



Harnessing the tillering ability of *Zea mays* ssp. *parviglumis* in fodder maize breeding

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ABSTRACT

Maize (*Zea mays* L.) has diversified uses in the form of food, feed and fodder. In India green fodder deficit of 61.1 % has been reported. Under this scenario, maize and its wild relatives with its wide adaptability have enormous potential to serve as nutritious fodder. The annual teosinte, *Zea mays* ssp. *parviglumis*, the closest ancestor of modern maize has good tillering and re-growth ability. In an experiment on *parviglumis*, the effect of 30 kg higher nitrogen than recommended dose showed 12.5% and 20% improvement in tiller re-growth ability (multi-cut) and green fodder yield, respectively. In a pilot trial, fresh cut (first cut) and re-growth (at the second cut) whole/unchaffed fodder samples of *parviglumis* were fed to the adult goats and grower kids (9 months old) of beetal breed. Re-growth based fodder samples were consumed completely (no leftover) by adult goats as well as grower kids, while fresh (first cut) samples had negligible leftover for adult goats but 32% leftover for grower kids. Goats being selective in feeding habits tend to eat soft and leafy parts and avoid hard and thick (stem) parts of fodder plants hence leftover might be lesser if fed to large ruminants. To exploit these traits, *parviglumis* was crossed to fodder variety, African tall and 11 promising fodder maize inbred lines. The F₁ generation of different wide crosses exhibited a good amount of tillering with many tillers ranging from 1 to 15 indicating partial dominant nature of tillering trait and background effect. The further advancement of promising crosses through backcrossing can help to develop multi-tiller as well as multi-cut trait possessing fodder maize cultivars. To the best of our knowledge, this is the first study on the systematic use of *Zea mays* ssp. *parviglumis* for harnessing its tillering and re-growth ability in fodder maize breeding programme.

Key words: Maize, Multi-tiller, Parviglumis, Re-growth, Tillering

Maize (*Zea mays* L.) is the third most important crop in the world, after rice and wheat (Yadav *et al.* 2015). It has diversified uses in the form of human food, animal feed, poultry, biofuel and industries (Kumar *et al.* 2013). Maize has wide adaptability that enables its cultivation under diverse agro-ecologies. Maize is having the highest growth rate (6.7%) amongst cereals in terms of grain yield but it lags in terms of fodder production. There is a net deficit of 61.1% green fodder and 21.9% dry crop residues in India (Kumar *et al.* 2012). Maize with its wide adaptability has enormous potential to serve as nutritious fodder as it provides nearly 30 million tonnes stover biomass per year. There is extensive demand for quality green fodder for sustainable dairy farming. Although, maize possesses enormous genetic diversity relative to other crops, however far lower than its wild relatives as resultant of its evolution through single domestication (Vigouroux *et al.* 2002; Warburton *et al.*

2008). Hence, the enormous genetic variation existing in wild relatives have reduced to a greater extent in modern maize during the domestication due to breeding bottlenecks (Tenaillon *et al.* 2004; Tarter *et al.* 2004; Le Clere *et al.* 2005; Liu *et al.* 2016). The use of limited cultivars in the derivation of new inbred lines further aggravated to the cause of genetic diversity reduction (Singh *et al.* 2017). Later, this reduction in genetic diversity in maize inspired the maize breeders to shift their focus back to the wild relatives for harnessing the wild alleles for improvement of various traits of economic importance.

The genetic architecture of differences in maize and teosinte have been well elucidated suggesting the role of particular genes in imparting particular phenotypic variation (Weber *et al.* 2008). Photoperiod sensitivity, ear morphology and kernel traits are among the most distinguishing characters between maize and teosinte (Iltis 2000). The difference in tillering is also a distinguishable feature between maize and teosinte ssp. *parviglumis*. However, despite such large phenotypic differences, the hybridization (sexual compatibility) occurs quite easily between maize and all of the teosintes (except *Z. perennis*) (Wilkes 1977; Doebley 1990). In particular spontaneous hybridization occurs between *Z. mays* ssp. *mays* and teosinte

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ssp. parviglumis (Ellstrand *et al.* 2007). The earliest efforts on potential use of teosinte in maize breeding was related to imparting resistance to various biotic and abiotic stresses and grain yield (Reeves 1950; Cohen and Galinat 1984; Casas *et al.* 2001; Choudhary *et al.* 2017; Singh *et al.* 2017; Mammadov *et al.* 2018). However, the wild relatives have not been utilized till date to enhance green fodder maize yield in fodder maize breeding programmes globally.

