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RESEARCH ARTICLE

THE IMPACT OF VARYING BULB SIZES, PLANT SPACING AND PLANTING DATES ON THE YIELD AND QUALITY OF ONION SEEDS VAR. TAHERPURI

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Abstract

Background and objective: Onion is a spice crops, which are particularly important because it uses in daily life. The crop is also appreciated as condiments for flavoring foods. It can be used as a stimulant, promotes the flow of urine, uses against tuberculosis, venereal disease, typhoid fever, chest and lungs problem and it contains vitamin B and trace of vitamin C and traces of iron and calcium. The objective to study to improve the yield and quality of onion seeds (var. Taherpuri) through management practices.

Methodology: The experiment was designed using the Randomized Complete Block Design (RCBD) with three replications and included three parameters. The unit plot was randomly assigned to the experiment treatments. In trial, the unit plot size was the same (2 m × 1 m). Plots were separated by 0.5 meters and blocks by 1 meter.

Main Results: The tallest plant height (48.50, 57.96 and 62.11 cm) and the maximum number of leaves per plant (15.52, 23.25 and 24.66) at 45, 60 and 75 DAP was found from the large bulb size (16-20 g) × widest plant spacing (25 cm × 20 cm) × early planting on 25th October treatments interaction, respectively. The highest seed yield of 1075.00 kg/ha, maximum weight of 1000 seeds (3.75 g), the highest germination percentage (88.33%), the highest shoot length (8.73 cm), highest root length (3.23 cm) and the maximum seed vigor index (1057.10) was obtained from the treatment interaction of the largest bulb (16-20 g) × widest plant spacing (25 cm × 20 cm) × early planting on 25th October treatments interaction.

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Conclusion: The integrated use of large mother bulbs, optimal plant spacing, and early planting significantly enhances onion seed yield and quality. Specifically, the combination of largest bulbs (16–20 g) and wider plant spacing (25 × 20 cm) with early planting dates (25th October) consistently results in the highest seed yield up to 1,075 kg/ha along with superior quality traits: heavier 1,000-seed weight, higher germination rates, longer shoots and roots, and elevated vigor index.

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Introduction:-

The onion (*Allium cepa* L.), a member of the Alliaceae family, is the most widely grown and significant spice crop worldwide including in Bangladesh. For the manufacture of bulbs, it has been grown annually for more than 4700 years. Additionally, it is a vegetable in many parts of the world (Brewster, 1994). According to McCollum (1976), the Mediterranean region is the second-largest origin center for onions, with Central Asia being the principal center. According to FAO (2022), China is the world's largest producer of onions, followed by India, the United States, and then Pakistan, Korea, the Netherlands, Israel, Japan, Turkey, Syria, Egypt, Lebanon, and so on. Bangladesh generates 2% of global production annually, while China and India account for 26% and 21% of global production, respectively (Quaiyum, 2020).

The onion is referred to be the "Queen of the kitchen" because of its highly prized flavor, scent, and distinct taste as well as the therapeutic qualities of its flavor compounds (Selvaraj, 1976). Of all the spice crops, onions are particularly important because of their many applications in daily life. The crop is also appreciated as condiments for flavoring foods. It can be used as a stimulant, promotes the flow of urine, uses against tuberculosis, venereal disease, typhoid fever, chest and lungs problem. Onion contains vitamin B and trace of vitamin C and traces of iron and calcium. In onions, allyl-propyl-disulphide, a volatile oil, is the cause of the onion's notable pungency. According to Ahmed (2020), the renowned physician Hippocrates recommended onions as emmenagogues, laxatives, and diuretics. Additionally, he utilized onions to cure pneumonia and to topically heal septic wounds. The most prevalent vitamin in onion bulbs is ascorbic acid, which has a concentration of 1 mg/g dry weight. It also contains steroidal saponins, which stop the intestines from absorbing cholesterol. In 2023, the top 20 nations that produced the most onions generated 80.04 million tons annually, with China, India, and the United States accounting for 24.97, 22.82, and 3.17 million tons, respectively (FAOSTAT, 2023). In BBS, 2023, the other 17 nations each produced over 1.36 million tons.

Egypt is the world's fourth-largest producer, with 3.08 million tons produced annually in Africa (FAO, 2023). Additionally, according to FAOSTAT (2023), 93.23 million metric tons of onions are produced annually worldwide. With 24.04 million metric tons produced annually, China leads the globe in onion production, followed by India with 21.42 million metric tons. In the larger districts of Pabna, Faridpur, Rajbari, Manikganj, Kushtia, Rajshahi, Jhenaidah, Magura, Meherpur, Madaripur, Shariatpur, Gopalganj, Narayanganj, Dinajpur, and Rangpur in Bangladesh, onions are grown extensively. Out of all the 64 districts, Pabna produces the most onions. The country's total onion acreage was 1.87 lakh hectares, of which 42566.40 hectares were in Pabna and 2617 hectares were in Faridpur (Akter et al., 2023). Roughly 75.79% of the nation's onion production comes from Pabna, Faridpur, Rajbari, Rajshahi, Kushtia, and Jhenaidah (BBS, 2023). Bangladesh's 3.5 million metric tons of annual demand for winter onions are primarily fulfilled by domestically grown winter onions. Still, 237,000 hectares of land are used to grow the current production, which is between 2.5 and 2.6 million tons. At a cost of almost BDT 40,000 million, the nation must import one million tons of onions annually to meet the present demand (ACI Seed Limited, 2023). Multi-crop cultivation methods, the challenges of increasing cultivation acreage in the winter, and the lack of adequate land all make output shortfalls and storage losses worse. According to Rahim *et al.* (1993), however, its seeds are grown in the districts of Faridpur, Natore, Pabna, Rajshahi, Dinajpur, and Thakurgaon.

