AICRP-SORGHUM

Objectives

- Development of high yielding, medium flowering and foliar disease resistant single cut forage and dual purpose varieties with high nutritional quality and seed yield.
- Development of high yielding, early flowering, sweet and highly nutritious multi cut forage sorghum varieties and cytoplasmic male sterility based multi cut forage sorghum hybrids between sorghum (CMS lines) and sudan grass pollinators.
- Basic genetic studies on inheritance of yield and nutritional quality parameters *viz.* protein, dry matter digestibility, sweetness, juiciness and anti- nutritional factors such as HCN, tannin and fiber (components of NDF and ADF like celluloses, hemicelluloses, lignin etc.)
- Improvement in nutritional quality of potentially high yielding genotypes by using appropriate breeding methodology based on information generated from basic genetic studies.
- Development of special types (red grain, BMR and high biomass) sorghum for industrial use
- Development of three way cross hybrids with red/white grain to address problem of F_1 seed yield and market/consumer preference
- Popularization of newly developed varieties and hybrids of forage sorghum among farmers through organizing Front Line Demonstrations.
- Promoting Public-Private Partnership (PPP) to commercialize seed production and to disseminate hybrid seeds of new and improved forage sorghum hybrids, to the target farmers/dairymen throughout the country.

A. Sorghum Breeding

1. Significant Achievements:

Being the only Agriculture University in the state of Uttar Pradesh at that time and keeping in view of the importance of sorghum as one of the major fodder crops in the state, the work on sorghum improvement was initiated at Pantnagar in the year 1967. Received from various national and international agencies, a collection of more than 2500 germplasm lines (mostly IS numbers) was evaluated for fodder yield and nutritional quality parameters. Selected on the basis of 2-3 years of evaluation, the lines *viz.* IS 4776, IS 6953, IS 9722, IS 7002, IS 3555, IS 6090, IS 8087, IS 607 and IS 4777 which were found promising in station trials were incorporated for evaluation in All India Coordinated Trials. Later, by including the above selected lines alongwith released and popular forage sorghum varieties of other states *viz.* Vidisha 60-1, (Madhya Pradesh), JS 73/53 (Haryana), SL 44 (Punjab), MP Chari (Madhya Pradesh) and sweet sorghum variety Rio (released in India through direct introduction), in the crossing block, the varietal development programme, based on inter-varietal crossing through hand emasculation and pollination, was also initiated in 1970. Identified donors for multiple traits like low HCN content, high digestibility and shoot fly resistance (IS 4776), high TSS (total soluble solids) and juiciness of stem (Rio, Leoti, IS 607), fast growth and regeneration (IS 6953), high forage yield (Vidisha 60-1) and good grain quality (CS 3541) were exhaustively used in the hybridization programme to generate variable breeding material for selection.

Considering the quantum and significance of research work done on forage sorghum improvement

and large number of entries contributed in the All India Coordinated Trials, Pantnagar was given the status of one of the Coordinating Centers of All India Coordinated Sorghum Improvement Project (ICAR) in 1976.

Development of forage sorghum varieties and Single cross hybrids

In view of the great popularity of multicut forage sorghum among the farmers and dairymen, the on-going research efforts are mainly focused at the development of high yielding multicut varieties and hybrids with high resistance to foliar diseases and improved nutritional quality. Improvement in conventional forage varieties of multicut types for nutritional quality, disease resistance and seed production ability is in progress through combined research efforts in the disciplines of Breeding and Genetics and Plant Pathology. Till date Pantnagar centre working on the mandate of developing high yielding, early flowering, disease resistant and improved nutritional quality varieties/hybrids have developed and released twelve (12) varieties of forage sorghum *viz.* UP Chari 1, UP Chari 2, Pant Chari 3, Pant Chari 4, Pant Chari 5, Pant Chari 6, Pant Chari 7, Pant Chari 8, Pant Chari 9, Pant Chari 10, Pant Chari 11 and CSV 35F and three hybrids *viz.* CSH 20 MF, CSH 24 MF and CSH 40F, brief details of which are given in the following table. New single cross hybrids and varieties of single cut and multicut types are regularly contributed in AICSIP and State Evaluation Trials.

