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Onion variety and season interaction for yield, storage and disease-insect dynamics under North-east Indian agro-climatic conditions

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Abstract

Aim: An experiments was conducted to investigate the performance of onion varieties in different growing season under agro-climatic conditions of North- east Indian state Tripura.

Methodology: Twenty onion varieties were evaluated in rabi, late kharif and kharif. Observations on the plant growth, yield, disease severity, thrips dynamics and storage loss were recorded. The experiments were laid out in a factorial randomized block design.

Results: The varieties Bhima Shakti (289.2 q ha^{-1}), Bhima Kiran (288.1 q ha^{-1}) and Bhima Super (284.1 q ha^{-1}) gave higher yield in rabi. season whereas, varieties Bhima Super (292.6 q ha^{-1}) and Sukhsagar (291.9 q ha^{-1}) performed better in late kharif. Severity (PDI) of purple blotch was higher in kharif (26.9) and *Stemphylium* blight in rabi (27.3) and late kharif (23.9). Thrips population was higher during January to March. Storage loss was less in the varieties Bhima Shakti, Bhima Super, Bhima Kiran, Bhima Shweta, Arka Kirthiman, Sukhsagar and Balwan.

Interpretation: A strong interaction effect of onion varieties and growing seasons (kharif, late kharif and rabi) was observed in the present investigation in terms of plant growth, bulb maturity, yield, and incidence of diseases and thrips. Under north east Indian mild tropical agro-climate conditions, varieties Bhima Super and Sukhsagar in late kharif and varieties Bhima Shakti, Bhima Kiran and Bhima Super in rabi season were the most suitable, and may be popularized for cultivation in this region.

Onion Nursery raising under low cost bamboo protected structure

Experimental Field: Transplanted onion varieties and recommended package of practices followed and recorded field observations

Varieties Bhima Shakti (289.2Q ha^{-1}), Bhima Kiran (288.1Q ha^{-1}) and Bhima Super (284.1Q ha^{-1}) in rabi and Bhima Super (292.6Q ha^{-1}) and Sukhsagar (291.9Q ha^{-1}) in late kharif gave higher marketable yield with minimum storage loss.

Key words: Onion agroclimatic condition, Rabi-kharif onion, Thrips dynamics

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Introduction

Onion (*Allium cepa* L.) is widely cultivated in almost all the parts of the world, with India (31.7 million tonnes) and China (24.5 million tonnes) being the leading producing countries 28.7% and 22.2% production share, respectively. Over the years, cultivation of onion has been widely adopted in north, west and south Indian states. Maharashtra ranks first in onion production with a 35%, share followed by Madhya Pradesh with a share of 17% in 2023-2024. Though India is exporting considerable quantity of onion, it has been observed that every year there is a shortage of onion supply in the domestic market. Under diverse Indian climatic conditions, onion is cultivated in all three seasons, kharif, late-kharif and rabi, though main season is rabi with around 50% production, followed by 30% in late kharif and 20% in kharif. Season, photoperiod and temperature effect on onion cultivation in temperate, tropical as well as subtropical climatic zones has been critical for varietal selection and production (Brewster, 1977; Lancaster *et al.,* 1996; Singh *et al.,* 2017).

Onion plant growth, bulb formation and bolting are influenced by local agroclimatic factors. Generally long day onion requires 13-14 hours day length in temperate hilly zone, whereas in subtropics and tropics, short day onion varieties are adapted under 10-12 hours day length and 15.5-25.0 °C temperature regime for bulb initiation, followed by cooler nights and warmer days (30.0-40.0 °C)for bulb growth and maturity in rabi season (Swarup, 2012; Singh, *et al.,* 2017). Depending upon the agro-climatic variability in different parts of India, transplanting and bulb maturity time has been critically defined for rabi, late kharif and kharif seasons (Swarup, 2012; Khade *et al.,* 2017). Over the years, major onion growing regions in India are facing climate change vulnerability during the critical growth stages, such as sudden rise in temperature and humidity, erratic rainfall which amounts to 30-40% production and around 40% storage loss (Chahal and Mishra, 2021). Under such situations, exploring the possibilities of onion cultivation in the non-conventional onion growing region, such as North-eastern states have been considered to be promising. Ever increasing demand for onion in this region are only met by long-distance transportation of fresh onions from Maharashtra which faces high post-harvest loss.

As a result, onion supply in the entire North-eastern region remains deficient throughout the year with inflated price. Mild tropical agro-climatic conditions with defined winter and summer seasons of the region is suitable for onion cultivation, however, due to unavailability of suitable varieties adapted to this region, cultivation of this crop has not been popular. Tripura is one of the North-eastern states with mild tropical climate characterized by hot and humid summer (temperature 20.3-34.0 °C, relative humidity 55.0-98.3%), mild winter (temperature 10.0-26.7 °C, relative humidity 42.0-97.3%) and high annual rainfall with average of 2000.0 mm. After critical analysis of the agro-climatic conditions of the state, it has been found that all the three cropping seasons viz., kharif, late kharif and kharif prevail in Tripura state; and accordingly, the present experiment was undertaken to examine the onion varietal interactions with the seasons in terms of plant growth, yield, bulb quality, disease and insect dynamics, and storability of bulbs under the agro-climate condition of North-eastern state, Tripura.

Materials and Methods

Experimental site: The present study, was carried out during 2020-2022 in the experimental field of Tripura Centre, ICAR Research Complex for North-eastern region, Lembucherra, Tripura state, the study area is situated at 23091' N latitude and 91031'E, longitude 30.0 m above MSL. The soil is acidic in nature (pH: 4.5-5.5) and mixture of red loam and sandy loam. The climate is mild tropical, temperature ranging between 10.0 (winter) to 34.4 °C (summer), relative humidity ranging between 42.0 to 98.3% and average annual rainfall 2000.0 mm (Table 1). Soil fertility status of the experimental field was, organic carbon 1.8 mg kg^{-1}, available nutrient elements namely nitrogen 295.0 kg ha^{-1}, phosphorus 63.5 kg ha^{-1}, potassium 158.0 kg ha^{-1}, sulphur 45.5 kg ha^{-1}, iron 25.5 mg ha^{-1}, manganese 19.5 mg ha^{-1}, zinc 2.5 mg ha^{-1} and copper 1.7 mg ha^{-1}.