Farmers employ a variety of seed types, including their own seed, enhanced seed, local quality seed, HYV and hybrid seeds, which result in varying onion bulb sizes. About 1245 metric tons of seeds were needed in 2018–19 to cultivate 1.73 lakh hectares of land (Quaiyum, 2020). It is estimated that farmers produce 90% of the seeds, with BADC and other private companies producing the remaining 10% (Quaiyum, 2020). Thus, a market crisis among Bangladeshi onion growers during the growing season is caused by a shortage of edible onion bulbs and an enormous amount of onion seed used to produce bulbs annually. Practically speaking, compared to bulb crops, onion plants grown from the bulb for seed production must be maintained in the field for a month as a standing crop. In addition to impacting onion producers and the nation's total onion crop, lower seed production makes the seed market susceptible. Because of some environmental constraints, such as Bangladesh's brief winter season, plants grown from seed typically do not produce quality seed in the same season.

The bulb-to-bulb method is generally suitable for Bangladeshi onion seed production. In Bangladesh, because the winter season is brief and mild, onions are typically planted when the season begins. This crop, which is favored by short days, aids in seed production. Climate constraints prevent Bangladeshi farmers from using early planting. Due to late rainfall or floods, illnesses frequently have a significant impact on early-planted onion seed crops (Ahmed, 2020). Normal seed growth and fruit setting are also impacted by high temperatures. In nature, onions are cross-

pollinated by flies, bees, and other insects. To maximize the potential of onion seed, a significant population of pollination insects must be present.

In Bangladesh, more and more land is being planted with onions each year, but farmers are having trouble finding high-quality seeds. Small farmers continue to supply high-quality onion seeds despite their lack of expertise in bulb grade selection. Our nation's farmers always produce onion seeds using tiny bulbs. Furthermore, the production of high-quality onion seeds is significantly impacted by the size of the mother bulb. Low quality and low seed production are caused by our nation's onion seed growers' ignorance of bulb size. Ahmed *et al.* (2020) discovered that for the Taherpuri variety, large bulbs outperformed small bulbs. Brewster (1994) noted that high-quality seeds and ideal plant spacing were thought to be crucial for excellent production, quality, and plant growth. Numerous studies have demonstrated the importance of plant and row spacing for the optimal plant population, which may be reflected in the best production and quality (Kumar *et al.*, 2018). Onions are a crop that is sensitive to photo thermoregulation (Davis and Jones, 1944). Temperature, humidity, rainfall, and length of day are some of the environmental elements that affect onion seed production. These elements are essential for seed growth and setting (Mishra and Mishra, 1991). For the largest yield and highest-quality onion seeds, Mondal (1980) believed that the latter week of October was the ideal time to plant.

Even with the right planting time and spacing between bulbs, small farmers still distribute high-quality onion seed because they lack the information necessary to choose the right bulb grade. Therefore, the experiment was conducted to find the ideal planting date, plant spacing, and bulb size for a high yield and excellent quality of onion seeds of var. Taherpuri in order to obtain detailed information about the aforementioned characteristics.

Materials and Methods:-

Experimental site:

During the rabi season (2020–21), an experiment was conducted to examine the impact of planting date, plant spacing, and bulb size on the yield and quality of onion seeds of the Taherpuri variety. The laboratory work was overseen at the MNT seed testing lab in Bashon, Gazipur, while the research was carried out at the LalTeer Research Farm. The experimental site is 8.4 meters above sea level and lies between 23°53' and 24°21' N latitudes and 90°09' and 90°39' E longitudes. The soil on the experimental site is clay loam, moderately acidic in reaction (soil pH 6–6.5, Haider *et al.*, 1991), and has poor fertility status. It is part of the Modhupur tract, which is classified as being in Agro Ecological Zone-28 (FAO, 1988).

Climatic conditions:

The most significant determinant of onion seed production is the agroclimatic component. The experimental area had a sub-tropical climate, which was marked by scarce rainfall, low humidity, low temperatures, and short days during the "Rabi season" (October–March) and high rainfall from April to September. Additionally, this climate is distinguished by several seasons, such as the pre-monsoon period or hot season from March to April, the winter or dry season from November to February, and the monsoon, which lasts from May to October (Edris *et al.*, 1979).

Experimental material:

The experimental material was the bulbs of "Taherpuri or BARI Piaz-1 (HRC, 1996), a cherished local open pollinated cultivar. This variety is well grown in Taherpur area at Bagmara Upazila of Rajshahi district according to the name of Taherpur area, it is called Taherpuri.

General characteristics of onion variety (var. Taherpuri):

It is selected from the local variety Taherpuri, selected by HRC, BARI, Joydebpur, Gazipur and registered by the NSB, MOA, and GOB in 1996 to grow all over the country. The variety is characterized by 50–55 cm plant height, 10–12 leaves, round-cum-flat shape and compact single bulb, thin necked, reddish-pink bulb, highly pungent, good shelf life (8–9 months), takes 130–140 days for bulb maturation, yields 12–16 tons/ha of fresh bulbs. The picking of matured umbels is made within 145–155 days of planting mother bulbs. The yield of seed is 950–1050 kg/ha. The diseases such as purple (Alternaria porri) blotch, leaf blight and insect like thrips and cutworms may attack the plants.

Source of the seed quality test:

The healthy, disease free and desired sizes of seeds were obtained from the store of (at ambient temperature) LalTeer R&D farm, Bashon, Gazipur. Seeds obtained from the respective experiments conducted for the seed production, were used for the quality test such as germination, 1000 seed weight and vigor test.