Table: Varieties and hybrids of forage sorghum released

S. No.	Variety/ Hybrid	Year of release (releasing agency)	Single cut/ Multicut (2-3 cuttings)	Salient features
1	UP Chari 1	1979 (SVRC/CVRC)	Single cut	High fodder yield, low HCN content, highly juicy & resistant to stem borer and shoot fly
2.	UP Chari 2	1983 (CVRC)	Single cut	High fodder yield, high protein and digestibility, tolerant to foliar diseases
3	Pant Chari 3	1989 (SVRC)	Single cut	High fodder yield, high protein and digestibility, tolerant to foliar diseases,
4.	Pant Chari 4	1994(SVRC)	Single cut	High fodder yield, high protein and digestibility very juicy and sweet stem
5.	Pant Chari 5	1999 (CVRC)	Single cut	High green fodder yield (550q/ha), high protein and digestibility, very juicy and sweet stem, resistant to foliar diseases with stay green character. Good grain quality and yield with pearly white bold grain.
6.	Pant Chari 6	2004(SVRC)	Multicut	High green fodder yield (700-800 q/ha) very low HCN content, high protein & dry matter digestibility.
7.	CSH 20 MF (Hybrid)	2005 (CVRC)	Multicut	High fodder yield (800-950 q/ha green fodder), very low HCN content, high protein & dry matter digestibility with resistance to foliar diseases.
8.	CSH 24 MF(Hybrid)	2009 (CVRC)	Multicut	High green fodder yield (800-950 q/ha) very low HCN content, high protein & dry matter digestibility, resistance to foliar diseases.
9.	Pant Chari 7	2010(SVRC)	Single cut	High fodder yield (550-650 q/ha green and 225-275 q/ha dry) high protein content (7.70%), high digestibility (56.90%) Resistant to major foliar diseases.

10.	Pant Chari 8	2010(SVRC)	Multicut	750-850 q/ha green and 200-275 q/ha dry fodder yield. Low HCN content, high protein content (7.48%) and high digestibility (55.73%).
11.	Pant Chari 9	2018(SVRC)	Multicut	High fodder yield (850-900 q/ha green and 275-318 q/ha dry). Low HCN, high protein (7.29%) and high digestibility (58.74%)
12.	Pant Chari 10	2018(SVRC)	Multicut	Average fodder yield (750-800 q/ha green and 175-225q/ha dry). Low HCN and high protein content (7.16%).
13.	Pant Chari 11	2018(SVRC)	Multicut	High fodder yield (800-875 q/ha green and 190-250 q/ha dry). Very low HCN (89.19 ppm) and high protein content (7.28%)
14	CSV 35F	2018(CVRC)	Single cut	High fodder yield (650-750 q/ha green and 175-200 q/ha dry).Very high protein content (8.38) and high digestibility (53.71%). Resistance to foliar disease stay green quality and red colour grain
15	CSH 40F (Hybrid)	2018(CVRC)	Single cut	Average yield 700-900 q/ha green fodder and 200-275 q/ha dry fodder. Low HCN content (92.42ppm), High protein content (8.39), high digestibility (53.46%).

Development of three way cross and red grain hybrids

To address the problem of poor seed yielding ability of conventional CMS lines being used in single cross hybrid development of forage sorghum, work is also in progress to develop three way cross and red grain hybrids. Two three way cross hybrids *viz*. SPH 1807 (UTMCH 1315-multicut) and SPH 1822 (UTFSH 3- single cut) are in advanced stage of testing in AICRP Trials.

Identification of best combiners for forage yield and quality

Best combining CMS lines *viz*. 2219A, ICSA 467, $11A_2$, $32A_2$, 104A, ICSA 469, ICSA 693 and ICSA 351 alongwith single cut restorer/ pollinator Pant Chari 5 and multicut restorer/ pollinator Pant Chari 6, SSG 59-3 and SGL 87 have been identified.

