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Assessment of the phenology, silage yield and quality of spring maize (*Zea mays*) in different crop rotations

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ABSTRACT

In north-western India, maize (*Zea mays* L.) is mainly grown in spring season for silage making. Sowing time of spring maize in different rice (*Oryza sativa* L.) and maize-based crop rotations varies, and it affects the yield and quality of silage. The present experiment was conducted during 2020–21 and 2021–22 at Punjab Agricultural University, Ludhiana, Punjab with four crop rotations i.e. maize–toria (*Brassica rapa* ssp. *oleifera*)-spring maize (silage); rice (*Oryza sativa* L.)–barley (*Hordeum vulgare* L.) (silage)–spring maize (silage); rice–wheat (*Triticum aestivum* L.) (silage)–spring maize (silage) and maize–rapeseed (*Brassica napus* L.)–spring maize (silage) to evaluate the spring maize silage yield and quality in randomised complete block design (RCBD) with three replications. Sowing of spring maize was undertaken from 8th February to 19th March in different crop rotations and harvested at milk stage for silage making. Spring maize grown in maize–toria–spring maize took greater number of days for reaching all phenological stages. During 2021, heat use efficiency (HUE) was higher in maize–toria–spring maize, was similar with rice–barley–spring maize and rice–wheat–spring maize. However, during 2022, maize–toria–spring maize recorded higher HUE and better silage quality than all other treatments. Higher silage yield of spring maize was recorded in maize–toria–spring maize, was similar to rice–barley–spring maize but higher than rice–wheat–spring maize and maize–rapeseed–spring maize rotations during both years. The delayed sowing altered the phenological development of maize, resulted in reduced silage yield and quality. Further, heat wave in northern India during March 2022 resulted in 24–28% reduction in silage yield in four crop rotations during 2022 than 2021. Results indicated that maize–toria–spring maize and rice–barley–spring maize rotations are most suitable for achieving high-quality spring maize silage production.

Keywords: Heat stress, Maize-based crop rotations, Phenology, Rice-based crop rotations, Sowing time, Silage

Round the year supply of quality fodder is very important for the success of dairy farming. The seasonal fluctuation in availability of quality fodder affects the production potential of dairy animals and there are certain period of time in year when there is acute shortage of green fodder. Under present situation, silage making is a technology which sustain the uniform supply of quality fodder round the year (Brar *et al.* 2024). Maize (*Zea mays* L.) is preferred for silage making by dairy farmers due to its high nutritive value, more yield (580–795 q/ha), and it also contains higher water-soluble carbohydrates fermented to lactic acid during ensiling (Darby and Lauer 2002, Brar *et al.* 2021, Singh *et al.* 2022, Brar *et al.* 2024).

In subtropical conditions of north-west India, spring maize is mainly grown for silage making in different rice- and maize-based rotations (Brar *et al.* 2023). The sowing time of spring maize varies with the crop rotation adopted by the farmers, as it depends upon the harvesting time of previous winter crop in the rotation. This variation in sowing time of maize forces the crop to grow under different weather conditions. For example, February-sown crop will experience milder temperature while March-sown crop will be growing in higher temperature regimes from the sowing to harvest. Different growing conditions because of varying sowing times lead to variation in crop growth and phenology, ultimately affecting spring maize silage yield and quality. Keeping these facts in view, different crop rotations were evaluated in this study to work out the best crop rotation for cultivation of spring maize and to maximise the production of quality spring maize silage. It was hypothesised that time of sowing of spring maize in different crop rotations may affect the yield and quality of spring maize silage.

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MATERIALS AND METHODS

Location and weather during the crop season:

The present experiment was conducted during 2020–21 and 2021–22 at Punjab Agricultural University, Ludhiana (30.9°N, 75.81°E), Punjab. The soil of experimental field was loamy sand with normal *p*H (7.3), electrical conductivity of 0.17 dS/m, medium in organic carbon (0.45%) and available nitrogen (229 kg/ha), high in available phosphorus (39.3 kg/ha) and available potash (150 kg/ha). The meteorological parameters, mean air temperature and rainfall for spring season from standard meteorological week (SMW) 5–26 are presented in Fig. 1. Mean air temperature ranged between 13.5–32.1°C and 12.5–33.6°C, and a total of 157.9 mm and 140.5 mm rainfall was received during spring (cropping) season of 2021 and 2022, respectively.