Preparing the land:

On October 15, 2020, the experimental ground was first ploughed with a tractor-drawn disc plough. Four cross-ploughs were then performed using a power tiller and ladder. The earth was then let to dry out. They spaded the land's corners. For the soil to be in good tilth condition, it was then harrowed. A ladder then leveled the land completely. We cleared the field of stubble and weeds. Every clod was fragmented into tiny bits. Before planting, the unit plots were also easily prepared with a spade.

Design and treatments of experiments:

Three replications of the experiment were set up using a randomized complete block design (RCBD). Various numbers of unit plots were created for each block based on the amount of treatments. The unit plot's experimental treatments were assigned at random. The experiment's bulb size, plant spacing, and planting date varied, but the unit plot size remained the same at 2 m × 1 m. Plots were separated by 0.5 meters and blocks by 1.0 meters. The experiment involved planting three different bulb sizes (~11 g, 12-15 g, and 16-20 g) at four different spacing's (25 cm × 20 cm, 25 cm × 15 cm, 20 cm × 20 cm, and 20 cm × 15 cm) on three separate dates (October 25, November 5, and November 15).

Observation data:

During the study period, morphological data were recorded, including seed germination, stalk length, plant height, and number of leaves per plant, as well as yield contributing characteristics, such as flower per umbel, fruit set percentage, seed yield, seed weight per hill, 1000 seed weight, etc.

Measurement and data collection:

At various growth phases, information on various growth, seed yield, and seed quality metrics was gathered from each plot's middle two rows. Data were collected on plant height (cm), leaves per plant (no), tillers per plant (no), length (cm) of the flowering stalk, umbels per plant (no), umbel diameter (cm), flowers per umbel (no), days to 80% maturity, seeded fruits per umbel (no), seed yield per plant (g), seed yield per plot (g), and seed yield per hectare by randomly selecting ten plants from each plot's two central rows. It was represented in kg/ha and was derived from the corresponding seed yield per plot. At Desire Seed Laboratory, however, seed quality contributing factors such seed weight (g), seed germination (%), and seed vigor test were carried out in accordance with ISTA (1985).

Records of growth and yield parameters:

Except for the percentage of bulbs that emerged, data on growth and development were gathered from ten randomly chosen plants for each treatment.

Statistical analyses:-

To determine the statistical significance of the experimental results, statistical analysis was performed on the gathered data on various growth, yield, and quality contributing parameters. Using Microsoft Excel, all treatments were computed, analyzed, and tabulated. The F-variance test was used to analyze the variance of the data for each parameter using Statistix 10 and RStudio software. The least significant difference (LSD) test was used to assess the significance between treatment means at 1% and 5% of provability for result interpretation (Gomez and Gomez, 1994).

Results and Discussion:-**Growth parameters:****Plant height and leaf count:**

In terms of plant height and the number of leaves per plant at 45, 60, and 75 DAP, the interaction impact of bulb size, plant spacing, and planting date was shown to be statistically significant. The findings showed that the bulb size (16–20 g) × spacing (25 cm × 20 cm) × planting date at 25th October were used to determine the tallest plant height (48.50, 57.96, and 62.11 cm) and the largest number of leaves per plant (15.52, 23.25, and 24.66) (Figure 1 and 2). The harvest from the smallest bulbs had the shortest plants at every stage of growth. This could be because large bulbs store a comparatively larger amount of internal food stores than small bulbs, which promotes robust

vegetative growth and increased plant height. The number of leaves dropped as the size of the bulb shrank. The reason why larger bulbs produce more leaves than smaller ones may be because they store more food material and have more sprouting leaf initials (Brewster, 1994).

The current results are in good accord with the findings of Islam *et al.* (2008), Haque (2011), Verlag (2013), and Muktadiret al. (2001), who also observed a substantial influence of bulb size on the augmentation of plant height. The findings of Kumar *et al.* (2015) also complement these findings. According to reports by Ali *et al.* (2015) and SK-Phoret al. (2019), the greatest mother bulb size resulted in the highest plant height. These findings corroborated those of Phoret al. (2019), who found that crops planted with the widest spacing generated noticeably taller plants than crops planted with the narrowest spacing. In contrast to the last eight plantings, the early planting may have given the plants a comparatively cooler period, which could have contributed to the rise in plant height. The cooler weather promotes the buildup of gibberellin and cytokines, which alters the hormonal balance and causes the plant to grow more. It is also the cause of the flower stalk's elongation. According to research by Ashagriiet al. (2014), onions planted in October grew to their maximum height when compared to those planted in November. These findings are also consistent with those of other authors who found that larger bulbs generated more leaves per plant since there were more food supplies stored, which led to more robust plants. Haque (2011), Asaduzzamanet al. (2012), and Hussainet al. (2001). According to a study by Mollahet al. (2015), onion plants planted in November had more leaves per plant and were longer than those planted in October. The study site's varying climate (temperature) may be the cause of this discrepancy.