Pre breeding programme

A core collection of 400-450 diverse germplasm including sorghum, forage sorghum, sudan grass and several wild type sorghums is being maintained and utilized under pre-breeding programme. New crosses (F_1s), single plant progenies and progeny bulks of different crosses of different generations from F_2 to F_7 onwards are being planted for rigorous evaluation and single plant/bulk selections through within and between progeny rows/progeny bulks selection for desirable fodder traits *viz.* multicut/tillering, single cut/dual purpose, sweetness/juiciness of stem, brown midrib traits, foliar disease resistant, earliness and colour (red/brown/yellow) grain every year. During last two *Kharif* seasons (2017 and 2018) 40 new inter varietal F_1 crosses were made. Approximately 1000 single plant progenies and 100 progeny bulks of 140 crosses of different generations from F_2 to F_7 onwards, have been planted for rigorous evaluation and single plant/bulk selections through within and between progeny rows/progeny and bulks selection for desirable fodder traits viz. multicut/tillering, single cut/dual purpose, sweetness/juiciness of stem, brown midrib traits, foliar disease resistant and earliness etc.

B and R line development/ improvement programme

Beside conventional pre-breeding approach of inter-varietal crossing and selection in segregating generation, for CMS based hybrid development programme a collection of 67 pairs of A/B lines (A_1,

S. No.	Traits	Bench Mark	Sources/ Germplasm lines
1.	Resistance to foliar diseases	Less than 2 score	IS 6953, CSV 15, Pant Chari 5, IS 9722, IS 3555, UPFS 38, ICSV 700, ICSV 702, IS 23586, PVK 806, SPV 462, IS 22996, 1939 (08RLD 01-5-1), 1930 (08RLD 01-1-3), 1941 (08RLD 01-5-3), 1946 (08RLD 01-7-2)
2.	High protein content	8% (minimum)	SDSL 92111, SDSL 92101, UP Chari 2, Pant Chari 5, IS 6953, GD 68717,GD 68724
3.	Low HCN content	100 ppm (maximum) at 25-35 DAS	SDSL 92140, SDSL 12111, SSG 59-3, IS 3359, CO(FS) 29, Pusa Chari 23, IS 3312, IS 3314, CSV 33MF, SGL 87
4.	Insect tolerance (Shoot fly)	Less than 15% dead heart	ICSV 700, ICSV 7002, Pant Chari 5
5.	Sweetness (T.S.S. %)	10-12% T.S.S. (minimum) at 50% flowering	SSV 84, IS 7002, IS 9722, CSV 19SS, Pant Chari 5, ICSV 77113
6.	Yield (Single cut type)	500-550 q/ha (GFY) 175-250 q/ha (DFY)	CSV 15, Pant Chari 5, IS 9722, Pant Chari 3, HJ 513, HJ 541, PSSV 61, IS 7002
7.	Yield (Multi cut type-Tillering and Regeneration)	750-900 q/ha (GFY) 200-250 q/ha (DFY) (in 2-3 cuttings)	IS 3312, IS 3314, SDSL 92102, SDSL 92101, SDSL 92140, IS 3359, SSG 59-3, CSV 33MF, UTMC 534, UPMC 512, PC 23, Pant Chari 6, SGL 87, Pant Chari 8, Pant Chari 9, UPMC 8, UPMC 6
8.	Brown midrib/high Digestibility	50% IVDMD (Minimum)	EC 582504, EC 582506, EC 582508, GD 68717, GD 68724
9.	Seed yield	18-25 q/ha (range)	SPV 422, SPV 1616, Pant Chari 5, IS 3555, IS 7002
10.	Coloured grain	Red, brown and yellow	**Red:** IS 7002, IS 6953, ICSV 693, ICSV 635, ICSV 94002, ICSV 351, E 28, ICSV 77113, IS 14756 **Yellowish brown:** IS 3821, IS 20703, IS 9722

A_2 and A_3) is being maintained and utilized. Beside for development of new CMS lines a separate B line improvement development programme for disease resistance, panicle size/ seed yielding ability, red seed colour and earliness is also in progress. Single plant progenies of 12 B×B crosses have been advanced to further generations. Under R line/donor/varietal development programme, 62 multicut high tillering types as restorers, 19 sweet and juicy types, 77 disease resistant stay green types and 22 stable brown midrib types, as donors have been identified during last six to seven years. Twenty elite lines of multicut forage sorghum and twenty nine elite of single cut forage sorghum based on their performance in station trials have been identified for multi-location testing yield and quality evaluation trials at State and National level.