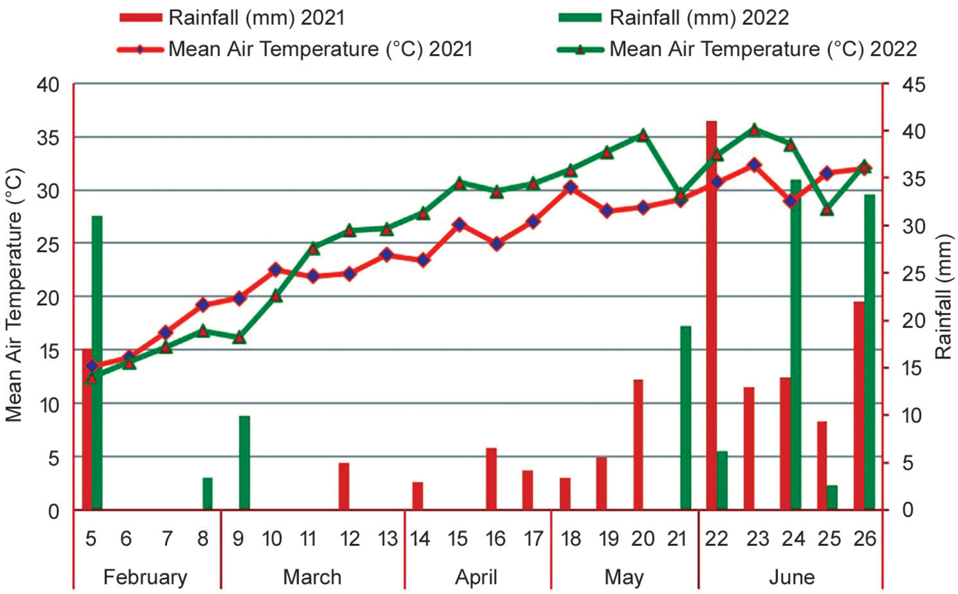

Fig. 1 Meteorological data comprising mean air temperature and rainfall during the experimental period (Standard Meteorological weeks from 5–26; February to June months).

Experimental detail: A total of four crop rotations were evaluated in randomised complete block design (RCBD) with three replications. Spring maize (spring season from February-June) was grown for silage production in four rotations, out of which two rotations were maize-based and two were rice-based (Supplementary Fig. 1). The four crop rotations were, maize (in summer season from June-September)–toria–spring maize (for silage) (m-t-spm); rice-barley (for silage)–spring maize (for silage) (r–b–spm); rice-wheat (for silage)–spring maize (for silage) (r–w–spm); and maize-rapeseed-spring maize (for silage) (m–rs–spm). In maize-based rotations i.e. m-t-spm and m–rs–spm, maize (cv. P3396) was sown during 3rd week of June and was harvested manually in last week of September during both years of study (Supplementary Fig. 1). During winter season, toria (cv. TL17) was sown in 1st week of October and was harvested manually in end of January. Rapeseed (cv. GSC7) was sown during 2nd week of October and was harvested manually during 2nd week of March (Supplementary Fig. 1). In rice-based rotations i.e. r–b–spm and r–w–spm, 25 days old rice nursery was manual transplanted in puddled field during 4th week of June and harvested manually in first week of October. Wheat (cv. PBW725) and barley (cv. DWRB123) were sown in last week of October. Barley was harvested at milk stage for silage making in fourth week of February and wheat was also harvested for silage making at milk stage in first week of March. For sowing of spring maize (cv. PMH10) in four crop rotations, after harvest of winter crops, seed bed was prepared by ploughing the field twice with disc harrow and then cultivated with tine cultivator twice followed by planking. In m–t–spm rotation, spring maize was sown on 9th February during 2021 and on 8th February during 2022, in r–b–spm rotation, it was sown on 26th February and 25th February, in r–w–spm rotation, it was sown on 8th March and in m–rs–spm cropping rotation, it was sown on 19th March and on 17th March during year 2021 and 2022, respectively (Supplementary Fig. 1). For sowing of spring maize, seed was dibbled on the southern side of 0.60 m apart east-west ridges keeping plant to plant distance of 0.20 m. In all crops, cultivation practices were followed as per recommendations of Punjab Agricultural University, Ludhiana, Punjab. In four crop rotations, spring maize was harvested at milk stage (2.5 milk line score) for silage making. For silage making, green fodder of spring maize from each plot was chopped and stored separately in low density polypropylene bags with packing density of 700 kg/m^3 for 45 days (Huang *et al.* 2021).

Crop data of spring maize: Observations were recorded with respect to days taken by spring maize to reach at different phenological stages (emergence, 50% tasseling, 50% silking and milk stage), yield attributing characters, green fodder and silage yield. For calculation of green fodder yield, harvested fresh fodder from net plot area was weighed and expressed as t/ha. Silage yield was calculated from the green fodder yield by considering the 18% loss in green fodder during the process of silage making (Borreani *et al.* 2018).