Experimental materials: Seeds of onion varieties were procured from different organizations viz. ICAR- Directorate of Onion and Garlic, Rajgurunagar, Pune, Maharashtra, ICAR- Indian Institute of Horticultural Research, Hessaraghatta, Karnataka, ICAR-Indian Institute of Agricultural Research, New Delhi and from other sources for this experiment. A total of 20 onion varities were evaluated namely, Bhima Shakti, Bhima Red, Bhima Kiran, Bhima Super, Bhima Dark Red, Bhima Shweta, Pusa Red, Arka Niketan, Arka Kalyan, Arka Pragati, Arka Kirthiman, Arka Lalima, Agrifound Light Red, Agrifound Dark Red, Brown Spanish, VL Piaz-3, Sukhsagar, Balwan, CITH-1 and N-53.

Experimental procedure: Onion seeds were treated with carbendazim @ 2g kg^{-1} of seed a day before sowing. Raised nursery beds (15 cm height, 1.0 m width x 3.5 m long) were prepared after proper soil treatments. Well decomposed farmyard manure along with *Trichoderma viride* were applied at the time of final soil preparation (Khade *et al.,* 2017), and seeds of each variety were sown on the nursery bed with proper spacing. Nursery was raised in bamboo made low cost protected structures. Seedlings were ready for transplanting 45 days after sowing. In kharif, nursery sowing was done in mid-June, transplanting in 1st week of August and harvested in the month of November; whereas in late kharif, nursery sowing was done in the 1st week of August, transplanting in mid-September and harvesting in the month of January-February. In rabi, nursery sowing was done in the 1st week of October, transplanting in mid-November and harvesting in the month of March. Experimental plots were prepared with dimension of 5 m x 2 m each. All the management practices were done as per the recommended packages of practices (Swarup, 2012; Sable, 2017; Das *et al.,* 2018). Harvesting was done when leaves turned yellow at neck fall stage and dug out plants with bulbs were spread for 1-2 days

Table 1: Weather parameters of experimental site in Tripura (Average of three years, 2020-2022)

Months	Temperature (^{0}C)		Relative humidity (%)		Rainfall (mm)
	Max.	Min.	Max.	Min.	
January	24.8	10.0	98.3	59.0	10.1
February	27.6	11.0	94.7	42.0	4.7
March	33.3	16.6	90.7	43.0	44.0
April	34.4	20.3	91.7	55.0	64.6
May	33.6	21.5	92.0	68.0	412.7
Jun	32.4	22.8	93.7	80.0	407.9
July	32.9	23.4	93.3	76.7	322.6
August	33.3	23.3	94.0	74.3	208.7
September	33.3	22.9	95.7	77.0	271.2
October	32.8	21.4	95.7	74.3	187.9
November	30.3	15.3	95.7	59.0	9.3
December	26.7	11.1	97.3	59.0	55.8
Annual Avg.	31.3	18.3	94.4	63.9	166.6
Total Rainfall	--	--	--	--	1999.4

on the open surface. Plant with bulb were hanged by tying the tops of the bulbs in bunches on a horizontal wire under well-ventilated shades for proper curing and data recording. Observations on plant height (cm), leaf number, premature bolting (%), neck thickness(cm), bulb weight(g), bulb equatorial diameter (cm), days to harvest after transplanting (DTH) and TSS (^{0}B) were recorded. Disease severity in terms of percent disease index (PDI) was recorded for purple blotch and *Stemphylium* blight after taking data from 10 plants randomly following the procedure given by Mckinney (1923). Scores for these two diseases were given using disease rating scale: score 0 for no disease severity; score 1 for 1-10% severity; score 2 for 11-20% severity; score 3 for 21-30% severity; score 4 for 31-50% severity; and score 5 for 51-100% severity. Percent disease index (PDI) was calculated using the formula, PDI= {Sum of all disease ratings/ (Observed plants x Maximum rating value)×100}. Number of thrips per plant was recorded very carefully at weekly interval. Thrips damage was recorded on 1-5 scale on the basis of foliar damage percentage as per procedures followed by Karuppaiah *et al*. (2022), score 1 given for 1-20% foliage damage; score 2 for 21- 40% foliage damage; score 3 for 41- 60% foliage damage; score 4 for 61-80% foliage damage; and score 5 for 81-100% foliage damage. Storage loss data was recorded by storing 5 kg of cured onion and observations were recorded at 1st, 2nd, 3rd and 4th month after harvesting (MAH). Cumulative storage loss due to weight loss, sprouting and rotting was recorded and expressed in percentage. The factorial Randomized Block Design (RBD) experiment was laid out with season as factor 1 and variety as factor 2. There were 60 treatment combinations with three replications.

Statistical analysis: The data on various parameters were analyzed using Minitab Statistical Software for main and interaction effects of two factors, onion varieties and seasons.

Results and Discussion

Season and variety interaction data in Table 2 revealed significantly lesser plant growth and leaf number in kharif (plant heigh 33.1 cm in CITH -1 and leaf number 6.3 in Bhima Red and CITH-1); whereas, the maximum plant height and leaf number were recorded in late kharif (plant height 60.5 cm and leaf number 12.5 in Bhima Super), followed by rabi season (plant height 61.5 cm in Arka Pragati and leaf number 11.5 in Sukhsagar). Seasonal effect (kharif, late kharif and rabi) on plant growth and leaf numbers, which is also influenced by the genotypic nature of varieties has been reported under Indian tropical conditions (Mohanty and Prusti, 2001; Naresh *et al.,* 2021). In kharif season, premature bolting was minimum (0.4%), whereas, maximum bolting was recorded in late kharif (4.6%), irrespective of varieties. However, significant varietal difference in bolting was also recorded with maximum in Brown Spanish (7.9%) and minimum in Bhima Super (0.4%) irrespective of the season. In late kharif, the maximum bolting was recorded in Brown Spanish (18.2%), Arka Pragati (8.3%), VL Piaz -3 (6.5%), CITH-1 (6.5%) and Bhima Dark Red (5.7%). Environment, nutrient management and genotypic interaction for expression of premature bolting in onion has been well reported (Shishido and Saito, 1975; Cramer, 2003; Khokhar, 2008; Kale *et al.,* 2024).