Identification of donors for various traits

Potential donors for high protein, high TSS, low HCN, disease and insect resistance, tillering and regeneration and special traits (BMR/coloured grain) have been identified and being used in the hybridization programme.

Diversification of cytoplasm source

Diversified cytoplasm (other than A_1 type Milo cytoplasm) for multi cut and single cut forage sorghum hybrid development is also in progress. Several collections of A_2, A_3 and A_4 cytoplasmic male sterile lines have been tested for their general combining ability with potential multicut type pollinator parents. The experimental hybrids based on alternate cytoplasm *viz.* 11 A_2 × Pant Chari 6 and 32 A_2 × Pant Chari 6 have been tested in the AICSIP multi location trials and the hybrids based on 11A_2 has been found to be promising for multicut and as well as single cut forage sorghum hybrids.

Sweet sorghum and high biomass sorghum for second generation bio fuel

Several sorghum genotypes with high sugar

content (high TSS) and high biomass production are available with the project which may be good choice as source of second generation bio fuel. Avenues are also available to develop high sugared multi cut varieties and hybrids by using sweet stemmed genotypes in the breeding programme to improve CMS lines and sudan grass type pollinators. Advanced elite lines developed with BMR trait at the centre may also be explored for their use as source for second generation bio fuel.

Fodder Quality Improvement and use of BMR trait

So far as nutritional quality is concerned, sorghum has highly palatable and digestible fodder with an average of 7.5-9.0 per cent crude protein and 48-55 per cent of dry matter digestibility. Furthermore, low HCN content is very important requisite for forage sorghum in general and for multi cut forage sorghum in particular, because it is to be fed before flowering and often face hot and dry weather before onset of monsoon. Therefore, besides improving the intake characteristics, elimination of toxic substances is another most important aspect of forage sorghum improvement programme. Brown Midrib (BMR) and coloured grain sorghum and three-way cross of forage sorghum hybrids are the prospects on which lot of opportunities are available to put concerted efforts in the coming years. Progenies of crosses between BMR (brown midrib) × GMR (green midrib) genotypes having the tan plants with brown midrib, less disease and other fodder quality attributes have been selected in advanced generations and some of the best elite lines have been evaluated for protein, fiber content and IVDMD per cent. Eight best BMR lines identified after evaluation will be registered under germplasm registration as potential donors for unique trait.

Registration of varieties/hybrids under PPV & FR Act

- Forage sorghum varieties Pant Chari 4, Pant Chari 5 and Pant Chari 6 and forage sorghum hybrids CSH 20 MF and CSH 24 MF have been registered with Protection of Plant Varieties and Farmers' Rights (PPV & FR) Authority, New Delhi, as Extant Notified Varieties.

Licensing for seed production through Public – Private Partnership

Several MOUs are in operations between IIMR, Hyderabad and private seed companies of Andhra Pradesh, Karnataka and Maharashtra for production of large quantity of hybrid seed of multicut forage sorghum hybrids CSH 24 MF developed by this centre. The CSH 24MF has become very popular and occupies large area for fodder production.

Nucleus and Breeder seed production

Sufficient quantity of nucleus seed is being produced to meet the demand for breeder seed production against indents of Department of Agriculture and Cooperation (DAC). Appropriate quantity of breeder seed of forage sorghum varieties (Pant Chari 5, Pant Chari 6) and parental lines (ICSA 467/ICSB 467 and 2219A/B) is being produced and supplied to the indenting agencies by the Breeder Seed Production Centre of the University.