The annual teosinte, *Zea mays ssp. parviglumis*, has tillering ability, having more than 20 tillers (basal tillers excluding the main stalk) with tender stem, many small but long leaves and stalk filled with sweeter sap. The plant is grown as a multi-cut, high-yielding, excellent fodder and silage (Corcuera 1991). It is highly palatable to the animals due to its high nutritive value. In spite of larger genetic polymorphism in teosinte, limited efforts have been made to tap the allelic diversity of teosinte species for diversification (Liu *et al.* 2016). Recently, *Zea mays ssp. luxurians* has been used to develop multi-tiller maize cultivar named as CRTM-2 (Jyothi Lakshmi *et al.* 2019). Hence, considering the good palatability, tillering and re-growth ability of *Zea mays ssp. parviglumis*, it can also serve as a good source for development of multi-tiller and multi-cut ability possessing fodder maize cultivars.

With elementary initial knowledge, the experiment was conducted on assessing the effect of nitrogen on tillering and re-growth ability of *Zea mays ssp. parviglumis*, exploring the photoperiod sensitivity as well as testing the preference of multi-cut (re-growth) fodder samples of *Zea mays ssp. parviglumis* for goats. Besides, the present investigation was planned to attempt the transfer of tillering trait from *Zea mays ssp. parviglumis* to promising fodder maize cultivars. Among these African tall is a tall, single-stemmed, white seeded cob with maturity duration of 125-130 days in the spring season. It is highly preferred for green fodder due to its good biomass and digestibility. In addition to this, it also has better silage quality. Besides African Tall, 11 promising high biomass containing yellow seeded inbred lines (including two lines with stay-green trait) identified under our fodder maize breeding programme were also included.

MATERIALS AND METHODS

The experiment was conducted in the spring season, 2018 on *Zea mays ssp. parviglumis* to check the effect of 30% higher nitrogen fertilization than the recommended dose (100 kg/ha) on re-growth ability of basal tillers (produced in two subsequent cuts at 15 days interval after two months of sowing). The sowing was done in two rows of three-meter length. The nitrogen was applied on the next day of giving cut. The per cent re-growth of basal tillers (including the main stalk) after the cut was calculated as the number of tillers exhibiting re-growth calculated as the number of tillers re-grown divided by the initial number of tillers. To study the preference of biomass obtained in this experiment, a pilot trial was conducted under which first and after re-growth cut based whole/unchaffed fodder samples of *Zea*

mays ssp. parviglumis were offered to the adult goats and growing kids (~ 9 months old) of Beetal breed at Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, India. The effect of cutting on the flowering and maturity of *Zea mays ssp. parviglumis* was also observed by recording the days to 50% flowering and maturity, respectively. The crosses of *Zea mays ssp. parviglumis* were executed with African Tall and 11 promising fodder maize inbreds in *kharif* 2018 (Table 1). The wide crosses (F_1) were sown in four rows of three meter each in spring 2019. The details on traits like days to 50 % anthesis (DAT), days to 50% silking (DAS), number of basal tillers, average plant height of basal tillers, leaves per basal tiller and cobs per basal tiller were recorded at completion of flowering. Similar traits were also recorded from three randomly chosen plants for main stalk. In addition, green fodder weight/plant was also taken by cutting the basal tillers and main stalk from the base and weighing separately followed by summing the weight of both. DAT and DAS were recorded as the number of days required to complete 50% anthesis and silking from date of sowing, respectively.

RESULTS AND DISCUSSION

Effect of higher nitrogen dose on re-growth ability of tillers and green fodder weight

Zea mays ssp. parviglumis exhibited the tillers in range of 8-10 till the period of cutting, i.e. 60 days after sowing. The 30% extra dose of nitrogen had a significant effect ($P < 0.05$) on the re-growth ability as well as green fodder yield in *Zea mays ssp. parviglumis* (Table 2). The higher nitrogen dose of 130 kg/ha showed 12.5% and 20% improvement in the percent re-growth ability of tillers and green fodder yield, respectively. Higher nitrogen dose was found to enhance the re-growth ability in *Zea mays ssp. parviglumis* and hence resulting in higher green fodder yield.