Photo-thermal period has been reported to be critical for favouring flower initiation and accordingly, prevalence of low temperature period (7-13^{0}C) at bulb formation stage (7-10 leaves stage) has been found to be responsible for premature bolting in the present study. Bolting incidence in late kharif onions under north eastern Indian conditions was also reported by Gogoi *et al.* (2023), where low temperature prevails during December to February. Varietal susceptibility or resistance response to bolting was also reported by Cramer (2003) and Gogoi *et al*. (2023). Neck

Table 2: Main and interaction effect of onion varieties and seasons on plant growth, bolters and neck thickness

	Plant height (cm)				Number of leaves/Plant				Bolter bulbs (%)*				Neck thickness (cm)			
Varieties	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**
Bhima Shakti	58.6	59.8	44.8	54.4	10.8	10.3	8.5	9.9	0.0(0.7)	2.0(1.6)	2.3(1.9)	1.4	0.83	0.87	0.67	0.79
Bhima Red	56.5	50.9	40.2	49.2	9.9	9.8	6.3	8.7	2.7(1.7)	3.5(1.9)	0.2(0.8)	2.1	1.30	1.23	1.13	1.22
Bhima Kiran	58.3	51.7	42.0	50.7	10.2	9.7	7.7	9.2	0.0(0.7)	5.3(2.5)	0.2(0.8)	1.8	0.83	0.90	0.77	0.83
Bhima Super	58.4	60.5	48.8	55.9	9.8	12.5	10.5	10.9	0.2(0.8)	0.8(1.1)	0.2(0.8)	0.4	1.00	1.07	1.00	1.02
Bhima Dark Red	46.1	55.1	42.2	47.8	8.8	10.4	7.7	9.0	4.0(2.1)	5.7(2.4)	0.5(0.8)	3.4	1.30	1.37	1.13	1.27
Bhima Shweta	54.5	53.7	40.6	49.6	11.3	10.7	8.0	10.0	0.8(1.1)	3.0(1.9)	0.5(0.8)	1.4	0.93	1.07	0.80	0.93
Pusa Red	56.5	56.1	42.8	51.8	9.4	9.5	8.0	9.0	0.7(0.9)	5.2(2.5)	0.0(0.7)	1.9	1.27	1.37	1.07	1.23
Arka Niketan	58.6	50.8	40.4	49.9	9.0	10.4	9.5	9.6	0.5(1.1)	5.2(2.5)	0.2(0.8)	2.0	1.25	1.35	1.22	1.27
Arka Kalyan	55.5	52.0	45.5	51.0	9.7	9.3	8.2	9.1	2.3(1.6)	2.2(1.6)	0.2(0.8)	1.6	1.07	1.10	1.00	1.06
Arka Pragati	61.5	60.4	50.1	57.3	10.7	10.0	9.8	10.2	4.5(2.2)	8.3(2.9)	0.2(0.8)	4.3	1.37	1.37	1.23	1.32
Arka Kirthiman	52.6	47.2	48.5	49.4	10.3	8.8	7.8	9.0	0.0(0.7)	5.0(2.4)	0.0(0.7)	1.7	0.90	0.87	0.83	0.87
Arka Lalima	57.5	59.3	45.2	54.0	11.0	10.3	8.8	10.0	1.7(1.4)	3.0(1.8)	0.5(08)	1.7	0.83	1.03	0.83	0.90
Agrifound Light Red	58.5	56.0	43.4	52.6	10.8	9.5	7.5	9.3	0.0(0.7)	3.2(1.9)	0.2(0.8)	1.1	1.02	1.07	1.02	1.03
Agrifound Dark Red	47.6	49.5	50.5	49.2	9.0	10.0	8.7	9.2	5.5(2.4)	1.7(1.5)	0.2(0.8)	2.4	1.33	1.33	1.22	1.29
Brown Spanish	38.5	37.6	33.2	36.4	7.2	7.2	6.8	7.1	5.5(2.4)	18.2(4.4)	0.0(0.7)	7.9	1.40	1.40	1.20	1.33
VLPiaz -3	35.5	40.3	35.1	37.0	7.0	8.2	7.5	7.6	4.2(2.1)	6.5(2.6)	0.2(0.8)	3.6	1.52	1.23	1.33	1.36
Sukhsagar	59.5	55.5	50.5	55.2	11.5	12.3	9.2	11.0	0.8(1.1)	1.8(1.5)	0.5(0.8)	1.1	0.80	1.03	0.70	0.84
Balwan	57.5	58.6	40.8	52.3	10.8	11.2	8.7	10.2	0.5(0.9)	2.3(1.8)	0.5(0.8)	1.1	1.00	1.10	0.90	1.00
CITH-1	37.4	39.8	33.1	36.8	7.5	7.1	6.3	7.0	1.8(1.4)	6.5(2.7)	0.2(0.8)	2.8	1.42	1.48	1.28	1.39
N-53	44.0	46.6	48.8	46.5	8.8	10.0	8.8	9.2	3.2(2.1)	2.0(1.6)	0.5(0.8)	1.9	0.97	0.97	0.87	0.93
Mean	52.7	52.1	43.3	49.4	9.7	9.9	8.2	9.3	1.9 (1.4)	4.6 (2.2)	0.4(1.0)	2.3	1.12	1.16	1.01	1.10
SE(m)	1.	Season:	0.80		1.	Season:	0.30		1.	Season:	0.02		1.	Season:	0.03	
	2.	Variety:	2.20		2.	Variety:	0.90		2.	Variety:	0.05		2.	Variety:	0.10	
	3.	Season x Variety:	3.80		3.	Season x Variety:	1.50		3.	Season x Variety:	1.0		3.	Season x Variety:	0.14	
CD(0.5)	1.	Season:	1.67		1.	Season:	0.66		1.	Season:	0.10		1.	Season:	0.06	
	2.	Variety:	4.30		2.	Variety:	1.70		2.	Variety:	0.15		2.	Variety:	0.17	
	3.	Season x Variety:	7.45		3.	Season x Variety:	2.93		3.	Season x Variety:	0.25		3.	Season x Variety:	0.30	

*Digits in parenthesis are transformed values

thickness (Table 2) ranged from 0.8 cm (Bhima Shakti, Bhima Kiran, and Sukhsagar) to 1.4 cm (VL Piaz-1 and CITH-1) irrespective of the season. However, neck thickness ranged from 1.0 cm (kharif) -1.12 cm (late kharif) in different seasons. Thicker neck was recorded in onions transplanted in September; however, neck thickness is also a varietal character which interacts with growing season (Gonzalez, 1997; Prasad and Maji, 2021).