Front Line Demonstrations

Sorghum is the major fodder crop of *Kharif* season in the state of Uttarakhand where dairy industry is very well developed, especially in the whole area in districts of Udham Singh Nagar, Haridwar and Dehradun and plain areas of Nainital and Champawat districts. The local cultivars of sorghum being used by the farmers and dairyman for fodder production, besides having poor fodder yield, has high incidence of foliar and stem diseases, thereby hampering the nutritive value of the fodder and ultimately reducing milk production.

Seeds of improved varieties/hybrids of forage sorghum *viz*. Pant Chari 5,

Pant Chari 6, CSV 30F, CSH 20MF, CSH 24MF and other promising hybrids are given to the farmers for conduction of FLDs. The feedback obtained from the farmers regarding improved cattle health and increased milk production as result of feeding of improved varieties, was very encouraging. The results on FLDs during last 5-7 years have shown fodder yield superiority of 55-80% along with greater

net monetary returns for Improved Practice (IP) with use of improved varieties and cultural practice in comparison to Farmers' Practice (FP) with use of local cultivars.

Strategic Services

Owing to leading centre for forage sorghum research in the country and favourable climate for character expression, Pantnagar is designated as notified centre for testing of Distinctiveness, Uniformity and Stability (DUS) for registration of forage type varieties/hybrids under PPV& FR Act. All the facilities required for DUS Testing such as net-wire fenced DUS Test field, field laboratory and digitalized database of DUS characteristics in sorghum have been developed at the Centre. A reference collection of sixty genotypes including extant notified varieties and hybrids, local varieties, example varieties and parental lines of forage and dual purpose hybrids was characterized and the data base for DUS characteristics of all the genotypes of reference collection has been developed at the centre and also submitted to the PPV & FR Authority.

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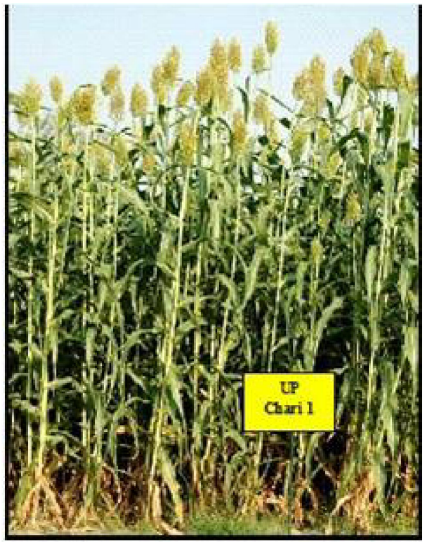
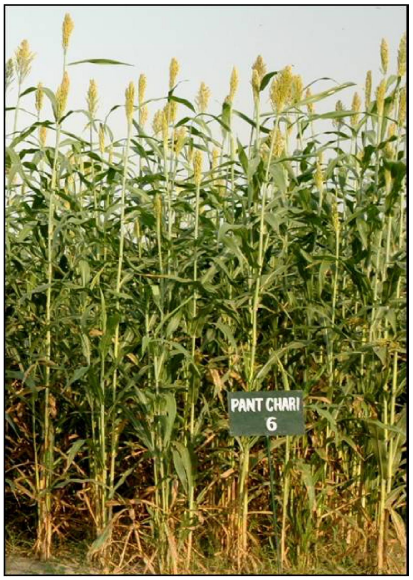
Released Varieties & Hybrids of Forage Sorghum





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13. Pandey, P.K.; Vikas Mangal and Verma, L.K. (2018). Hybrid seed production techniques in sorghum. *Indian Farmer's Digest*. 51(7): 27-32.

3. Thesis Research:

1. Meenu Agarwal. 1999. Varietal characterization and divergence studies in elite lines of sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc .Ag. to GBPUAT under supervision of Dr. Rameshwar Singh.
2. Birendra Prasad.2000. Effect of row ratio and staggered planting of parental lines on seed yield and quality of forage sorghum hybrid PCH-106 submitted for Ph. D. to GBPUAT under supervision of Dr. Rameshwar Singh.
3. Sanjay Gupta. 2001. Callus induction, plant regeneration and *Agrobacterium* mediated genetic transformation studies in sorghum

submitted for Ph. D. to GBPUAT under supervision of Dr. Rameshwar Singh.