Table 1 List of genotypes indicating seed colour, type and days to 50% anthesis to be used as recipient parent in crossing with *Zea mays ssp. parviglumis*

Genotype (F_1)	Seed colour	Type	Days to 50% anthesis
MCFL117	Yellow	Inbred	89
MCFL121	Yellow	Inbred	92
MCFL141	Yellow	Inbred	88
MCFL158	Yellow	Inbred	87
MCFL174	Yellow	Inbred	89
MCFL177	Yellow	Inbred (Stay green)	92
MCFL179	Yellow	Inbred (Stay green)	91
MCFL182	Yellow	Inbred	90
MCFL185	Yellow	Inbred	88
LM13	Yellow	Inbred	88
LM14	Yellow	Inbred	92
African Tall	White	Composite	86

Table 2 Effect of nitrogen on re-growth ability and green fodder yield in *Zea mays* ssp. *parviglumis*

Trait	100 kg N/ha	130 kg N/ha	P-value
Per cent re-growth (in tillers) after the cut	80%	90%	0.048
Weight (15 days after the cut)	15.6 q/ha	18.8 q/ha	0.047

However, main stalk as compared to basal tillers exhibits less re-growth ability due its relatively harder stem. Its ability of producing tillers and to exhibit re-growth upon cutting can be observed in Fig 1 which shows it along with that in which no cut was given to the plant. It was observed that re-growth based leaves were found to be soft and tender and have a reduction in sharp edges of leaf margins as compared to that of the first cut (non-re-growth based) as well as non-cut (original with no cut given). Hence the soft and tender leaves containing re-growth based samples can be used to feed ruminants.

Pilot Trial on testing the preference of goats for re-growth and fresh-cut fodder based feeding: The weighed unchaffed samples (re-growth based) obtained from treatment of different nitrogen doses along with freshly cut (first time cut or not based on re-growth) were given to adult goats as well as grower kids for testing the irrelative preferences. The re-growth based samples were fed completely (no leftover) by adult goats as well as grower kids while first-time cut (not based on re-growth) fodder samples had negligible leftover for adult goats but 32% leftover for grower kids was observed. Goats are more selective in feeding habits especially high-quality feeds than sheep and cattle (Domingue *et al.* 1991; Hadjigeorgiou *et al.* 2003; Moyo and Nsahlai 2017) and tend to eat soft and leafy parts of fodders and avoid eating thick or hard (stem) parts of fodder plants. Further, kids need relatively good pasture (Vincent 2018) than adult goats which could be the reason for relatively more wastage of first cut fodder in grower kids. Increase in fodder intake after chaffing too has been noted in goats (Omokanye *et al.* 2001, Kumari and Patel

2015). Hence leftover might be much lesser if fed to large ruminants (cattle and buffalo), however, still confirmation studies are required.

Effect of cutting in Zea mays ssp. parviglumis on flowering and maturity

Zea mays ssp. *parviglumis*, sown in the first week of February was found to flower in about 235 days (October first week) as compared to that in 85 days in *kharif* season at Ludhiana. This is due to the fact that unlike the almost day-neutral nature of modern maize especially temperate maize. Eventually, *Zea mays* ssp. *parviglumis* require short-day period (longer-nights or continuous dark phase more crucial) to induce flowering (Emerson 1924; Meng *et al.* 2011). Hence, due to change in weather condition days get shorter (nights get longer) towards the December in India, *Zea mays* ssp. *parviglumis* requires less time to come to flowering as compared to spring sowing. Spring sowing does not get a short day to attain flowering as days get to start shorter after June in India (the shortest day on 22nd December). It was quite interesting to note that, no significant effect of cutting was observed on the flowering time as well as the maturity of *Zea mays* ssp. *parviglumis*, as both re-growth and original (non-re-growth) based plants exhibited nearly similar time for flowering and maturity. This indicates towards the involvement of fixed time frame mechanism in plants (upon getting favourable photoperiod) to transit to reproductive phase without getting affected by the multi-cut nature (Song *et al.* 2015). Hence, considering the almost three times of duration taken to initiate flowering in the spring season as compared to *kharif*, it is better to avoid it's sowing in spring/*rabi* season in Indian conditions for execution of crosses. Therefore, breeders engaged in pre-breeding using *Zea mays* ssp. *parviglumis* should target *kharif* sowing for the execution of crosses and hence saving a season as compared to spring sowing. Furthermore, the photoperiodism in wild relatives can be harnessed through the use of speed breeding for rapid generation advancement (Watson *et al.* 2018).