Comparatively better bulb weight (Table 3) was recorded in late kharif (59.4g) and rabi (57.7 g) season onions irrespective of variety, however, var. Bhima Super (75.1 g) and Sukhsagar (74.5 g) produced the maximum bulb weight in late kharif, var. Bhima Shakti (75.1 g), Balwan (74.3 g), Arka Kirthiman (74.2 g), Bhima Shweta (73.7 g) and Bhima Kiran (73.4 g) produced the maximum bulb weight in rabi season. Bulb weight in kharif season under Tripura condition was poor ranging between 22.5 g (CITH-1) to 47.0 g (Bhima Kiran). Similarly, equatorial bulb diameter (Table 3) was higher in rabi (4.7 cm) and late kharif (4.6 cm), compared to kharif season (3.3 cm). The maximum bulb diameter was recorded in varieties, Bhima Shakti (5.8 cm), Bhima Red (5.8 cm), Arka Kirthiman (5.6 cm), Arka Lalima (5.5 cm), Sukhsagar (5.5 cm) and Balwan (5.5 cm) in rabi season, whereas, Bhima Super (5.4 cm), Sukhsagar (5.3 cm), Bhima Shakti (5.2 cm), Agrifound Light Red (5.1 g), Arka Lalima (5.1 g) and Arka Niketan (5.0 g) and Arka Kirthiman (5.0 g) produced higher bulb diameter in late kharif. Influence of transplanting time on bulb weight was also reported by Sharma *et al.* (2009), Dhar *et al.* (2019) and Naresh *et al.* (2021). Similarly, bulb weight and diameter were also higher in September transplanted onions in comparison to August under West Bengal conditions (Dhar *et al.,* 2019), which is also a varietal character (Halder *et al.,* 2009).

Ready to harvest bulb maturity (Table 3) was observed to be highly influenced by the growing season, in rabi 128.0 days and in late kharif 125.0 days to harvest after transplanting was recorded irrespective of varieties, whereas in kharif, DTH after transplanting was 115.0 days. Though in rabi season, Arka Pragati (136.0 days), Arka Lalima (135.0 days), Arka Niketan (134.0 days) and Arka Kirthiman (134.0 days) took comparatively higher DTH, whereas, varieties Sukhsagar (122.0 days), Bhima Shweta (123.0 days), Bhima Red (125.0 days), and Bhima Shakti (126.0 days) took comparatively lesser days. In late kharif,DTH after transplanting was in the range of 120.0 (Bhima Red and N-53) to 136.0 days (Arka Lalima), whereas, other better performing varieties took 122.0 days (Bhima Shweta), 122.0 days (Balwan), 123.0 days (Bhima Shakti), 125.0 days (Sukhsagar), 126.0 days (Bhima Super), 126.0 days (Arka Kalyan), 126.0 days (Agrifound Light Red), 128.0 days (Arka Niketan), 129.0 days (Arka Kirthiman) and 131.0 day (Arka Pragati). In kharif season,DTH after transplanting was 106.0 days (CITH-1) to 120.7 days (Bhima Shakti). Gupta *et al.* (2017, 2021) evaluated a wide range of onion genotypes and also reported genotypic and season interaction on bulb maturity. TSS (Table 3) of all the varieties ranged from 9.6 ^{0}B to 13.2 ^{0}B in both the seasons, rabi and late kharif. In kharif season, TSS was 8.0 to 12.1 ^{0}B. Naresh *et al.* (2021) and Gupta *et al.* (2017, 2021) also reported similar range of TSS in various onion genotypes. TSS content in onion is positively correlated with storage suitability and dehydrated recovery (Malik *et al.,* 2024).

In rabi season climatic conditions of Tripura, total yield and marketable yield (Table 4) were maximum in varieties Bhima Shakti (302.1 and 289.2 q ha^{-1}), Bhima Kiran (297.9 and 288.1 q ha^{-1}), Bhima Super (293.1 and 284.1 q ha^{-1}), Arka Kirthiman (290.5 and 275.8 q ha^{-1}), Bhima Shweta (287.8 and 275.9 q ha^{-1}), Sukhsagar (285.9 and 276.2 q ha^{-1}), Balwan (285.2 and 276.2 q ha^{-1}), Agrifound Ligh Red (284.1 and 274.7 q ha^{-1}) and Arka Lalima (275.9 and 267.3 q ha^{-1}). In late kharif, the total yield and marketable yield was maximumin in varieties Bhima Super (298.6 and 292.6 q ha^{-1}), Sukhsagar (298.2 and 291.9 q ha^{-1}), Arka Lalima (286.6 and 279.8 q ha^{-1}), Agrifound Light Red (285.3 and 277.7 q ha^{-1}), Arka Kalyan (282.9 and 278.7 q ha^{-1}), Balwan (282.6 and 274.5 q ha^{-1}), Bhima Shweta (279.9 and 273.1 q ha^{-1}), Bhima Shakti (277.9 and 270.7 q ha^{-1}), Arka Pragati (275.9 and 263.7 q ha^{-1}) and Arka Kirthiman (272.9 and 269.8 q ha^{-1}).