4. Meenu Agarwal. 2002. Studies on heterosis, inbreeding depression and combining ability and genetic variability by RAPD in sorghum submitted for Ph. D. to GBPUAT under supervision of Dr. Rameshwar Singh.

5. Arun Bhatt.2003. Studies on SDS-PAGE and RAPD profiles and heterosis and combining ability in sorghum submitted for Ph. D. to GBPUAT under supervision of Dr. Rameshwar Singh.

6. Shivji Singh.2003. Heterosis and combining ability studies on yield and quality traits in forage sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. P. K. Shrotria.

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10. Rajneesh Kumar Singh. 2006. Genetic analysis of yield and quality traits in forage sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. P. K. Shrotria.

11. Rajeev Kumar. 2007. Studies on genetic divergence and seed protein profiling in forage sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. P. K. Shrotria.

12. Suneeta Pandey. 2009. Studies on heterosis, inbreeding depression, combining ability and estimation of genetic variability through molecular markers in sorghum [*Sorghum bicolor* (L.) Moench] submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Shrotria.

13. Ajay Paliwal. 2012. "Studies on Combining Ability and Heterosis in Forage Sorghum [*Sorghum bicolor (L.) Moench*] Hybrids Developed on Alternate Cytoplasms" submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Shrotria.

14. Ankita. 2014. "Assessment of Seed Quality Parameters and DUS Characterization of Sorghum [*Sorghum bicolor (L.) Moench*] Genotypes by Morphological Biochemical and Molecular Markers" submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Shrotria.

15. Pankaj Kumar. 2015. Studies on Heterosis and Molecular Diversity in Forage Sorghum [*Sorghum bicolor (L.) Moench*] Hybrids submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Shrotria.

16. Rajendra.2017. "Genetic analysis of economic traits in sorghum (*Sorghum bicolor* L. Moench*)"* submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Shrotria.

17. Mahendra Kumar Dubey.2014. Studies on variability, correlation and path coefficient analysis in sorghum [*Sorghum bicolor* (L.) Moench] submitted for M.Sc. to GBPUAT under supervision of Dr. P. K. Pandey.

18. Bijendra Meena.2015. Evaluation and genetic analysis for yield and quality traits in Sorghum [*Sorghum bicolor* (L.) Moench] submitted for M.Sc. to GBPUAT under supervision of Dr. P. K. Pandey.

19. Priyamvada Chauhan. 2016. Studies on molecular diversity, heterosis, combining ability and seed vigor

in sorghum [*Sorghum bicolor* (L.) Moench] submitted for Ph.D. to GBPUAT under supervision of Dr. P. K. Pandey.

20. Devendra Upreti. 2017. Divergence analysis for morphological and quality characters in sweet sorghum [*Sorghum bicolor* (L.) Moench] genotypes submitted for M.Sc. to GBPUAT under supervision of Dr. P. K. Pandey.
21. Naveen Chandra. 2018. Studies on genetic divergence and genotype x environment interaction in sorghum [*Sorghum bicolor* (L.) Moench] submitted for M.Sc. to GBPUAT under supervision of Dr. P. K. Pandey.
22. Naveen Sihag. 2018. Evaluation of elite sorghum [*Sorghum bicolor* (L.) Moench] germplasm lines for fodder yield and nutritional attributes submitted for M.Sc. to GBPUAT under supervision of Dr. P. K. Pandey.

4. Awards:

Based on the review of the work done on the aspects of variety release, publications, breeder and nucleus seed production, proper conduction of experiments, quality of data reported, basic and strategic research, contribution of entries/checks to AICRP and State Trials and reports of QRT and Monitoring Team from ICAR, Pantnagar Centre was adjudged the ***"Best Performing Kharif Centre 2010"*** amongst all the AICSIP (All India Coordinated Sorghum Improvement Project) Centers of the country, during 41st Annual Sorghum Group Meeting held at UAS, Dharwad from April 15-17, 2011 and

Pantnagar centre achieved the distinction again in 2019 for its **"Immense Contribution in the Development of Many Promising Elite Lines in Sorghum leading to better livelihood and nutritional security in dryland ecosystems of India "** during 49th Annual Sorghum Group Meeting held at CCS HAU, Hisar from May 28-30, 2019.