Fig 1 Tillering and re-growth ability of *Zea mays* ssp. *parviglumis*.

Transfer of tillering trait in elite fodder maize lines

The tillering and re-growth ability of *Zea mays* ssp. *parviglumis* can be transferred to the promising fodder maize inbreds and composites. The seed colour of the F₁ was slightly different from the recipient parent (seed parent) and hence, assisting in the differentiation of true wide crosses from false crosses (if any) by visual observation (Fig 2). Such differences in seed colour on crossing with wild relatives arise due to xenia effect (Waller 1917). The basal tillering was recorded in F₁ wide crosses in un-replicated trials (limited seed) as it was grown for advancement purpose by backcrossing with recipient parent. The wide crosses exhibited basal tillers in the range of 1-15 with highest (15) and lowest (2) tillers observed in the cross MCFL182 × ZMP and African Tall × ZMP, respectively (Table 3; Fig 3 and 4). However, it was interesting to note that each plant of MCFL182 × ZMP cross had a minimum of three basal side tillers as compared to only one in some plants of remaining crosses. This difference in the number of tillers in wide crosses can be attributed to the different genetic background of the recipient parents. The tillering trait as observed in wide crosses (F₁s) indicates towards its partially dominant nature. This partially agrees with the findings of Srinivasan and Brewbaker (1999) who noticed the dominant nature of tillering in crosses of maize with Jutiapa teosinte and *Zea diploperennis*. It was interesting to notice that the inbreds were found to be more responsive to tillering as compared to composites as evident from the high number

of tillers observed in crosses of *parviglumis* with inbreds. It may be due to homozygous nature of inbreds for most of the genome content as compared to composites as well as favourable gene interactions. However, it needs further validation by using more number of composites as only one composite (African Tall) was used in this experiment.

For flowering traits, most of the crosses were late than respective recipient parents except MCFL185 × ZMP and African Tall×ZMP as both were nearly similar to recipient parents in days to flowering (Table 1 and 3). However, all wide crosses exhibited flowering almost before half the duration of *Zea mays* ssp. *parviglumis*. It is quite obvious to get early flowering in wide crosses, as hybrids exhibit tendency towards early flowering (Ali *et al.* 2013). The wide crosses, MCFL185×ZMP and African Tall×ZMP came to flowering earlier than respective recipient parents (MCFL 185 and African Tall) indicating towards the possible transgressive segregants. The cross, MCFL179×ZMP had taken about four months for anthesis which was the highest amongst all crosses attempted in our study. For the average height of basal side tillers and main stalk, the range was 192.3 (MCFL185×ZMP)-255 (MCFL179×ZMP) and 186.7 cm (MCFL185×ZMP)-275(MCFL179×ZMP), respectively. Similarly, average leaves in basal side tillers and main stem ranged from 10.5(MCFL185)-16.3(MCFL179×ZMP) and 10(MCFL185)-16(MCFL179×ZMP), respectively (Table 3).

The green fodder weight per plant in crosses ranged from 1.4 kg to 4.5 kg. The maximum and minimum green