Computation of agroclimatic indices: Different agroclimatic indices mentioned below were calculated as per Nuttonson (1955). Growing degree days (GDD) were calculated from daily maximum and minimum temperature recorded during the spring maize cropping season with following formula, and cumulative GDD was calculated:

$$\text{GDD (°C day)} = \frac{(T_{max} + T_{min})}{2} - T_b$$

Where T_{max}, Daily maximum temperature (°C); T_{min}, Daily minimum temperature (°C); T_b, Base temperature (10°C).

Heliothermal units (HTU) were calculated by multiplying GDD with the actual bright sunshine hours received during the cropping season of spring maize:

$$\text{HTU (°C days hours)} = \text{GDD} \times \text{Actual bright sunshine hours}$$

Photothermal units (PTU) were calculated by multiplying GDD with the day length during the cropping season of spring maize:

$$\text{PTU (°C days hours)} = \text{GDD} \times \text{Day length}$$

Heat use efficiency (HUE) calculated by dividing dry matter yield (fodder) with the accumulated GDD acquired during the cropping season of spring maize:

$$\text{HUE (kg/ ha/°C day)} = \frac{\text{DMY}}{\text{AGDD}}$$

Where DMY, Dry matter yield (kg/ha); AGDD, Accumulated growing degree days (°C days) i.e. GDD acquired by crop during life cycle.

Heliothermal use efficiency (HTUE) was calculated by dividing dry matter yield (fodder) with the accumulated HTU acquired during the cropping season of spring maize:

$$\text{HTUE (kg/ha/°C days h)} = \frac{\text{DMY}}{\text{AHTU}}$$

Where AHTU, Accumulated helio thermal units (°C day hour).

Photothermal use efficiency (PTUE) was calculated by dividing dry matter yield (fodder) with the accumulated PTU acquired during the cropping season of spring maize:

$$\text{PTUE (kg/ha/°C days h)} = \frac{\text{DMY}}{\text{APTU}}$$

Where APTU, Accumulated photo thermal units (°C day hour).

Quality analysis of silage of spring maize: Silage samples were analysed for their nutritive value and fermentation characteristics at Ruminant Nutrition Lab, Department of Animal Nutrition, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab. Representative samples were taken separately from three replications of each treatment to determine *p*H, lactic acid (Barker and Summerson 1941), ammonical-N content, dry matter (DM), crude protein (CP), ether extract (EE) (AOAC 2007), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) (Robertson and Van Soest 1981).

Statistical analysis: The data was analysed by following randomised complete block design (RCBD) design using IBM SPSS Statistics 22. Crop rotations and years were taken as fixed variable and replications were considered as random variable for performing ANOVA. The significance of differences of treatment means of response variables such as phenological observations, agroclimatic indices, yield contributing characters, silage yield and quality of silage was verified using Duncan's Multiple Range *test* ($p \leq 0.05$).

RESULTS AND DISCUSSION

Crop phenology: Phenology of spring maize varied significantly with change in date of sowing of spring maize in different crop rotations (Table 1). Spring maize sown in m–t–spm took significantly higher number of days for reaching all phenological stages i.e. emergence, 50% tesseling, 50% silking and milk stage as compared to other rotations. Further, there were yearly variations in days taken to reach milk stage in four crop rotations. Spring maize crop sown in r–b–spm and r–w–spm took similar number of days to reach milk stage during 2021; whereas, crop sown in r–w–spm took significantly less number of days than r–b–spm during 2022 (Table 1). During 2022, spring maize crop under r–w–spm and m–rs–spm took 7 and 6 days less than the days taken by the crop to reach at milk stage under these rotations during 2021.

The differential effect of sowing time of spring maize on phenology was observed in different crop rotations. In m–t–spm rotation, sowing of spring maize was done during

Table 1 Phenological development of spring maize grown in different crop rotations