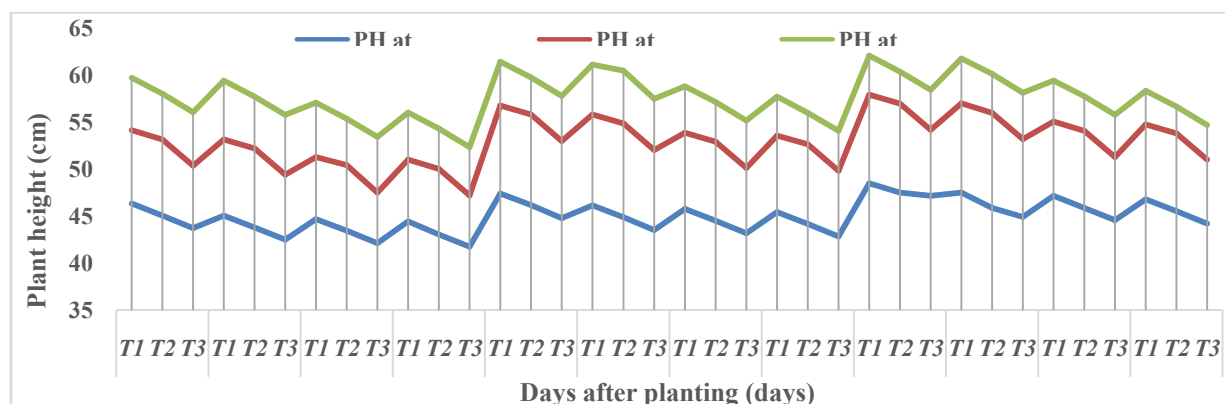


Fig 1.Interaction effects of bulb size, plant spacing and planting date on plant height (cm) of onion seeds var. Taherpuri

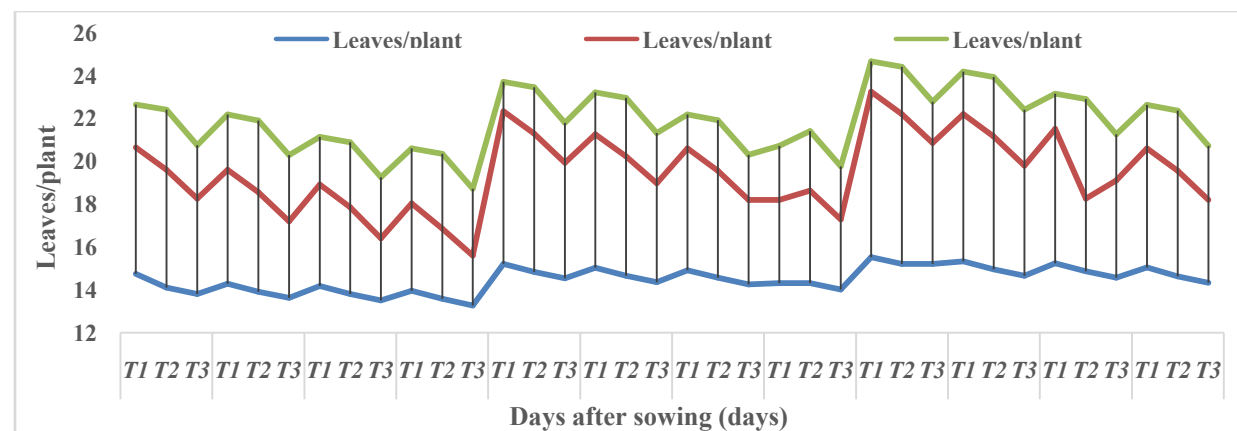


Fig 2.Interaction effects of bulb size, plant spacing and planting date on leaves/plant of onion seeds var. Taherpuri

Note: $B_1 = \sim 11$ g size bulb, $B_2 = 12-15$ g size of bulb and $B_3 = 16-20$ g size of bulb, $D_1 =$ Planting distance $25\text{ cm} \times 20\text{ cm}$, $D_2 = 25\text{ cm} \times 15\text{ cm}$, $D_3 = 20\text{ cm} \times 20\text{ cm}$ and $D_4 = 20\text{ cm} \times 15\text{ cm}$, $T_1 =$ Planting date 25 October, $T_2 = 5$ November and $T_3 = 15$ November.

Number of flowers and fruits per plant, number of tillers, length of stalk, number of umbels, and diameter of umbels:

Statistically significant effects were observed in the number of tillers, stalk length, umbel number, umbel diameter, and number of flowers and fruits per plant when varying bulb size, plant spacing, and planting date were combined. According to Table 1, the interaction effect of bulb size ($16-20\text{ g}$) $\times$ plant spacing ($25\text{ cm} \times 20\text{ cm}$) $\times$ planting date (25thOctober) resulted in the highest number of tillers per plant (3.46), the longest flowering stalk (95.03 cm), the number of umbels per plant (3.50), the maximum umbel diameter (7.50 cm), the highest number of flowers per umbel (486.43), and the maximum number of seeded fruits per umbel (374.0). The current findings closely align with those of other researchers. The findings of Ashagrie (2021) corroborate the considerable influence of bulb size on improving plant growth indices, as reported by Muktaidiret al. (2000), Hussainet al. (2001), Haque (2011), Asaduzzaman et al. (2012), and El-Helaly and Karam (2012).

Additionally, Singh and Sachan (1999) discovered that the plants with the widest spacing had the most tillers per plant. Asaduzzaman et al. (2012) and Haque (2011) also discovered that the plants with the widest spacing had more tillers per plant. Because there was less competition for nutrients, light, space, and moisture, plants with the widest spacing produced more green leaves. In the end, these leaves promoted the production of new flowering stalks by accumulating photosynthate. The widest spacing also produced the greatest number of blooming stalks per plant, according to Singh and Sachan (1999). The current findings were nearly identical to those of Haque (2011) and Asaduzzaman et al. (2012), who reported that the length of the flowering stalk rose as plant separation increased. The reason for this could be that the plants with the widest spacing helped to develop more green leaves and extra nourishment, which could later promote the length of the flowering stalk.