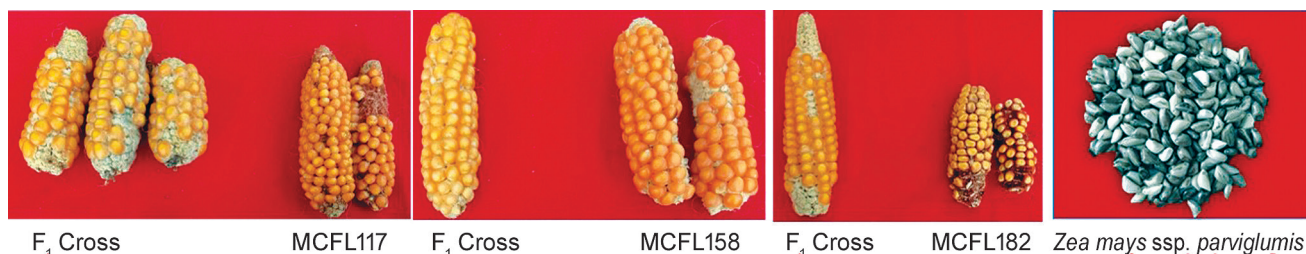


Fig 2 Seed colour variation in F₁ cross (left) and inbred parents (right) and *Zea mays* ssp. *parviglumis*.

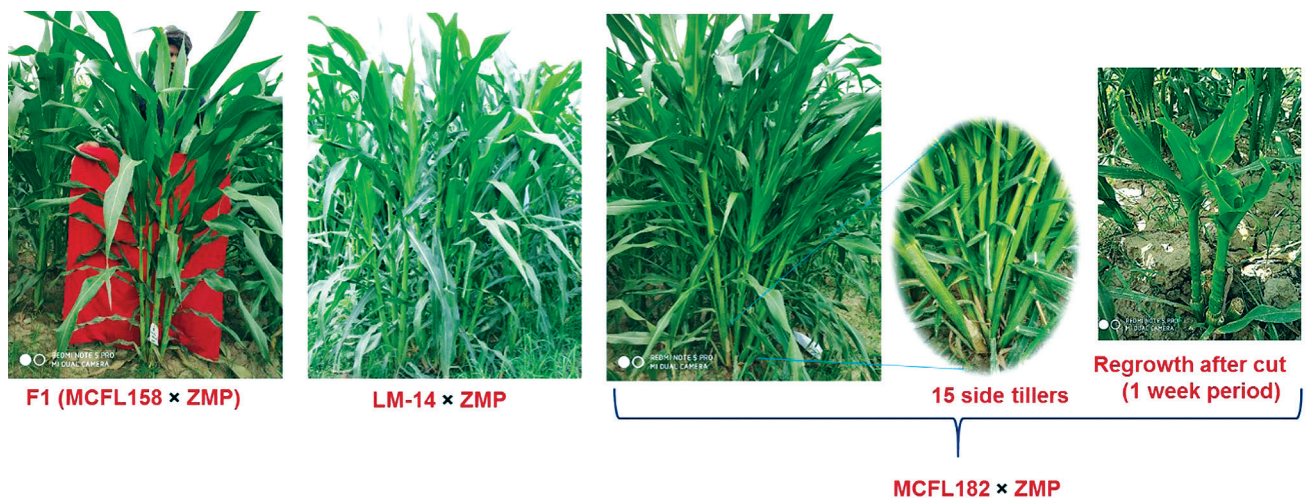


Fig 3 Tillers in wide crosses (F₁) crosses and re-growth ability.

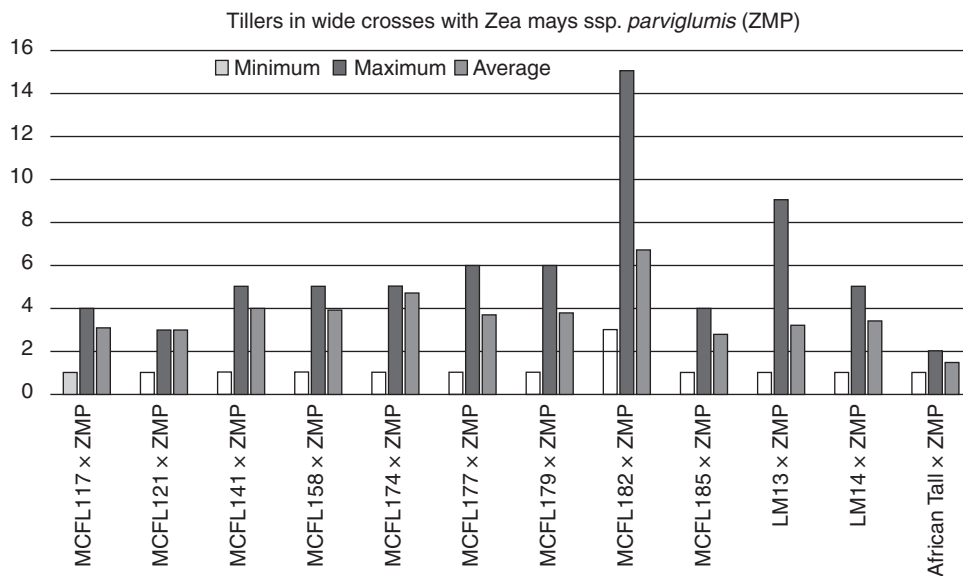


Fig 4 Range of tillers and average tillers in wide crosses with *Zea mays* ssp. *parviglumis*.