Crop rotation	Date of sowing/harvesting (dd/mm/yyyy)		Days taken to							
			Emergence		50% tesseling		50% silking		Milk stage	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
m–t–spm	09.02.2021/ 17.05.2021	08.02.2022/ 17.05.2022	11a	13a	69a	72a	73a	76a	97a	98a
r–b–spm	26.02.2021/ 26.05.2021	25.02.2022/ 24.05.2022	9ab	9b	65b	64b	68b	67b	89b	88b
r–w–spm	08.03.2021/ 03.06.2021	08.03.2022/ 27.05.2022	8b	7bc	64bc	57c	66bc	60c	87b	80c
m–rs–spm	19.03.2021/ 11.06.2021	16.03.2022/ 02.06.2022	7b	6c	62c	56c	65c	59c	84c	78c
p value	--	--	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Treatment means with different lowercase letters differ significantly at probability levels (*p* value). m, Maize; t, Toria; spm, Spring maize; r, Rice; b, Barley; w, Wheat; rs, Rapeseeed.

second week of February while it was sown in last week of February, second week of March and third week of March in r–b–spm, r–w–spm and m–rs–spm rotations, respectively (Table 1 and Supplementary Fig. 1). Spring maize crop planted in m-t-spm, r–b–spm, r–w–spm and m–rs–spm rotations remained in fields during 6–19, 9–21, 10–22 and 12–24 SMW, respectively. It was observed that spring maize crop in m–t–spm rotation experienced lower temperature during its growth period (Fig. 2). However, the crop planted in r–b–spm, r–w–spm and m–rs–spm rotations experienced continued higher temperature during entire cropping season (Fig. 2) which resulted in significant shortening of growing season in these rotations than m–t–spm rotation. The crop achieved the milk stage (harvest stage for silage) earlier by 13–20 days in r–b–spm, r–w–spm and m–rs–spm rotations than m–t–spm rotation. Although maize is a C_4 crop, tolerant to heat stress but prolonged exposure to higher temperature is unfavourable (El-Sappah *et al.* 2022). Shortening of grain filling stage of spring maize due to high temperature stress was also reported by (Tao *et al.* 2013, Mayer *et al.* 2014). The delayed sowing of spring maize from end February to third week of March in other three rotations (r–b–spm, r–w–spm and m–rs–spm rotations) forced the crop to experience elevated temperature during entire cropping season (Fig. 2). The heat units acquired by the spring maize in m–t–spm to reach at milk stage were less than other rotations (Table 2).

There was yearly variation in effect of rotations on the phenology of the crop. Heat wave were observed in north-west India during 2022 that largely impacted the productivity of field crops and livestock (Singh *et al.* 2022). The heat wave in starting from end-March 2022 (SMW 12, Fig. 1) affected the phenological development of spring maize sown in r–w–spm and m–rs–spm rotations, and it resulted in decrease in duration of spring maize crop in these rotations by 6–7 days in 2022 than the duration of crop in these rotations during 2021. The decreased growth period of maize from 7–15 days due to high temperature stress was reported by Zhi-qiang *et al.* (2016).

Agroclimatic indices: Spring maize grown in m–t–spm rotation acquired significantly lower AGDD for emergence than in other three crop rotations during first year of the study (Table 2). During second year of study, spring maize in m–rs–spm rotation acquired maximum AGDD that was statistically at par to heat units acquired in r–w–spm. During both years of study, AGDD were significantly lower in m–t–spm for reaching 50% tesseling and 50% silking than in other crop rotations. During 2021, AGDD acquired by spring maize in r–w–spm and m–rs–spm to reach at milk stage were significantly higher than crop in m–t–spm and r–b–spm rotations. During 2022, more heat units were acquired by spring maize in m–rs–spm which was similar with heat units acquired in r–b–spm and r–w–spm but significantly higher than heat units acquired by crop in m–t–spm. In all crop rotations, crop acquired more heat units to reach at milk stage during second year than first year of study. The results were confirmatory with Ge *et al.* (2022).

During 2021, HUE was the maximum in m–t–spm

Table 2 AGDD acquired by spring maize crop up to different phenological stages, HUE, HTUE and PTUE of spring maize grown in different crop rotations

Crop rotation	AGDD(°C day)								HUE (Kg/°C day)		HTUE (kg/°C day hour)		PTUE (kg/°C day hour)	
	Emergence		50% tesseling		50% silking		Milk stage							
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
m–t–spm	70.9b	66.4b	811.9c	920.6c	868.0d	996.2c	1306.4b	1497.8b	10.86a	8.31a	1.47a	0.96a	0.87a	0.66a
r–b–spm	89.3a	68.3b	896.2b	1008.0b	961.0c	1078.1b	1344.4b	1567.5a	10.67a	7.26b	1.41ab	0.84ab	0.84ab	0.56b
r–w–spm	89.7a	80.4ab	972.0a	1021.9b	1007.7b	1081.8b	1413.8a	1538.8ab	9.97a	7.17b	1.28b	0.83ab	0.76b	0.55b
m–rs–spm	95.0a	101.2a	995.1a	1075.8a	1049.2a	1152.1a	1448.5a	1582.6a	8.21b	6.26c	1.02c	0.73b	0.61c	0.47b
p value	0.032	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	0.002	<0.001	0.003	<0.001	0.001

AGDD, Accumulated growing degree days; HUE, Heat use efficiency; HTUE, Helio thermal use efficiency; PTUE, Photo thermal use efficiency. Treatment means with different lowercase letters differ significantly at probability levels (*p* value). m, Maize; t, Toria; spm, Spring maize; r, Rice; b, Barley; w, Wheat; rs, Rapeseeed.