The number of umbels per plant and the width of the umbels were found to be superior when bulbs were planted with a larger spacing of 25 cm by 20 cm , followed by another treatment, and a smaller umbel was planted with a spacing of 20 cm by 15 cm . The quantity of umbels and their diameter per plant, however, rose as planting spacing increased. With the wider plant spacing, there may be less competition amongst the plants for nutrients, light, and moisture. Significantly larger umbel was the outcome of the greater nitrogen rate at wider spacing (Nehraet al., 1988; Pandey et al., 1992). These results can be explained by the fact that plants with wider spacing absorb more water and nutrients, particularly nitrogen, than plants with closer spacing, which may account for the larger and more numerous umbels.

These results are similarly consistent with those of Khan (2003), Singh and Sachan (1999a), and Hoque (2010) and Haque (2011), who also found that greater spacing led to a bigger umbel diameter. Both Phor et al. (2019) and Asaduzzaman et al. (2012) concurred that wider-spaced crops result in higher umbel diameters. Wider spacing was seen to result in a significant increase in the number of flowers per umbel. Bulbs spaced at the widest spacing of $25\text{ cm} \times 20\text{ cm}$ produced the most blooms per umbel (350.14), while bulbs spaced at the closest spacing of $20\text{ cm} \times 15\text{ cm}$ produced the fewest 311.80. It's possible that this is because the widest spacing resulted in the largest umbel diameter and length by absorbing more nutrients, which in turn promoted the production of the most flowers per umbel. Begum (1998) also made a comparable observation.

While the number of seeded fruits gradually decreased with the closest spacing, the maximum number of seeded fruits per umbel (263.76) was recorded from the wider spacing of $25\text{ cm} \times 20\text{ cm}$. The preceding aspects mentioned in the earlier criteria may be to blame for this. Begum (1995) found that the greater spacing resulted in the greatest quantity of seeded fruits per umbel. These findings also supported those of Haque (2011) and Asaduzzaman et al. (2012), who found that crops planted with the widest spacing produced considerably more seeded fruits per umbel than crops planted with the narrowest spacing. Regarding growth parameters such as the number of umbels, the diameter of the umbels per plant, and the length of the stalks, there was a notable fluctuation in the planting time. Out of the three planting dates, the outcomes were best when done early (25thOctober) as opposed to late (15thNovember). Larger bulbs had enough reserve food to support plant growth, which led to the maximum plant growth attributes. Other possible explanations for the increase in plant growth parameters include early planting, which may have given plants a comparatively cooler period compared to later plantings. This outcome is consistent with research by Haque (2011) and Nag and Oishimaya (2017), which found that planting date may have an impact

on plant growth parameters. Furthermore, Khodadadi (2012) found that the date of onion bulb planting significantly impacted plant growth characteristics. The current investigation's findings are consistent with those of Healy and Karam (2012), as well as with those of Kumar et al. (2018), Thalkariet al. (2019), and Ashagriect al. (2021). Because of the planting timing, there was a substantial (5% level) variation in the amount of flowers and seeded fruits available per umbel. The crop was planted early on 25th October, which produced the most flowers and seeded fruits per umbel, and late on 15th November, which produced the fewest flowers and seeded fruits per umbel. This could be because of the crop's poor growth and delayed bolting in November, as well as the high temperatures during the umbel-forming stage, which may have decreased the quantity of flowers and seeds per umbel. The current findings are in good agreement with those of Mishra (1986), Nehraet al. (1989), and Singh and Singh (1985). Furthermore, comparable findings were observed by Ashagriect al. (2014) and Thalkar (2019), who found that crops planted early generated the most flowers and seeds per umbel.

Table 1. The number of tillers, stalk length, umbel count, umbel diameter, and number of flowers and fruits per onion seed plant are all impacted by the interaction of bulb size, plant spacing, and planting date

Interaction effect			Number of tillers/plant	Length of flowering stalks (cm)	No. of umbels/plant	Umbel diameter (cm)	No. of flowers /umbel	No. of fruits /umbel
B1	D1	T1	2.43k-o	89.40a-e	2.57h-k	6.20f-k	297.87mnopq	231.60f-l
		T2	2.37l-o	88.23a-f	2.53h-k	6.17f-l	293.53opqr	224.77g-m
		T3	2.27m-p	86.23def	2.43i-l	6.07g-n	290.20pqr	218.07i-m
	D2	T1	2.50j-n	87.90b-f	2.53h-k	6.10f-m	294.30nopq	224.97g-m
		T2	2.33mno	87.00c-f	2.37i-l	5.90i-o	284.30qrs	151.83n
		T3	2.20nop	86.20def	2.23jkl	5.70mno	274.30s	213.33klm
	D3	T1	2.47k-n	88.43a-f	2.43i-l	5.87j-o	289.53pqr	226.00g-m
		T2	2.37l-o	87.13b-f	2.37i-l	5.77l-o	274.27s	216.00j-m
		T3	2.27m-p	86.93c-f	2.23jkl	5.67no	274.20s	209.33lm
	D4	T1	2.37l-o	83.70ef	2.30i-l	6.03h-n	285.67qrs	232.63e-l
		T2	2.10op	83.90ef	2.20kl	5.87j-o	289.00pqrs	215.97j-m
		T3	1.93p	82.03f	2.10l	5.60o	279.00rs	205.97m
B2	D1	T1	2.97d-h	88.27a-f	3.10b-f	6.97bc	332.53hij	241.27d-i
		T2	2.83f-j	88.10b-f	3.07b-f	6.90cd	312.87l	239.27d-j
		T3	2.77g-k	87.00c-f	3.03c-f	6.87cde	308.93lmn	233.53e-l
	D2	T1	2.87f-i	93.93ab	2.90e-h	6.50def	360.97de	253.17c-f
		T2	2.60i-m	92.60a-d	2.63ghi	6.33fgh	347.63efg	237.17d-k
		T3	2.50j-n	88.93a-f	2.60g-j	5.80k-o	317.63jkl	229.17f-m
	D3	T1	2.90e-i	92.57a-d	2.97d-g	5.97h-o	339.53fghi	235.03e-k
		T2	2.83f-j	91.60a-d	2.90e-h	6.03h-n	332.87ghi	223.97g-m
		T3	2.70h-l	91.17a-d	2.87fgh	5.97h-o	302.87lmnop	218.37i-m
	D4	T1	3.00c-h	91.23a-d	3.10b-f	6.46efg	342.00fghi	248.17c-g
		T2	2.43k-o	91.23a-d	2.40i-l	6.20f-k	312.00lm	222.50h-m
		T3	2.37l-o	89.67a-e	2.30i-l	5.93h-o	306.33lmno	205.83m
B3	D1	T1	3.47a	95.03a	3.50a	7.50a	486.43a	347.00a
		T2	3.33abc	94.03ab	3.37abc	7.37ab	419.43b	327.50ab
		T3	3.27a-d	93.70abc	3.30a-d	7.17abc	409.43b	310.83b
	D2	T1	3.40ab	93.23abc	3.43ab	6.30f-i	381.00c	268.80c
		T2	3.30a-d	90.57a-e	3.33a-d	6.20f-k	364.00d	260.13cd
		T3	3.17a-f	89.57a-e	3.20a-f	6.03h-n	345.67fgh	246.80c-h
	D3	T1	3.37ab	93.70abc	3.40abc	6.50def	332.60hi	256.97cde
		T2	3.23a-e	92.37a-d	3.27a-e	6.30f-i	349.27def	247.63c-g
		T3	3.17a-f	90.97a-d	3.27a-e	6.17f-l	332.60hi	236.63d-k
	D4	T1	3.30a-d	93.00a-d	3.20a-f	6.23f-j	346.93efgh	256.87cde
		T2	3.17a-f	92.00a-d	3.17a-f	6.13f-l	328.30ijk	230.87f-l
		T3	3.10b-g	90.37a-e	3.07b-f	6.13f-l	316.93kl	226.50g-m
LSD (0.05)			0.25	5.20	0.29	0.31	11.25	18.39