traits of *Zea mays* ssp. *parviglumis*. The developed multi-tiller inbreds can be used to develop multi-tiller hybrids and composites. The intervention of nutrient management practices can further help in augmenting the green fodder yield in multi-tiller fodder maize cultivars. Furthermore, speed breeding can also be utilized for better utilization of wild relatives by inducing early flowering and hence achieving rapid advancement of generations of wide relatives-based crosses per year. The use

Table 3 Details of average plant height, number of leaves and cobs per plant and green fodder weight per plant of wide crosses

F ₁ crosses	Range of tillers/ tillers	Average tillers/ plant	DAT	DAS	Average height/ BT (cm)	Average height/ MS (cm)	Average leaves/ BT	Average leaves/ MS	Average cobs/ BT	Average cobs/ BT	Average weight of tillers/ plant (kg)	Average weight of main stalk/ plant (kg)	Average weight/ plant (kg)
MCFL117×ZMP	1-4	3.1	101	104	203.6	226.7	13.4	15.0	3.3	5.5	3.5	0.9	4.4
MCFL121×ZMP	1-3	3	100	104	231.7	230.0	13.4	12.5	3.0	3.0	1.9	0.7	2.5
MCFL141×ZMP	1-5	4	98	102	214.6	220.0	10.0	10.0	3.7	4.0	1.6	0.4	2.0
MCFL158×ZMP	1-5	3.9	102	107	218.3	225.0	13.0	12.5	3.3	4.0	1.7	0.7	2.4
MCFL174×ZMP	1-5	4.7	101	105	216.5	215.0	12.7	13.0	2.5	6.0	2.3	0.6	2.9
MCFL177×ZMP	1-6	3.7	104	108	238.8	248.3	12.5	13.0	2.8	4.5	3.6	0.8	4.3
MCFL179×ZMP	1-6	3.8	120	126	255.0	275.0	16.3	16.0	2.8	2.5	2.4	0.9	3.3
MCFL182×ZMP	3-15	6.7	100	105	233.3	208.3	14.2	14.0	3.4	4.5	3.6	0.8	4.5
MCFL185×ZMP	1-4	2.8	84	89	192.3	186.7	10.5	10.0	3.0	4.5	0.9	0.6	1.5
LM13×ZMP	1-9	3.2	101	105	239.3	261.7	13.0	14.0	4.0	9.0	1.6	1.0	2.6
LM14×ZMP	1-5	3.4	103	108	245.0	216.7	13.2	13.5	3.8	7.5	1.7	0.9	2.6
African Tall×ZMP	1-2	1.5	84	86	245.0	265.0	14.0	15.0	2.0	2.0	0.6	0.8	1.4

BT, Basal Tillers; MS, Main Stalk; ZMP, *Zea mays* ssp. *parviglumis*

fodder weight per plant was observed in (MCFL182×ZMP) and (African Tall×ZMP), respectively. Such a difference in weight between these two crosses is attributable to the highest and lowest average tillers, respectively. The average weight of wide crosses is significantly higher (thrice in few cases) than that of existing fodder maize cultivars including African Tall and J-1006 that are being used as a national check-in fodder maize trials. The cross with highest tillers, MCFL182×ZMP exhibited re-growth on cutting (Fig 3). Thus, wide crosses exhibiting tillering can be tested for re-growth too once the progenies get fixed. Further advancement of promising crosses through backcross breeding will help to harness the fodder yield-enhancing

of molecular markers can also complement the transfer of tillering which is reported to be governed by major genes like *tba1*, *thr1* and *gt1*. It can also help in efficient recovery of recipient background genome and hence saving time and resources. Hence, *Zea mays* ssp. *parviglumis* can serve as an excellent source to fodder maize breeders to develop multi-tiller and re-growth ability possessing high biomass yielding cultivars.