Whereas in kharif season, the range of total yield and marketable yield was only 18.2 (CITH-1) to 120.8 q ha^{-1} (N-53) and 6.5 (CITH-1) to 107.5 q ha^{-1} (Sukhsagar), respectively. Perusal of marketable yield of these onion varieties revealed that under Tripura condition, the late kharif (222.5 q ha^{-1}) and rabi season (212.9 q ha^{-1}) were suitable for onion growing. The poor yield performance of all the varieties in kharif season is due to the prevailing climatic condition characterized by high monsoon rainfall and humidity (Table 1) during May to October, irrespective of variety. Though, few varieties, Sukhsagar (107.5 q ha^{-1}), N-35 (102.7 q ha^{-1}) and Agrifound Dark Red (94.5 q ha^{-1}) gave comparatively good marketable yield. Low productivity (80.0-100.0 q ha^{-1}) of kharif season grown onion has been well reported by Singh *et al.* (2017) due to rainfall and cloudy weather, which favour diseases like anthracnose and bulb rotting. Apart from suitable weather conditions in the North-eastern Indian state Tripura during late kharif and rabi, varietal sensitivity to day length and temperature has been the key factor for better yield in such zone making the zone suitable for short day onions.

The day length in Tripura ranges between 10-13 hr during December and January, 11 hr in February, March, October and November, 12 hr in April and September and 13 hr May, June, July and August. This may be the reason for very low yield of long day varieties namely Brown Spanish, CITH-1 and VL Piaz-3. Day length and temperature sensitivity for suitability of onion cultivation has been well reported and reviewed by Ud-deen (2008), Lancaster *et al.* (1996), Karim and Ibrahim (2013) and Bachie *et al.* (2019). In case of late kharif season onion, which is transplanted in September-October and harvested in January-February, prevailing low temperature and day length during November-January favour good bulb initiation and development, followed by warm days and cooler nights that favoured bulb maturity, although neck thickness was found to be slightly higher in this season. Similarly, in rabi season cooler temperature and short-day conditions favoured plant growth followed by bulb

Table 3: Main and interaction effect of onion varieties and seasons on bulb weight, bulb diameter, days to harvest and TSS

	Bulb weight (g)				Equatorial bulb diameter (cm)				Day to harvesting (DTH)				TSS(°B)			
Varieties	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**
Bhima Shakti	75.1	70.7	40.5	62.1	5.8	5.2	3.8	4.9	126	123	121	123	13.1	12.7	10.8	12.20
Bhima Red	55.7	56.8	40.5	51.0	4.7	4.6	3.6	4.3	125	120	115	120	11.4	11.8	10.5	11.23
Bhima Kiran	73.4	57.4	47.0	59.3	5.8	4.2	3.2	4.4	127	126	116	123	12.7	11.9	10.2	11.60
Bhima Super	72.8	75.1	42.2	63.4	5.3	5.4	3.7	4.8	128	126	111	121	12.6	12.7	10.1	11.80
Bhima Dark Red	40.0	45.6	38.8	41.5	3.5	3.8	3.4	3.6	127	126	118	124	9.6	10.6	9.5	9.90
Bhima Shweta	73.7	66.0	38.8	59.5	5.3	4.7	3.0	4.3	123	122	116	120	12.5	12.8	12.2	12.50
Pusa Red	47.4	53.3	41.1	47.3	4.6	4.2	3.2	4.0	129	131	115	125	11.2	11.9	10.2	11.10
Arka Niketan	58.2	65.5	38.5	54.1	5.0	5.0	3.2	4.4	134	128	113	125	11.8	12.4	9.3	11.17
Arka Kalyan	54.2	70.2	38.2	54.2	5.2	5.3	3.5	4.7	129	126	115	123	12.1	10.9	10.9	11.30
Arka Pragati	65.9	68.7	41.8	58.8	5.1	4.8	3.7	4.5	136	131	118	128	11.7	11.5	11.2	11.47
Arka Kirthiman	74.2	69.7	35.6	59.8	5.6	5.0	3.2	4.6	134	129	116	126	11.5	12.6	11.6	11.90
Arka Lalima	72.1	72.5	37.5	60.7	5.5	5.1	3.4	4.7	135	136	113	128	12.4	12.5	10.1	11.67
Agrifound Light Red	70.3	71.7	36.8	59.6	5.3	5.1	3.0	4.5	130	126	115	124	12.6	12.2	10.2	11.67
Agrifound Dark Red	41.2	53.7	38.5	44.5	4.0	5.0	3.5	4.2	128	125	120	124	10	11.8	10.3	10.70
Brown Spanish	33.4	31.8	29.2	31.5	3.1	3.1	2.3	2.8	126	122	108	119	9.6	8.9	8	8.83
VLPiaz -3	34.5	35.6	29.1	33.1	3.4	3.7	2.8	3.3	131	124	108	121	9.6	9.7	8.8	9.37
Sukhsagar	70.4	74.5	42.6	62.5	5.5	5.3	4.5	5.1	122	125	120	122	12.7	13.2	12.1	12.67
Balwan	74.3	70.0	38.5	60.9	5.5	4.8	3.0	4.4	127	122	115	121	12.2	11.6	10.1	11.30
CITH-1	25.3	24.5	22.5	24.1	3.1	2.8	2.4	2.8	125	121	106	117	9.1	8.4	9.2	8.90
N-53	42.1	55.3	40.5	46.0	3.4	4.3	4.2	4.0	128	120	117	122	9.6	11.1	11.9	10.87
Mean	57.7	59.4	37.9	51.7	4.7	4.6	3.3	4.2	128	125	115	123	11.40	11.56	10.36	11.11
SE(m)	1.	Season:	0.70		1.	Season:	0.10		1.	Season:	0.53		1.	Season:	0.17	
	2.	Variety:	1.8		2.	Variety:	0.20		2.	Variety:	1.37		2.	Variety:	0.45	
	3.	Season x Variety:	3.1		3.	Season x Variety:	0.30		3.	Season x Variety:	2.38		3.	Season x Variety:	0.78	
CD(0.05)	1.	Season:	1.35		1.	Season:	0.13		1.	Season:	1.05		1.	Season:	0.34	
	2.	Variety:	3.49		2.	Variety:	0.32		2.	Variety:	2.72		2.	Variety:	0.89	
	3.	Season x Variety:	6.05		3.	Season x Variety:	0.56		3.	Season x Variety:	4.71		3.	Season x Variety:	1.54	

Table 4: Main and interaction effect of onion varieties and seasons on yield, disease incidence and thrips damage