5. Future Thrusts:

- ✓ Foliar disease resistance breeding through screening/ identification/validation of sources and recombination breeding and selection in segregating generation
- ✓ Intensive inter-varietal crossing to develop coloured grain genotypes
- ✓ Testing of nutritional quality traits of coloured grain genotypes
- ✓ Quality evaluation (IVDMD, ADF, NDF, Lignin, protein) of stable BMR lines (8) and their use in breeding
- ✓ Standardization of screening techniques to identify sources of resistance to shoot fly, stem borer and pyrilla
- ✓ Development of high biomass sorghum genotypes with good lignocellulosic biofuel traits
- ✓ Selection in segregating generations of cross with CO (FS) 29 and CSV 33F and attempting new wide crosses to develop multi cut forage genotypes

B. Sorghum Pathology:

1. Significant Research Achievements:

- TH 39 and PSF 28, isolates of *Trichoderma*

harzianum and *Pseudomonas fluorescens,* respectively have been found to be best isolates for control of anthracnose (*Colletotricum graminicola*) and zonate leaf spot (*Gloeocercospora sorghi*) foliar diseases.

- Soil solarization in combination with *Trichoderma harzianum* (TH 43 and TH 39) and *Pseudomonas fluorescens* (PSF 27) resulted in significant increase in plant growth and reduction of anthracnose severity in sorghum and hence can be recommended for management of anthracnose of sorghum.
- Eight grain sorghum genotypes (SPV 1659, SPV 1643, IS 14332, SPV 1685, SPV 1686, SPV 1713, SPV 1714 and SPV 1727) and four forage sorghum genotypes (UTFS 45, UTMCH 1302, UTMC 532 and PC 5) have been found consistently resistant against anthracnose and zonate leaf spot.
- Intercropping of sorghum with pigeonpea (3:3) reduces disease severity of anthracnose besides providing remunerative return.
- The isolates *viz*. TH 2, TH 14 and PSF 173, of *Trichoderma harzianum* and *Pseudomonas fluorescens* respectively, have been found to be best bio-control agent isolates for the management of Erwinia stalk rot.
- TH 32 isolate has been found promising for the management of sugary disease.
- Leaf whorl inoculation, stem injection and Root tip cut and dip methods were evaluated under field conditions for germplasm screening against stalk rot of sorghum caused by *E.chrysanthemi*. Root tip cut and dip method was found best for screening against ESR.
- Isolates of *Colletotricum graminicola* and *Gloeocercospora sorghi* from leaves of diseased sorghum plants collected from different locations of Uttarakhand were characterized which differed morphologically, in cultural characters and at molecular level Using RAPD markers. Estimation of similarity indices showed a relatively high level of variability among isolates.

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Books:

- फसल–सब्जी–फल रोग, पहचान एवं प्रबंध –योगेन्द्र सिंह व अखिलेश सिंह 2009. Directorate of Publication, G B Pant Univ. of Agric. & Technology, Pantnagar, India. 116 pp.
- Singh, V. K., Singh, Y. and Singh, A. (Eds.) 2012. Ecofriendly Innovative Approaches in Plant Disease Management. International Book Distributers, Dehradun, India. 682 pp.
- मुख्य फसलों व सब्जियों के रोग एवं प्रबन्धन –अखिलेश सिंह व योगेन्द्र सिंह 2014. Directorate of Publication, G B Pant Univ. of Agric. & Technology, Pantnagar, India. 179 pp.

Lab Manual

Singh, Y. and Kharayat, B.S. (2013). Plant Bacteriology Laboratory Manual. 109 pp.