REFERENCES

- Ali F, Zahid K R, Shah F, Gul R, Pan Q, Mustafa G, ...and Ullah H. 2013. Heterosis and early generation testing is a pivotal method for production of hybrid. *Australian Journal of Crop*

- Science* 7(11): 1728.
- Casas SJF, Sánchez GJJ, Ramírez DJL, RonPySand Montes HJ. 2001. Rendimiento y sus componentes en retrocruzamiento de maíz teosinte. *Revista Fitotecnia Mexicana* 24: 17–26.
- Choudhary M, Singh V, Muthusamy V and Hussain S. 2017. Harnessing crop wild relatives for crop improvement. *LS: International Journal of Life Sciences* 6(2) : 73–85.
- Cohen J I and Galinat W C. 1984. Potential use of alien germplasm for maize improvement. *Crop Sci.* 24: 1011–1015.
- Corcuera V R. 1991. Maize-Balsas teosinte and maize-Guatemala teosinte hybrids: inheritance of prolificity. *Maize Genet Coop Newsl* 65: 79–80.
- Doebley J F (1990). Molecular evidence and the evolution of maize. *Econ. Bot.* 44: 6–27.
- Domingue B F, Dellow D W and Barry T N. 1991. The chewing efficiency during eating and ruminating in goats and sheep. *British Journal of Nutrition* 65: 355–363.
- Ellstrand N C, Garner LC, Hegde S, Guadagnuolo R and Blancas L. 2007. Spontaneous hybridization between maize and teosinte. *Journal of Heredity* 98(2): 183–187.
- Emerson R A. 1924. Control of flowering in teosinte. *Journal of Heredity* 15:41–48.
- Gaudin A, McClymont S A and Raizada M N. 2011. The nitrogen adaptation strategy of the wild teosinte ancestor of modern maize, *Zea mays* subsp. *parviglumis*. *Crop Science* 51(6): 2780–2795.
- Hadjigeorgiou I E, Gordon I J and Milne J A. 2003. Intake, digestion and selection of roughage with different staple lengths by sheep and goats. *Small Ruminant Research* 47: 117–132.
- Itlis H H. 2000. Homeotic sexual translocations and the origin of maize (*Zea mays*, Poaceae): A new look at an old problem. *Econ. Bot.* 54: 7–42.
- Jyothi Lakshmi N, Raghuram Reddy P, Amol Patil, Vanaja M, Salini K, Sarkar B, Shishodia S S, Yadav S K, Maruthi V, Maheswari M, Sammi Reddy K and Ravindra Chary G 2019. CRIM-2: Maize with effective tillering trait. *Int. J. Curr. Microbiol. App. Sci.* 8(05): 1320–1327.
- Kumar R, Srinivas K and Sivaramane N. 2013. Assessment of the maize situation, outlook and investment opportunities in India. Country Report-Regional Assessment Asia (MAIZE-CRP), National Academy of Agricultural Research Management, Hyderabad, India.
- Kumar S, Agarwal R K, Dixit A K, Rai A K and Rai S K. 2012. Forage Crops and Their Management. IGFRI, Jhansi, UP, India, p 60.
- Kumari A and Patel B H M. 2015. Wastage of green fodder under different feeding systems in Rohilkhandi kids. *Livestock Research International* 3(3): 74–76.
- Le Clerc V, F Bazante, C Baril, J Guiard and D Zhang. 2005. Assessing temporal changes in genetic diversity of maize varieties using microsatellite markers. *Theor. Appl. Genet.* 110: 294–302.
- Liu Z, J Cook, S Melia-Hancock, K Guill, C Bottoms, A Garcia, O Ott, R Nelson, J Recker, P Balint-Kurti, S Larsson, N Lepak, Ed Buckler, L Trimble, W Tracy, M D McMullen, and S A Flint-Garcia. 2016. Expanding maize genetic resources with predomestication alleles: Maize-teosinte introgression populations. *Plant Genome* 9: 1–11.
- Mammadov J, Buyarapu R, Guttikonda S K, Parliament K, Abdurakhmonov I Y and Kumpatla S P. 2018. Wild relatives of maize, rice, cotton, and soybean: treasure troves for tolerance to biotic and abiotic stresses. *Frontiers in Plant Science* 9: 886.