LSD (0.01)	0.33	6.90	0.39	0.42	14.948	24.42
Level of sig.	**	**	**	**	**	**
CV (%)	5.59	3.56	6.50	3.12	2.12	4.74

Note: ** = Significant at 1% level of probability. B₁ = ~ 11 g size bulb, B₂ = 12-15 g size of bulb and B₃ = 16-20 g size of bulb, D₁ = Planting distance 25 cm × 20 cm, D₂ = 25 cm × 15 cm, D₃ = 20 cm × 20 cm and D₄ = 20 cm × 15 cm, T₁ = Planting date 25 October, T₂ = 5 November and T₃ = 15 November.

Seed yield (kg/ha):-

The seed yield had a considerable impact on the interactions between bulb size, spacing, and planting date. When the data on seed yield per plot was converted to yield (kg/ha), the smallest bulb, widest spacing, and early planting all showed the same upward trend. The largest bulb (B₃) × widest plant spacing (D₁) × early planting (T₁) treatments produced the highest calculated seed yield of 1075.00 kg/ha, while the bulb planted of the smallest bulb (B₁) × closest spacing (D₄) × late planting of (T₃) interaction produced the lowest performance for the same parameter, 700.0 kg/ha (Table 2). As crops grew from larger bulbs, the seed production per hectare increased, whereas the small bulb treatment yielded a lower yield. As the size of the bulb expanded, so did the seed weight. The disparity in seed output may have resulted from the comparatively large food reserves kept in large bulbs, which increased the formation of robust, healthy plants with abundant seed heads and, as a result, increased seed yield kg/ha (Table 2). This outcome supports the findings of Haque (2011), who found that the size of the mother bulb could have an impact on the amount of onion seed produced per hectare, with large mother bulbs producing the maximum harvest and small mother bulbs producing the lowest. The findings of Healy and Karam (2012), Ashagrie et al. (2014), Ali et al. (2015), Mollahet al. (2015), Debashiet al. (2016), Khan (2016), Thalkari (2019), Ahmed et al. (2020), and Ashagrie et al. (2021) that the larger bulb produced the higher seed yield per hectare are also consistent with this result.

The highest seed output was obtained from bulbs planted at the tightest spacing (20 cm × 15 cm) and the widest spacing (25 cm × 20 cm). As plant spacing increased, there was a discernible rise in seed yield per plot and per hectare (Table 2). This result validates the findings of Kanware et al. (2000) and Cuocolo and Barbieri (1988). Similar outcomes were also reported by Haque (2011), who achieved higher seed yields per hectare and per plot with wider plant spacing. Early planting on 25th October produced the highest seed yield, which may have been caused by pollination-friendly weather conditions that resulted in more seed sets per umbel and per plant. Late planting on 15th November produced the lowest seed yield per unit area, which may have been caused by weather conditions that negatively affected pollination and seed set, resulting in fewer seed sets per plant (Table 2). According to Healy and Karam (2012), flower abortion may potentially be the cause of the decreased seed output in crops that are planted later. Furthermore, our findings are consistent with those of Haque (2011), Asaduzzaman et al. (2012), and Thalkari (2019), who found that the highest seed production was observed on an early planting calendar. The findings of Ashagrie et al. (2021), Debashiet al. (2016), Ali et al. (2015), and Mollahet al. (2015) are all consistent with this outcome.