	Total yield(Q ha^{-1})				Marketable yield (Q ha^{-1})				Purple blotch (PDI)				Stem phylium blight (PDI)				Thrips damage (Score)			
Varieties	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**
Bhima Shakti	302.1	277.9	77.5	219.2	289.2	270.7	54.5	204.8	11.3	12.2	22.8	15.4	18.5	18.5	9.8	15.6	1.2	0.9	0.4	0.8
Bhima Red	243.9	258.0	90.2	197.4	227.6	242.5	81.5	183.9	9.1	15.7	27.5	17.4	23.5	22.8	11.7	19.4	1.5	1.2	0.6	1.1
Bhima Kiran	297.9	253.6	71.0	207.5	288.1	241.5	56.3	195.3	12.1	15.6	28.2	18.6	29.1	26.8	11.6	22.5	1.3	0.9	0.5	0.9
Bhima Super	293.1	298.6	100.7	230.8	284.1	292.6	88.5	221.7	10.5	9.5	23.5	14.5	20.8	11.2	9.1	13.7	1.5	1.3	0.4	1.0
Bhima Dark Red	184.5	214.2	102.8	167.2	173.4	203.5	80.7	152.5	12.3	15.0	31.4	19.6	24.6	28.4	12.5	21.8	2.3	1.2	0.1	1.2
Bhima Shweta	287.8	279.9	53.8	207.2	275.9	273.1	32.4	193.8	13.4	14.5	24.5	17.4	22.1	23.9	12.5	19.5	1.9	1.3	0.2	1.1
Pusa Red	227.5	244.0	67.5	179.7	213.2	235.6	50.5	166.4	11.5	18.3	27.5	19.1	27.6	29.7	14.8	24.0	2.3	1.8	0.4	1.5
Arka Niketan	261.1	260.8	64.3	195.4	238.3	251.7	47.3	179.1	12.1	16.5	27.2	18.6	31.4	26.8	11.4	23.2	1.7	1.6	0.3	1.2
Arka Kalyan	225.2	282.9	95.6	201.2	204.1	278.7	75.4	186.1	11.4	17.1	27.6	18.7	32.1	20.6	10.8	21.2	2.0	1.3	0.1	1.1
Arka Pragati	269.8	275.9	98.8	214.8	244.7	263.7	81.7	196.7	9.7	17.2	31.5	19.5	27.0	23.3	12.3	20.9	1.5	0.8	0.2	0.8
Arka Kirthiman	290.5	272.9	99.5	221.0	275.8	269.8	84.3	210.0	10.2	16.7	29.9	18.9	32.7	28.5	11.4	24.2	1.6	1.1	0.3	1.0
Arka Lalima	275.9	286.6	60.7	207.7	267.3	279.8	38.5	195.2	8.8	16.5	25.3	16.9	34.9	21.3	15.4	23.9	1.9	1.3	0.1	1.1
Agrifound Light Red	284.1	285.3	67.1	212.2	274.7	277.7	43.5	198.6	12.4	14.3	30.2	18.9	26.4	23.1	13.1	20.9	1.8	0.8	0.5	1.0
Agrifound Dark Red	192.6	234.5	104.7	177.3	179.5	221.0	94.5	165.0	12.6	15.0	27.6	18.4	27.9	27.2	13.8	23.0	2.5	1.4	0.4	1.4
Brown Spanish	100.3	88.8	28.1	72.4	28.9	10.8	7.4	15.7	16.5	19.6	26.5	20.8	36.4	27.2	10.0	24.5	2.4	1.1	0.3	1.3
VLPiaz -3	125.7	133.1	27.1	95.3	57.6	57.2	9.5	41.4	15.1	21.4	30.9	22.4	39.0	22.2	14.7	25.3	2.5	1.4	0.4	1.4
Sukhsagar	285.9	298.2	118.2	234.1	276.3	291.9	107.5	225.2	8.2	9.2	20.5	12.6	16.4	17.9	8.8	14.4	2.2	0.9	0.3	1.1
Balwan	285.9	282.6	79.2	215.9	276.2	274.5	58.7	203.1	10.3	10.1	25.6	15.3	17.1	16.2	14.7	16.0	1.5	1.0	0.3	0.9
CITH-1	105.2	97.2	18.2	73.5	21.8	12.1	6.5	13.5	15.0	24.8	29.5	23.1	34.1	34.2	16.1	28.1	1.8	1.3	0.4	1.2
N-53	173.7	208.9	120.8	167.8	161.9	200.9	102.7	155.2	10.5	15.3	20.5	15.4	31.6	28.1	11.7	23.8	2.2	1.1	0.3	1.2
Mean	235.6	241.7	77.3	184.9	212.9	222.5	60.1	165.2	11.6	15.7	26.9	18.1	27.7	23.9	12.3	21.3	1.9	1.2	0.3	1.1
SE(m)	1.	Season:	1.13		1.	Season:	0.97		1.	Season:	0.31		1.	Season:	0.32		1.	Season:	0.03	
	2.	Variety:	2.91		2.	Variety:	2.49		2.	Variety:	0.80		2.	Variety:	0.82		2.	Variety:	0.08	
	3.	Season x Variety:	5.03		3.	Season x Variety:	4.32		3.	Season x Variety:	1.40		3.	Season x Variety:	1.42		3.	Season x Variety:	0.14	
CD(0.05)	1.	Season:	2.23		1.	Season:	1.91		1.	Season:	0.87		1.	Season:	0.90		1.	Season:	0.06	
	2.	Variety:	5.75		2.	Variety:	4.94		2.	Variety:	2.30		2.	Variety:	2.31		2.	Variety:	0.16	
	3.	Season x Variety:	9.97		3.	Season x Variety:	8.56		3.	Season x Variety:	3.90		3.	Season x Variety:	4.00		3.	Season x Variety:	0.28	

Table 5: Main and interaction effect of onion varieties and seasons on storage losses