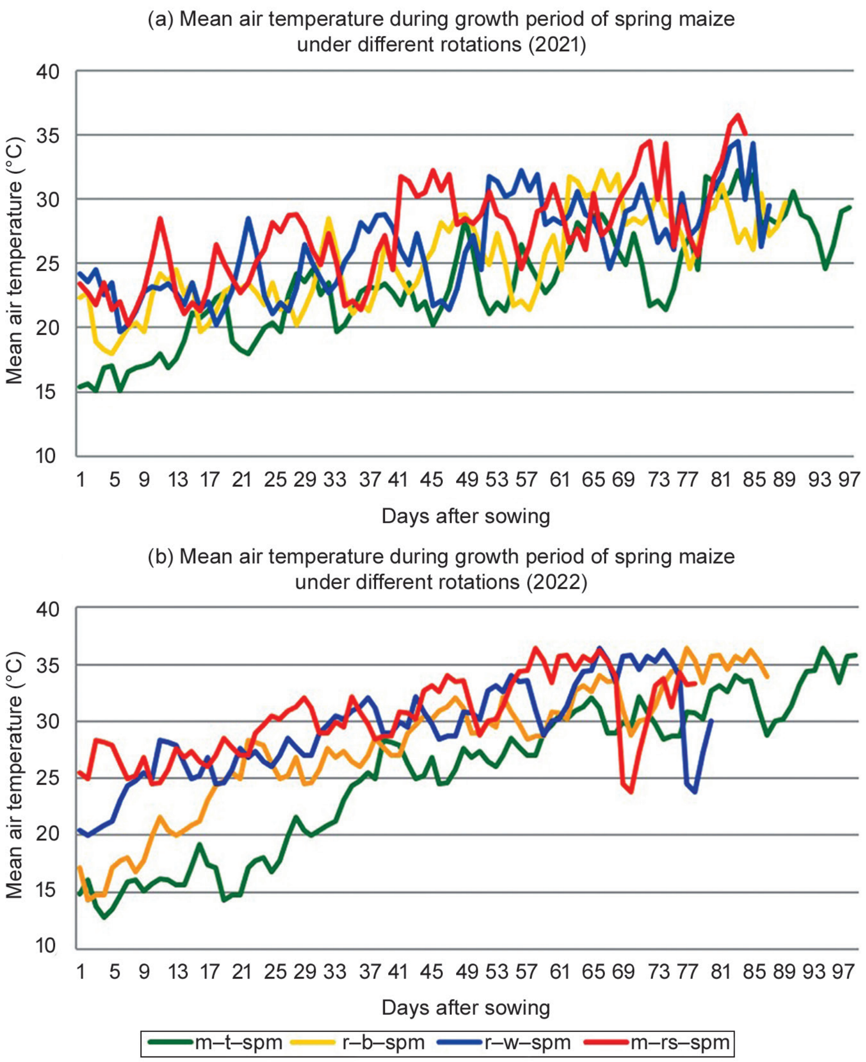

Fig. 2 Mean air temperature experienced by spring maize crop in four crop rotations during (a) 2021 and (b) 2022.
m, Maize; t, Toria; spm, Spring maize; r, Rice; b, Barley; w, Wheat; rs, Rapeseeed.

which was statistically at par to r–b–spm and r–w–spm rotations but significantly higher than m–rs–spm. However, higher HUE was achieved in m–t–spm rotation as compared to other rotations during 2022 (Table 2). The HTUE and PTUE were the highest in m–t–spm that were similar with r–b–spm rotation during 2021. The lowest efficiencies (HTU, HTUE, PTUE) were observed in m–rs–spm rotation.