- Meng X, Muszynski M G, Danilevskaia O N. 2011. The FT-like ZCN8 gene functions as a floral activator and is involved in photoperiod sensitivity in maize. *Plant Cell* 23: 942–960.
- Moyo M and Nsahlai I V. 2017. Rate of Passage of Digesta in Ruminants; Are Goats Different?, Goat Science, SándorKukovics, IntechOpen, DOI: 10.5772/intechopen.69745. Available from: <https://www.intechopen.com/books/goat-science/rate-of-passage-of-digesta-in-ruminants-are-goats-different>
- Omokanye A T, Balogun R O, Onifade O S, Afolayan R A and Olayemi M E. 2001. Assessment of preference and intake of browse species by Yankasa sheep at Shika Niger. *Small Ruminant Research* 42:201-208. [https://doi.org/10.1016/S0921-4488\(01\)00250-4](https://doi.org/10.1016/S0921-4488(01)00250-4)
- Reeves R G. 1950. The use of teosinte in the improvement of corn inbreds. *Agronomy Journal* 42: 248–251.
- Rutagwenda T, Lechner-Doll M, Schwartz H J, Schultka W and Von Engelhardt. 1990. Dietary preference and degradability of forage on a semi-arid thornbush savanna by indigenous ruminants, camels and donkeys. *Animal Feed Science and Technology* 31: 179–192.
- Singh N K, Kumar A, Chandra H, Pal K and Verma S S. 2017. Enhancement of maize allelic diversity using wild relative teosinte (*Zea mays* ssp. *parviglumis*). *Indian Journal of Plant Genetic Resources* 30 (3): 253–257.
- Song Y H, Shim J S, Kinmonth-Schultz H A and Imaizumi T. 2015. Photoperiodic flowering: time measurement mechanisms in leaves. *Annual Review of Plant Biology* 66: 441–464.
- Srinivasan G and Brewbaker J L. 1999. Genetic analysis of hybrids between maize and perennial Teosinte I: Morphological traits (No. CIS-2364. CIMMYT.).
- Tarter J A, M M Goodman and J B Holland. 2004. Recovery of exotic alleles in semiexotic maize inbreds derived from crosses between Latin American accessions and a temperate line. *Theor. Appl. Genet.* 109: 609–617.
- Tenaillon M I, J U'Ren, O Tenaillon and B S Gaut. 2004. Selection versus demography: A multilocus investigation of the domestication process in maize. *Mol. Biol. Evol.* 21: 1214–1225.
- Vigouroux Y, Mitchell S, Matsuoka Y, Hamblin M, Kresovich S, Smith J S, Jaqueth J, Smith O S and Doebley J. 2005. An analysis of genetic diversity across the maize genome using microsatellites. *Genet.* 169: 1617–1630.
- Vincent B. 2018. *Farming meat goats: breeding, production and marketing*. CSIRO Publishing, p 103.
- Waller A E. 1917. Xenia and other influences following fertilization. *Ohio J Sci.* 17: 273–84.
- Warburton M L, J C Reif, M Frisch, M Bohn, C Bedoya, X C Xia, J Crossa, J Franco, D Hoisington, K Pixley, S Taba and A E Melchinger. 2008. Genetic diversity in CIMMYT non-temperate maize germplasm: landraces open pollinated varieties, and inbred lines. *Crop Sci.* 48: 617–624.
- Watson A, Ghosh S, Williams M J, Cuddy W S, Simmonds J, Rey M D, ...and Adamski N. M. 2018. Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature Plants* 4(1): 23.
- Wilkes H G. 1977. Hybridization of maize and teosinte in Mexico and Guatemala and the improvement of maize. *Econ. Bot.* 31: 254–293.
- Yadav O P, Hossain F, Karjagi C G, Kumar B, Zaidi P H, Jat S L, Chawla J S, Kaul J, Hooda K S, Kumar P, Yadava P and Dhillon B S. 2015. Genetic improvement of maize in India-retrospect and prospects. *Agricultural Research* 4: 325–38.