	1 Month after harvest				2 Month after harvest				3 Month after harvest				4 Month after harvest			
Varieties	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**	**Rabi**	**Late Kharif**	**Kharif**	**Mean**
Bhima Shakti	4.9	3.3	15.1	7.8	9.8	7.5	32.9	16.7	22.8	13.2	41.5	25.8	38.9	31.8	91.5	54.1
Bhima Red	9.2	5.7	16.5	10.4	18.1	13.1	40.5	23.9	38.2	16.5	54.5	36.4	54.0	46.1	98.0	66.0
Bhima Kiran	6.7	4.1	22.2	11.0	8.8	6.8	37.0	17.6	23.9	15.2	56.1	31.7	46.5	44.1	88.7	59.8
Bhima Super	5.8	4.0	12.4	7.4	11.8	8.2	27.2	15.7	24.4	10.8	41.1	25.5	43.8	38.2	94.5	58.8
Bhima Dark Red	18.3	10.7	20.8	16.6	26.4	16.5	38.8	27.2	40.2	23.1	54.4	39.2	67.5	51.6	96.2	71.7
Bhima Shweta	7.7	5.2	15.2	9.3	11.7	9.6	26.8	16.0	25.2	11.5	44.9	27.2	41.7	38.1	89.8	56.5
Pusa Red	15.5	10.0	19.2	14.9	24.5	20.5	35.8	27.0	42.2	30.2	55.9	42.7	64.5	54.2	92.9	70.5
Arka Niketan	14.2	4.2	23.5	14.0	23.5	10.3	38.2	24.0	37.1	32.4	64.2	44.6	67.2	52.1	93.2	70.8
Arka Kalyan	16.3	6.8	23.5	15.5	21.5	12.1	30.8	21.5	39.8	26.4	48.2	38.2	65.3	54.2	91.8	70.4
Arka Pragati	17.8	13.2	26.3	19.1	22.9	17.8	38.5	26.4	43.2	34.2	57.4	44.9	73.1	67.1	96.2	78.8
Arka Kirthiman	4.8	4.0	22.7	10.5	12.5	8.4	35.8	18.9	28.1	18.2	44.4	30.2	48.5	39.5	91.8	59.9
Arka Lalima	6.2	5.3	20.8	10.8	9.5	7.3	37.5	18.1	26.1	20.6	46.5	31.1	50.3	41.5	94.5	62.1
Agrifound Light Red	7.8	5.3	24.5	12.6	10.8	8.2	42.4	20.5	29.2	18.5	52.2	33.3	55.7	50.6	91.5	65.9
Agrifound Dark Red	10.8	5.0	22.4	12.8	18.5	10.0	38.8	22.4	37.8	28.2	51.3	39.1	71.1	67.2	97.8	78.7
Brown Spanish	24.4	21.1	47.2	30.9	46.8	36.8	70.5	51.4	53.8	48.8	90.0	64.2	73.2	71.5	99.8	81.5
VLPiaz -3	20.2	19.4	45.1	28.2	32.9	27.8	66.1	42.3	45.8	38.5	82.1	55.5	82.3	76.8	93.2	84.1
Sukhsagar	5.8	4.7	18.5	9.7	11.1	9.3	35.5	18.7	16.2	14.5	42.5	24.4	40.1	37.4	88.5	55.4
Balwan	4.5	3.0	22.9	10.1	9.3	6.3	40.8	18.8	20.2	14.4	56.5	30.4	41.8	36.2	94.7	57.6
CITH-1	34.8	28.9	37.5	33.7	52.1	45.2	57.1	51.5	57.5	52.4	77.6	62.5	85.5	75.2	93.7	84.8
N-53	10.1	9.7	15.8	11.9	17.8	14.9	23.5	18.7	25.5	22.5	37.8	28.6	45.3	41.5	95.5	60.8
Mean	12.3	8.7	23.6	14.9	20.0	14.8	39.7	24.9	33.9	24.5	55.0	37.8	57.8	50.7	93.7	67.4
SE(m)	1.	Season:	0.64		1.	Season:	0.72		1.	Season:	0.81		1.	Season:	0.80	
	2.	Variety:	1.67		2.	Variety:	1.86		2.	Variety:	2.10		2.	Variety:	2.10	
	3.	Season x Variety:	2.88		3.	Season x Variety:	3.23		3.	Season x Variety:	3.61		3.	Season x Variety:	3.60	
CD(0.05)	1.	Season:	1.28		1.	Season:	1.43		1.	Season:	1.60		1.	Season:	1.60	
	2.	Variety:	3.30		2.	Variety:	3.70		2.	Variety:	4.10		2.	Variety:	4.11	
	3.	Season x Variety:	5.45		3.	Season x Variety:	6.10		3.	Season x Variety:	6.83		3.	Season x Variety:	6.80	

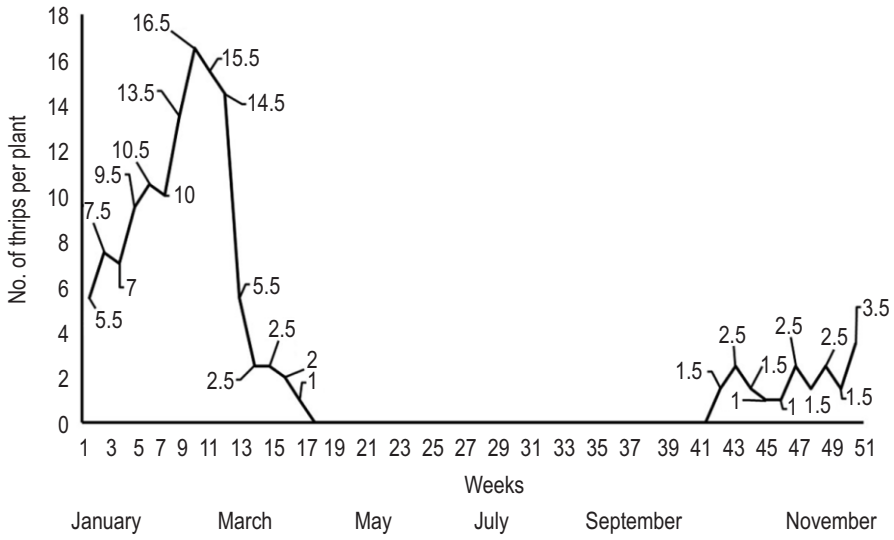

Fig. 1: Seasonal thrips dynamics (No. of thrips per plant) on onion crop under agro-climatic conditions of Tripura.

initiation and congenial temperature in January to March favouring bulb development and maturity.