Yield attributes and silage yield: During 2021, similar plant height of spring maize in four crop rotations was recorded, however during 2022, spring maize planted in m–t–spm rotation attained significantly more plant height than other three crop rotations (Table 3). During 2021, number of leaves per plant were significantly higher in spring maize grown in m–t–spm rotation than other three rotations (Table 3). Number of cobs per plant was higher in m–t–spm rotation during both years of study. During 2021, similar plant fresh weight was recorded in m–t–spm and r–b–spm and was higher than other rotations. However, during 2022, spring maize crop sown in m–t–spm rotation recorded significantly higher plant fresh weight than other rotations (Table 3). Spring maize silage yield was the maximum in m–t–spm that was statistically similar with silage yield of spring maize in r–b–spm but was significantly more than r–w–spm (15.1% and 12.4%) and m–rs–spm (23.0% and 24.0%) rotations during both years of study (Table 3). During 2022, silage yield of spring maize under four crop rotations was 24.4–28.0% less than the silage yield during 2021.

The higher yield of spring maize silage under m–t–spm rotation was due to longer duration of crop in this rotation which might have led to accumulation of more photosynthates and higher dry matter and silage yield. Highest crop yields with relatively mild temperatures maximise the total duration of growth was also reported by Muchow and Bellamy (1991). Earlier researchers, Harrison *et al.* (2011) and Li *et al.* (2022) also reported

Table 3 Plant height, yield attributes and silage yield of spring maize grown in different crop rotations

Crop rotation	Plant height (cm)		Number of leaves/ plant		Number of cobs/ plants		Plant fresh weight (g)		Silage yield (t/ha)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
m–t–spm	233.00	220.00a	16.33a	13.68a	1.60a	1.28a	845.00a	676.67a	46.71a	33.93a
r–b–spm	224.00	203.00b	14.50b	12.75ab	1.43b	1.00b	737.50ab	595.00b	42.11ab	31.83ab
r–w–spm	226.50	202.25b	14.50b	12.75ab	1.20c	1.00b	716.25b	515.00c	40.57b	30.20bc
m–rs–spm	225.00	198.67b	14.68b	12.33b	1.23c	1.00b	726.68b	506.68c	37.98b	27.36c
p value	0.356	<0.001	0.016	0.061	<0.001	0.020	0.082	0.001	0.002	0.010

Treatment means with different lowercase letters differ significantly at probability levels (*p* value). m, Maize; t, Toria; spm, Spring maize; r, Rice; b, Barley; w, Wheat; rs, Rapeseeed. Treatment details are given under Materials and Methods.

that accelerated maize growth due to higher temperatures reduced the time for crop development and limited the attainment of potential yield. The negative effect of heat stress on yield attributes, above ground biomass and grain yield was also reported by Wang *et al.* (2022) and Li *et al.* (2022). The higher yield in m–t–spm rotation leads to higher value of HUE, HTUE and PTUE as compared to other rotations. During both years, the lowest silage yield was obtained in m–rs–spm rotation. Further, silage yield in four crop rotations were less in second year of study than first year. The mean air temperature during growth period of spring maize during 2022 was 0.25–5.55°C higher than during 2021 (Fig. 1). The mean air temperature starting from 17^{th} SMW was more than 30°C during 2022. This heat stress during the growth and reproductive stage of crop during 2022 resulted in lower yield as compared to 2021. Schauberger *et al.* (2017) have reported the sensitivity of maize plant to heat stress at temperature above 30°C and the significant reduction in yield.

Silage quality: The *p*H of silage was recorded similar in all crop rotations during 2021 but it was significantly lowest in m–t–spm rotation during 2022 (Table 4). The *p*H of spring maize silage produced in all four crop rotations was within optimum range of 3.5–4.3 as suggested by Roth and Heinrichs (2001). Lactic acid in silage is an indicator of good fermentation and silage having lactic acid content above 4% (on dry matter basis) is of good quality (Chahine *et al.* 2009). During both years of study, lactic acid content of silage produced in m–t–spm, r–b–spm and r–w–spm was above 4% (Table 4), indicating the good quality of silage while its value in m–rs–spm was recorded below 4% indicating the inferior quality. NH_3-N content, an indicator of breakdown of protein during silage making was recorded within 5.09–5.19% of total CP in all four crop rotations during first year of study (Table 4), which is within range (5–10%) of good quality silage (Brar *et al.* 2019). During second year, NH_3-N content was recorded above 10% of total CP in m–rs–spm rotation indicating the more forage protein degradation in this rotation because of higher temperature at the time of ensiling spring maize in m–rs–spm. An increase in ammonia nitrogen content of silage ensiled at higher temperature was also reported by Jia and Yu (2022).