Quality parameters:

The interaction effect of large bulb size (16-20 g) × the widest spacing (25 cm × 20 cm) × early planting (25 October) produced the highest values for the 1000-seed weight (3.75 g), the highest germination percentage (88.33%), the maximum root length (3.23 cm), the maximum shoot length (8.73 cm), and the maximum seed vigor index (1057.10). This result is consistent with larger onion bulbs increasing the weight of 1000 seeds, as reported by Ali et al. (1998), Mukhtadir (2000), Asaduzzaman et al. (2012), Khan (2016), Ahmed et al. (2020), and Ashagrie et al. (2021). The germination rate was higher for seeds harvested from large bulbs and lower for seeds harvested from small bulbs. The medium-sized bulbs were used to produce seeds with germination percentages in the middle. Asaduzzaman et al. (2012), Islam (2008), Hoque (2010), El-Helaly and Karam (2012), Khan (2016), and Ashagrie (2021) also found higher germination percentages of seed from larger bulbs, which was in keeping with the aforementioned findings. The bulb size significantly increased the seed vigor index. The findings showed that as bulb size increased, the vigor index rose as well. The larger bulbs may have a higher vigor index because their roots and shoots are longer and their seeds germinate at a higher rate than those of smaller bulbs. This result is consistent with that of Ashagrie et al. (2014) and Badawiet al. (2010). Ashagrie et al. (2014) discovered that the big bulbs had the highest seed vigor index.

Additionally, the results of Badawiet al. (2010) were nearly identical to the current findings, indicating that the quality of onion seed as measured by the percentage of germination shoot and root lengths, varied significantly

across the three mother bulb sizes. These outcomes also supported Khan's (2016) findings, which showed that the maximum SVI from large bulbs was much higher than that from smaller ones. Aliet al. (1998) also discovered that the wider spacing resulted in a much greater onion seed weight of 1000. Moreover, Haque (2011) and Asaduzzamanet al. (2012) concurred that the onion's 1000-seed weight was noticeably greater at the wider spacing. The plants that are closer together may have less access to water and nutrients. According to Khan (2003a) and Hogue (2010), who found a higher percentage of seed germination at wider spacing, the current result is consistent with their findings. According to Teshomeet al. (2015), a wider spacing and fewer fungal pathogen incidences often resulted in a higher percentage of seeds germinating. This outcome is similar to that of Asaduzzamanet al. (2012), who found that the maximum spacing resulted in the highest germination percentage (92.64%) while the smallest spacing resulted in the lowest germination percentage (83.85%). When compared to seeds with the closest intra-row spacing, the widest plant spacing produced the highest seed vigor index, which may be explained by the maximum root and shoot length and germination % of seeds. This could be because, in contrast to plants with closer spacing, the plants with wider spacing had greater access to food materials for the developing seeds, while the plants with closer spacing had less access to water and nutrients. According to Teshome et al. (2015), this may also be because plants with small populations (wide spacing) have less rivalry for assimilation and seed distribution, which could lead to vigor growth.

Similar findings were made by Singh et al. (1985), who showed that a wider spacing improved the seedling vigor index more than a narrower spacing did. In general, when space rose (plant population density decreased), the seed vigor index increased as well. This may be explained by less rivalry amongst plants for growth components, which promotes greater development and the accumulation of food sources in the seed for the following generation. In their study, Sarkeret al. (2021) discovered that the wider spacing outperformed the closing ones in terms of germination percentage, seedling length, and seedling vigor index. They did this with spacing of 30 cm × 20 cm (S1), 25 cm × 20 cm (S2), and 20 cm × 20 cm (S3). Significant differences in seed germination were noted depending on the planting date. According to the results, seeds originating from the 25th October planting date had the highest seed germination rate (78.78%), while seeds originating from the 15th November planting date had the lowest seed germination rate (70.92%). According to the following authors, this outcome is consistent. Early planting produced the highest percentage of seed germination, according to El-Helaly and Karam (2012) and Ashagrieet al. (2021), who also found that planting date had a major impact on seed germination. Malik et al. (1999) found that early planting produced the highest seed vigor index, which was connected to this finding. According to Ashagrieet al. (2021), early planting resulted in a significantly higher seed vigor index after the planting date.

Table 2. Effects of planting date, plant spacing, and bulb size on the yield and quality characteristics of onion seed varieties. Taherpuri

Interaction effect			Seed yield (kg/ha)	1000 seed weight (g)	Germination (%)	Shoot length (cm)	Root length (cm)	Seed vigor Index
B1	D1	T1	970.0d	3.46c-g	79.00d-h	7.96b-f	2.53d-g	829.8e-i
		T2	891.7ij	3.36e-i	78.00e-k	7.93b-g	2.66c-f	827.0e-i
		T3	850.0mn	3.16i-m	71.00n-qr	7.06i-n	2.60d-g	686.8l-p
	D2	T1	915.0gh	3.35e-i	78.33e-j	7.63d-j	2.90a-d	825.2e-j
		T2	841.7n	3.30f-k	77.00f-l	7.60e-j	2.63c-f	788.3g-k
		T3	795.0p	3.10klm	70.33o-s	6.70mno	2.56d-g	652.0n-q
	D3	T1	895.0ij	3.36e-i	74.33j-o	7.20g-m	2.56d-g	726.2j-o
		T2	816.7o	3.26g-l	73.00l-p	7.13h-m	2.23g	684.0m-p
		T3	775.0q	3.06lmn	66.33st	6.33nop	2.23g	568.6qr
	D4	T1	820.0o	3.15i-m	68.00q-t	6.96j-n	2.56d-g	648.5opq
		T2	741.7r	3.06lmn	67.33rst	6.73l-o	2.33fg	610.5pq
		T3	700.0t	2.85n	61.00u	6.06op	2.23g	507.1r
B2	D1	T1	995.0c	3.65abc	79.00d-h	8.50ab	3.13ab	919.4b-e
		T2	916.7g	3.55a-e	82.66bcd	7.60e-j	2.90a-d	868.7c-h
		T3	875.0kl	3.35e-i	75.66h-m	7.56e-k	2.80b-e	784.7h-l
	D2	T1	940.0ef	3.60a-d	82.66bcd	8.16a-e	3.13ab	934.8bcd
		T2	861.7lm	3.50b-f	81.33cde	8.13a-e	2.90a-d	897.6c-f
		T3	820.0o	3.30f-k	74.66i-n	7.26f-m	2.80b-e	751.9i-n
	D3	T1	920.0g	3.55a-e	78.66d-i	7.73c-i	2.80b-e	828.7e-i