This is crucial for exploring the potential of onion cultivation in non-conventional areas like north eastern states of India. Variations in days to bulb maturity from transplanting and yield among different onion varieties due to genotypic nature of onion varieties has been well reported by Gupta *et al.* (2017) and Naresh *et al.* (2021). Which can further be discussed on the basis of the reports by Brewster (1977), Singh *et al.* (2017), Ansari (2007) and Kiani and Mashayekhi (2023) that onion bulb initiation and maturity duration is regulated by genetics and origin of the variety, growing season, day length and temperature regimes during the plant growth to bulb developmental stages. On the basis of this interaction effect, onion varieties have been classified as short day rabi, short day late kharif and short day kharif onion suitable for subtropical and tropical agro-climatic Indian conditions, long day onions for temperate zones and day neutral varieties (Swarup, 2012 and Narayan *et al.*, 2022, Kiani and Mashayekhi, 2023). Disease incidence in terms of percent disease index (PDI) in Table 4, revealed that occurrence of purple blotch was higher in kharif season (26.9%) and *Stemphylium* blight in rabi (27.7%) and late kharif season (23.9%), irrespective of variety. The range of PDI of purple blotch in kharif was 20.5% (Sukhsagar and N-53) to 31.5% (Arka Pragati) whereas in rabi season, percent disease index of *Stemphylium* blight disease ranged from 16.4% (Sukhsagar) to 39.0% (VL Piaz-3), and in late kharif 11.2% (Bhima Super) to 34.2% (CITH-1), respectively. It can be inferred that incidence of these two diseases was recorded in all the varieties under Tripura climatic conditions, though purple blotch was significantly higher in kharif and *Stemphylium* blight in rabi and late kharif. Thrips population per plant was maximum during January to March (5.5-16.5 thrips per plant) and minimum in April, October, November and December (1.0-3.5 thrips per plant), whereas, from mid-April to 3rd week of October thrips infestation was almost nil (Fig. 1). Thrips damage score ranged from 1.2 (Bhima Shakti) to 2.5 (Agrifound Dark Red and VL Piaz-3) in rabi, and 0.9 (Bhima Shakti) to 1.8 (Pusa Red) in late kharif. Whereas, thrips population was significantly low in kharif (0.3 thrips per plant) and thrips appearance could only be observed from October. In the present study, thrip damage was more during rabi season under Tripura condition. Similar thrips dynamics was also reported by Merene (2015) and Senjalia *et al.* (2024), where thrips population was high during December to March and sharp decline was recorded in population during rainy season.In rabi season also, high infestation of thrips aggravates incidence of Stemphylium blight (Singh *et al.,* 2017).

Storage of onion was critical under Tripura conditions as evident in Table 5, in rabi season, combined storage loss due to weight loss, sprouting and rotting ranged between 4.5% (Balwan) to 34.8% (CITH-1) after one month of harvest, which gradually increased to 8.8% (Bhima Kiran) to 52.1% (CITH-1) after second month of harvest, 16.2% (Sukhsagar) to 57.5% (CITH-1) after third month of harvest and reached 38.9% (Bhima Shakti) to 85.5% (CITH-1) after fourth month of harvest. Similarly in late kharif, loss ranged between 3.0 (Balwan) to 28.9% (CITH-1) after one month of harvest, which gradually increased to 6.3% (Balwan) to 45.2% (CITH-1) after second month of harvest, 10.8 (Bhima Super) to 52.4% (CITH-1) after third month of harvest and reached 31.8% (Bhima Shakti) to 76.8% (VL Piaz-3) after fourth month of harvest. Comparatively more storage loss was recorded in kharif season with 23.6%, 39.7%, 55.0% and 93.7% respectively after 1st, 2nd, 3rd and 4th month of harvest, irrespective of variety. Variety, post-harvest management and storage length have significant effect on the severity of storage loss which increases with storage time, though degree of varietal susceptibility to storage loss is also important (Singh *et al.,* 2017; Tripathi and Lawande, 2019; Rani *et al.,* 2024).

High storage loss in kharif season onion was also reported by Tripathi and Lawande (2019) compared to late kharif and rabi onions. Mahajan *et al.* (2017) reported 40-50% post-harvest storage loss in India. In the present study, the neck thickness was recorded to be higher in many varieties under agroclimatic growing conditions of Tripura and it has been reported that bulbs with thicker neck have more rooting tendency (Mahajan *et al.,* 2017; Tripathi and Lawande, 2019). High humidity (>75%) coupled with high temperature favour rooting in stored bulbs and incidence of diseases (Tripathi and Lawande, 2019; Ko *et al.,* 2002). Prevailing high humidity and high temperature during storage period under agroclimatic conditions Tripura (Table 1) is the prime reason for higher storage loss especially after 3rd month of harvest, however, in rabi and late kharif season varieties Bhima Shakti (38.9% and 31.8%), Sukhsagar (40.1% and 36.2%), Balwan (41.8% and 36.2%), Bhima Shweta (41.7%and 38.1%y), Bhima Super (43.8% and 38.2%), N-53 (45.3% and 41.5%), Bhima Kiran (46.5% and 44.1%) and Arka Kirthiman (48.5% and 39.5%) gave comparatively lesser storage loss. Better pre-harvest management of the crop in field, harvest at the right bulb maturity stage, followed by proper post-harvest management including curing, sorting-grading and using recommended onion storage method may minimize the storage loss (Mahajan *et al.,* 2017).

It may be concluded that under agroclimatic conditions of Tripura, late kharif and rabi seasons are suitable for onion cultivation and short-day varieties, Bhima Shakti, Bhima Kiran, and Bhima Super recorded higher marketable yield in rabi; and Bhima Super and Sukhsagar recorded higher yield in late kharif. High humidity and high temperature were the reasons for higher degree of storage losses. Thrips incidence was higher during winter season due to dry weather and less rainfall. Appropriate disease and pest management practices should be followed for diseases (Mishra and Singh, 2017) and thrips (Karuppaiah *et al.,* 2023) during late kharif and rabi. To minimize the storage loss, better pre-harvest management of onion crop with recommended dose of manures and fertilizer, timely irrigation and harvesting at right stage (50-60% neck fall), followed by proper curing, sorting grading and recommended storage method should be followed.

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