During both year of study, crude protein content (Table 4) of silage in all treatments were within optimum range (7–9%), but ether extract content of silage produced in r–b–spm, r–w–spm and m–rs–spm was lower than optimum range of 2.8–3.8% as suggested by Chahine *et al.* (2009). NDF content in all treatments was higher while ADF and ADL content were within the optimum range during both year of study (Chahine *et al.* 2009). During 2022, higher value NDF, ADF and ADL in m–rs–spm as compare to other treatments may be due to more lignifications of spring maize fodder produced in higher temperature. Mahmood *et al.* (2010) also reported the increase in crude fiber content in maize fodder produced under heat stress.

The study investigated the effect of different crop rotations on the phenology, yield, and silage quality of spring

Table 4 Fermentation characteristics and nutrient composition of spring maize silage produced in different crop rotations

Crop rotation	*p*H		Lactic acid (% DM)		NH_3-N (% total N)		Dry matter (%)0		Crude protein (% DM)		Ether extract (% DM)		NDF (% DM)		ADF (% DM)		ADL (% DM)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
m–t–spm	4.23	3.89a	4.55a	4.37a	5.09	6.07a	25.29a	28.53a	9.34a	8.21a	2.77a	3.43a	57.67	60.23a	29.53	28.73a	2.93	2.53a
r–b–spm	4.35	4.18b	4.57a	4.88a	5.18	5.33a	26.23a	25.64b	9.03a	7.17b	2.63a	2.35b	60.70	58.78a	31.60	27.55a	3.10	2.43a
r–w–spm	4.31	4.02b	4.80a	4.77a	5.19	5.43a	26.85a	26.09b	8.29a	7.13b	2.60a	2.30b	57.50	58.38a	28.00	27.60a	2.98	2.60a
m–rs–spm	4.23	4.24b	3.42b	3.75b	5.17	10.37b	23.83b	25.68b	8.05b	7.20b	2.20b	2.70b	58.90	63.33b	29.87	30.87b	2.87	2.90b
p value	0.054	<0.001	<0.001	<0.001	0.970	<0.001	0.006	<0.001	0.022	<0.001	0.027	<0.001	0.365	<0.001	0.223	<0.001	0.970	0.008

Treatment means with different lowercase letters differ significantly at probability levels (*p* value). NDF, Nutrient detergent fibre; ADF, Acid detergent fibre; ADL, Acid detergent lignin. m, Maize; t, Toria; spm, Spring maize; r, Rice; b, Barley; w, Wheat; rs, Rapeseed maize over two years. Spring maize sown in the m–t–spm rotation experienced lower temperatures took significantly more days to reach all phenological stages compared to other rotations. Higher silage yield of spring maize was recorded in m–t–spm, was similar to r–b–spm but higher than r–w–spm and m–rs–spm rotations during both years. It is concluded from the study that maize–toria–spring maize (for silage) and rice-barley (for silage)–spring maize (for silage) are the best crop rotations for maximising the spring maize quality silage production.

REFERENCES

AOAC. 2007. *Official Methods of Analysis*, 18th edn. Association of Official Analytical Chemists, Gaitherburg, Arlington.

Barker S B and Summerson W H. 1941. The colorimetric determination of lactic acid in biological material. *Journal of Biological Chemistry* **138**: 535–54.

Borreani G, Tabacco E, Schmidt R J, Holmes B J and Muck R E. 2018. Silage review: Factors affecting dry matter and quality losses in silages. *Journal of Dairy Science* **101**(5): 3952–79.

Brar N S, Kaur S, Hundal J S, Kaur M, Bhadauria P, Sheoran P and Singh R. 2023. *Silage Making: An Emerging Enterprise for Dairy Sector,* pp. 112. ICAR-Agricultural Technology Application Research Institute, Zone-1, Ludhiana, Punjab, India. https://atariz1.icar.gov.in/pdf/Silage%20Making.pdf

Brar N S, Kaur S, Sandhu P S, Hundal J S and Singh Y. 2024. Agronomic interventions for production and preservation of quality maize fodder. *Maydica* **67**(1): 1–16.

Brar N S, Kumar B, Hundal J S, Singla A, Kumar A and Verma H K. 2021. Maize (*Zea mays*) cultivars evaluation for herbage yield and silage quality. *The Indian Journal of Agricultural Sciences* **91**(8): 1131–35.

Brar N S, Kumar B, Kaur J, Kumar A, Verma H K, Singh R and Singh P. 2019. Qualitative study of corn silage of cattle farms in subtropical conditions of Indo-Gangetic plains. *Range Management and Agroforestry* **40**(2): 306–12.

Chahine M, Fife T E and Shewmaker G E. 2009. Target values for corn silage. (*In*) *Idaho Alfalfa and Forage Conference Proceedings*, Idaho, 04 February 2009, pp. 1–5.