	D4	T2	841.7n	3.45c-h	77.66e-k	7.70c-j	2.56d-g	797.7f-k
		T3	800.0p	3.25g-m	70.00p-s	6.83k-n	2.46efg	651.7opq
		T1	845.0n	3.33e-j	73.00l-p	7.50e-k	2.80b-e	752.9i-m
		T2	766.7q	3.23h-m	72.00m-q	7.46e-l	2.56d-g	722.5k-o
		T3	725.0s	3.03mn	64.66tu	6.53m-p	2.46efg	582.3qr
B3	D1	T1	1075.0a	3.75a	88.33a	8.73a	3.23a	1057.1a
		T2	996.7c	3.65abc	87.33a	7.83b-h	3.00abc	946.0bcd
		T3	955.0de	3.45c-h	80.33d-g	7.83b-h	2.90a-d	862.7d-h
	D2	T1	1020.0b	3.70ab	86.00ab	8.43abc	3.23a	1003.5ab
		T2	941.7e	3.60a-d	85.00abc	8.36a-d	3.00abc	966.8abc
		T3	900.0hi	3.40d-h	74.66i-n	7.50e-k	2.90a-d	776.9h-m
	D3	T1	998.3c	3.65abc	81.66cde	7.96b-f	2.90a-d	888.3c-g
		T2	921.5g	3.45c-h	81.00c-f	8.06a-e	2.66c-f	869.7c-h
		T3	880.0jk	3.35e-i	74.00k-p	7.06i-n	2.56d-g	713.3k-o
	D4	T1	925.0fg	3.43c-h	76.33g-l	7.70c-j	2.90a-d	809.5f-k
		T2	846.7mn	3.35e-i	75.33h-m	7.70c-j	2.66c-f	781.0h-m
		T3	805.0op	3.11j-m	68.33q-t	5.80p	2.53d-g	568.9qr
LSD _{0.05}			11.62	0.16	3.21	0.57	0.28	75.32
LSD _{0.01}			15.43	0.22	4.26	0.75	0.37	100.00
Level of sig.			**	**	**	**	**	**
CV (%)			0.81	2.98	2.60	4.68	6.42	5.93

** = Significant at 1% level of probability. B₁ = ~ 11 g size bulb, B₂ = 12-15 g size of bulb and B₃ = 16-20 g size of bulb, D₁ = Planting distance 25 cm × 20 cm, D₂ = 25 cm × 15 cm, D₃ = 20 cm × 20 cm and D₄ = 20 cm × 15 cm, T₁ = Planting date 25 October, T₂ = 5 November and T₃ = 15 November.

Economic analysis:

The findings from economic analysis in Table 3 demonstrated that the larger the seed bulbs (16–20 g), the higher the gross return, net return, and gross margin. However, the smallest net return, gross margin, and benefit-cost ratio (BCR) were obtained from the tiny seed bulbs (~11 g). Because of the greater seed rate, the larger bulbs had the highest possible overall cost of production. Accordingly, the larger seed rate and larger yield from the large seed bulbs may be the cause of the larger net-return, higher gross margin, and lower BCR from the large bulbs (Table 3). Accordingly, differences in production costs, net returns, and benefit-cost ratios were noted for various bulb sizes. Although the benefit cost ratio (2.17) was higher for small size bulbs because of their relatively lower production costs and smaller quantity, the cost of production (TK.584410/ha) and net return (TK 681050/ha) were highest for large size bulbs. The benefit cost ratio (1.49) was lowest for large bulbs because of the relatively bigger quantity of bulbs and higher production costs, while the net return (TK. 440652/ha) and production cost (TK. 780335/ha) were lower for tiny bulbs.

Table 3. The impact of bulb size and plant spacing on the cost of production, net profit, gross return, and benefit cost ratio (BCR) of Taherpuri onion seeds

Interaction effect		Cost of production (tk ha ⁻¹)	Gross return (tk ha ⁻¹)	Net return (tk ha ⁻¹)	BCR
B1	D1	604410	1265460	681050	2.09
	D2	619159	1169575	550416	1.89
	D3	611140	1119015	507875	1.83
	D4	651235	998918	347682	1.53
B2	D1	614110	1311683	709572	2.14
	D2	648859	1223460	574601	1.89
	D3	640840	1174113	533272	1.83
	D4	680935	1051515	370580	1.54
B3	D1	605550	1432905	789395	2.37
	D2	708259	1359308	651048	1.92
	D3	700240	1306620	606380	1.87
	D4	780335	1160988	440652	1.49

Conclusion:-

The integrated use of large mother bulbs, optimal plant spacing, and early planting significantly enhances onion seed yield and quality. Specifically, the combination of largest bulbs (16–20 g) and wider plant spacing (25 × 20 cm) with early planting dates (around late October) consistently results in the highest seed yield up to 1,075 kg/ha along with superior quality traits: heavier 1,000-seed weight, higher germination rates, longer shoots and roots, and elevated vigor index.

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Ethics declarations:**Competing Interests:**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability:

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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