-12 mm) and (13-16 mm) while maximum splitting (8.73 & 13.65%) was recorded in large set size (25-28 mm) during 2021 and 2022 respectively (Table 3A). Our results showed increasing trend in splitting percentage with increase in set size. Khokhar et al. (2002) also studied the impact of set size on yield and reported more splitting in larger onion set compared to smaller set. Our results also confirmed the findings of Matimati *et al*. (2006) who compared two onion cultivars for splitting percentage and concluded that larger sets produced unmarketable bulbs and similar yield was produced from smaller sets. Correlation results showed that splitting exhibited a significant and positive correlation with number of leaves (r = 0.740), bolting (r = 0.889), bulb diameter (r = 0.589), bulb weight (r = 0.844), and yield (r = 0.657) (Table 4). This suggests that more leave consist more photosynthetic area which ultimately contribute to plant height and final yield but decrease marketable yield due to changes in plant morphology and physiology.

Bulb Diameter (mm) and Single Bulb Weight (g)

Bulb diameter and weight are the key indicators to estimate final yield. Significant differences in bulb diameter and single bulb weight were detected among treatments, but treatment responses remained stable across the years with no significant year × treatment interaction (Table 1B and 2). Mean data in table 3B shows minimum single bulb weight (120.0 & 120.3 g) in set size (09-12mm) while maximum single bulb weight (200.3 & 193.3 g) was observed in larger set size (25-28 mm) during 2021 and 2022 respectively. Similarly, minimum bulb diameter (66.5 & 73.1 mm) was recorded in set size (13-16 and 21-24 mm) while, maximum (82.9 & 78.1 mm) was observed in larger set size (25-28 mm) during 2021 and 2022, respectively (Table 3B). Variations in bulb diameter are mostly due to genetic makeup of the varieties, environment and management practices (Yang et al., 2004). Similarly, Singh and Singh (2003) and Khan et al. (2005) also reported significant effect of set size on bulb diameter and single bulb weight. Large sets possess high food reserves and water contents, which promote vigorous plants growth with an expanded canopy, ultimately yielding bulbs of diameter and weight (Khokhar, 2014). Yaseen and Hajos (2020) reported highest bulb diameter from the largest set size. Mondal and Alam (2003) reported that larger set attain more bulb weight, but after deducting unmarketable bulbs weight net yield reduce up to 25%, and in medium sets up to 10%, compared to small sets. Correlation analysis indicate that bulb diameter and bulb weight are closely related in onion crops. Bulb diameter was positive and significantly correlated with bolting (r = 0.925), splitting (r = 0. 844), bulb weight (r = 0.910), white rot (r = 0.470) and yield (r = 0.444) (Table 4). Which indicate that increase in bulb diameter also increase bolting incidence, splitting, white rot, bulb weight and yield as well. This positive correlation attributed to the fact that larger bulbs are more prone to bolting, splitting and disease due more reserve food and early completion of juvenile period. Moreover, it increases overall yield but due to splitting and white rot marketable yield reduced.

White Rot Percentage (%)

White rot is a devastating soil-borne disease affecting onion and garlic crops worldwide. The pathogen survives in the soil for up to 20 years (Lourenço et al. 2018). The data revealed significant differences across the treatments and years, which indicate inconsistent disease incidence patterns across the year (Table 1B and 2). Mean values showed that minimum incidence of white rot (4.06 & 4.57%) was recorded in set size (09-12 mm) and (17-20 mm) while maximum (13.20 & 8.53%) was recorded in large set size (25-28 mm) during 2021 and 2022, respectively (Table 3B). Our results showed that larger sets produced larger bulbs coupled with more incidence of white rot which is the confirmation of results published by Davis et al., 2007. They also reported that due to increased root biomass larger onion bulbs are more prone to white rot infection. Kumar et al., 2015 stated that approximately 35-40% post-harvest losses occurs due to poor storage in which 15-30% losses is directly related to diseases. Utkhede, 1982 also reported that significant yield losses range from 5-50% occurs due to white rot while conducive environment leads to even total failure of the crop. Lourenço et al. 2018 concluded that effective control measure of white rot are soil treatments, fungicides application, biocontrol agents, cultural practices and more importantly is development of resistant cultivars to reduce yield losses. Correlation analysis highlight that white rot was positive and significantly correlated with bolting (r = 0.707), bulb diameter (r = 0.470), bulb weight (r = 0.728) and yield (r = 0.719) (Table 4). This positive correlation is attributed to the fact that white rot infection led to change in plant morphology and physiology and making the plant more susceptible to bolting and increasing bulb size and weight. Larger bulbs contribute to higher yields, but it also increases the risk of white rot due to larger surface area. This increase disease susceptibility and ultimately lead to reduce marketable bulb yield, which offset the potential benefits of larger bulbs.

Bulbs Yield (ton ha^{-1})

Onion yields depend on adequate vegetative growth prior to bulb formation, triggered by suitable temperature and day length conditions (Ibrahim, 2010). Significant differences were observed among the treatment during 2021 and 2022 which is the confirmation of the results published by Khan et al. (2021). Year × treatment interaction was non-significant which shows stability in yield over the years (Table 1B and 2). Minimum yield of 16.97- & 15.50 tons ha^{-1} was recorded in set size (09-12 mm) while maximum 40.0- & 39.67 tons ha^{-1} was recorded in large set size (25-28 mm) during 2021 and 2022 respectively (Table 3B). Overall yield shows that larger sets produced highest bulb yield. Which is the confirmation of Khan et al. 2021 findings that larger sets produce vigorous plant having greater leaf canopy and more photosynthetic area which results more yield. In our study direct linear relationship was observed between set size and yield, indicating higher yields from larger sets. Similar findings were also published by Singh *et al*. (1999) that higher bulb yield obtained from larger onion sets. Although, after deducting unmarketable bulbs more net returned was observed from smaller or average sets. Several researchers including Singh et al., (2014) concluded that yield obtained from smaller size onion sets providing more return as compared to larger set size after calculating cost benefit ratio and this increase might be due to low disease incidence. Correlation analysis showed that yield was positively and significantly correlated with bolting (r = 0.717), splitting (r = 0.657), bulb diameter (r = 0.444), bulb weight (r = 0.875), and white rot (r = 0.719) (Table 4). This suggests that as the incidence of bolting, splitting, and white rot increases, and as bulb diameter and weight increase, yield also tends to increase. On one hand, larger bulbs and heavier weights contribute to higher yield. However, on the other hand, increased incidence of splitting and white rot accompanies with larger bulbs lead to reduction in marketable bulb weight and resultantly reduce marketable bulb yield. Similarly, significant and positive correlation was also reported by Mane et al. 2024.

CONCLUSION

Better results were observed in set size 17-20 mm. Large sets achieved higher yield, but more susceptible to bolting, splitting and white rot disease. In contrast, smaller and medium size sets demonstrated lower incidence of bolting and diseases. Complex network of relationships between various traits was observed. Bolting, splitting, bulb diameter, bulb weight, and white rot were all positively correlated with each other, suggesting that these traits are interconnected and can influence each other. Yield was positively correlated with these traits, indicating that they can contribute to increased yields. However, the increased risk of splitting and white rot associated with larger bulbs and heavier weights can ultimately reduce the weight of final bulbs and negate the yield benefits.

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