Darby H M and Lauer J G. 2002. Harvest date and hybrid influence on corn forage yield, quality and preservation. *Agronomy Journal* **94**: 559–66.

El-Sappah A H, Rather S A, Wani S H, Elrys A S, Bilal M, Huang Q, Dar Z A, Elashtokhy M M A, Soaud N, Koul M, Mir R R, Yan K, Li J, El-Tarabily K A and Abbas M. 2022. Heat stress-mediated constraints in maize (*Zea mays*) production: Challenges and solutions. *Frontiers in Plant Science* **13**. https://doi.org/10.3389/fpls.2022.879366

Ge J, Xu Y, Zhao M, Zhan M, Cao C, Chen C and Zhou B. 2022. Effect of climatic conditions caused by seasons on maize yield, kernel filling and weight in central China. *Agronomy* **12**(8): 1816. https://doi.org/10.3390/agronomy12081816

Harrison L, Michaelsen J, Funk C and Husak G. 2011. Effects of temperature changes on maize production in Mozambique. *Climate Research* **46**: 211–22.

Huang Y, Liang L, Dai S, Wu C, Chen C and Hao J. 2021. Effect of different regions and ensiling periods on fermentation quality and bacterial community of whole-plant maize silage. *Frontiers in Microbiology* **12**: 743695.

Jia T and Yu Z. 2022. Effect of temperature and fermentation time on fermentation characteristics and biogenic amine formation of oat silage. *Fermentation* **8**: 352.

Li T, Zhang, Peng X, Liu Q, Liu J, Chen Y Quan and Sui P. 2022. Yield penalty of maize (*Zea mays* L.) under heat stress in different growth stages: A review. *Journal of Integrative Agriculture* **21**(9): 2465–76.

Mahmood S, Wahid A, Javed F and Basra S M A. 2010. Heat stress effects on forage quality characteristics of maize (*Zea mays*) cultivars. *International Journal of Agricultural Biology* **12**: 701–06.

Mayer L I, Edreira J I R and Maddonni G A. 2014. Oil yield components of maize crops exposed to heat stress during early and late grain-filling stages. *Crop Science* **54**: 2236−50.

Muchow R C and Bellamy J A. 1991. *Climatic Risk in Crop Production: Models and Management for the Semiarid Tropics and Subtropics*. CAB International, Wallingford, UK. https://oar.icrisat.org/4625/1/CP_581.pdf

Nuttonson M Y. 1955. *Wheat Climate Relationships and Use of Phenology in Ascertaining the Thermal and Photothermal Requirement of Wheat*, pp. 338. American Institute of Crop Ecology, Washington DC.

Robertson J B and Van Soest P J. 1981. The detergent system of analysis and its applications to human foods. (*In*) *The Analysis of Dietary Fiber in Food,* pp. 123–58. James W P T and Theander O M D (Eds). Inc. New York.

Roth G W and Heinrichs A J. 2001. Corn silage production and management. *(In) Agronomy Facts-18*, The Pennsylvania State University.

Schauberger B, Archontoulis S, Arneth A, Balkovic J, Ciais P, Deryng D, Elliott J, Folberth C, Khabarov N and Muller C. 2017. Consistent negative response of US crops to high temperatures in observations and crop models. *Nature Communications* **8**: 13931.

Singh R, Kaur S, Murai A S, Brar N S, Brar P S, Kumar A and Singh A K. 2022. *Heat Wave in Northern India: Farmers' Perspective,* pp.76. Division of Agricultural Extension, ICAR, New Delhi.

Tao Z Q, Sui P, Chen Y Q, Li C, Nie Z J, Yuan S F, Shi J T and Gao W S. 2013. Subsoiling and ridge tillage alleviate the high temperature stress in spring maize in the North China Plain. *Journal of Integrative Agriculture* **12**: 2179−88.

Wang N, Liu Q, Ming B, Shang W, Zhao X, Wang X, Wang J, Zhang J, Luo Z and Liao Y. 2022. Impacts of heat stress around flowering on growth and development dynamic of maize (*Zea mays* L.) ear and yield formation. *Plants* **11**(24): 3515. https://doi.org/10.3390/plants11243515

Zhi-qiang T, Yuan-quan C, Chao L, Juan-xiu Z, Peng Y, Shu-fen Y, Xia W and Peng S. 2016. The causes and impacts for heat stress in spring maize during grain filling in the North China Plain-A review. *Journal of Integrative Agriculture* **15**(12): 2677–87.