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Singh, Y., Kharayat, B.S. and Gupta, A.K. (2013). Sanitary and Phytosanitory Measures for controlling Plant Pathogens. *In* Plant Disease Management for Food Security. Eds. Prajapati, C.R., Singh, K.P. and Gupta, A.K.pp.546-586. . LAP LAMBERT Academic Publishing, Germany.

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Singh, Y. and Sharma, D. (2018). Biological control of major diseases of sorghum. *In* Biological Control of Crop Diseases: Recent Advances & Perspectives. Eds. Singh, D., Chakraborty, B.N., Pandey, R.N., and Sharma, P. pp. 463-478. Today and Tomorrow's Printers and Publishers, New Delhi, India.

Popular Articles

1. Singh Y., Singh A. and Singh V. K. 2007. ज्वार के प्रमुख रोग एवं उनकी रोकथाम। खेती दुनिया. 8.

2. Shrotria P.K.; Singh Y; Singh Shiv Ji; Kumar A and Hetram. 2011. अखिल भारतीय समन्वित ज्वार उन्नयन परियोजना, पन्तनगरः एक परिचय. ज्वार सौरभ. 2: 38-43.

3. Singh, V. and Singh Y. 2014. Important diseases of sorghum in Uttarakhand. *Indian Farmers' Digest* 47(05):20-22.

4. Sharma, D. and Singh Y. 2016. Major diseases of sorghum in Tarai region of Uttarakhand and their management. *Indian Farmers' Digest* 49 (2): 16-17.

3. Thesis Research:

1. Jameel Akhtar. 2000. Evaluation of oil cakes and bio-agents against *Colletotrichum sublineolum* (Henn, Kabat et Bub.), the causal agent of anthracnose of sorghum submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. R.R. Dwivedi.

2. Ram Narayan. 2001. Antifungal activity of essential oils and some plant extracts against *Colletotrichum graminicola* (Ces.) Wilson, the causal organism of anthracnose of sorghum submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. R.R. Dwivedi.

3. Shri Nivasa D.H. 2004. Studies on hydrocyanic acid (HCN) content of sorghum in relation to infection of *Colletotrichum graminicola* (Ces.) Wilson, the causal organism of anthracnose submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. R.R. Dwivedi.

4. Pratibha Sati. 2005. Studies on different components of integrated disease management for anthracnose of sorghum caused by *C.graminicola* (Ces.) Wilson submitted for Ph.D. to GBPUAT under supervision of Dr. R.R. Dwivedi.

5. Indra Kumar Tiwari. 2006. Studies on zonate leaf spot of sorghum caused by *Gloeocercospora sorghi* submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

6. Gitanjali Bangari. 2007. Studies on anthracnose of sorghum caused by *Colletotrichum graminicola* submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

7. Yogesh Kumar Meena. 2008. Biological control of anthracnose of sorghum caused by *Colletotrichum graminicola* submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

8. Bhupendra S. Kharayat. 2009. Management of zonate leaf spot of Sorghum caused by *Gloeocercospora sorghi* submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

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11. Vimlesh Kumar Singh. 2013. Management of Zonate Leaf Spot of Sorghum with non chemical methods submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

12. Prachi Singh. 2015. Studies on characterization, inoculation methods and management of stalk rot of sorghum caused by *Erwinia chrysanthemi* submitted for M.Sc. Ag. to GBPUAT under supervision of Dr. Y Singh.

13. Rekha. 2013. Studies on characterization and management of *Colletotrichum graminicola*, the causal agent of anthracnose of sorghum submitted for Ph.D. to GBPUAT under supervision of Dr. Y Singh.

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15. Gaurav Verma. 2014. Induction of Host Defence through Biocontrol agents in *Sorghum bicolor* Moench against *Gloeocercospora sorghi* Bain&Edg. submitted for Ph.D. to GBPUAT under supervision of Dr. Y Singh.

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17. Sweta Badoni. 2015. Isolation, characterization and evaluation of antagonistic potential of *Trichoderma* isolates against *Colletotrichum graminicola* and *Gloeocercospora sorghi* submitted for Ph.D. to GBPUAT under supervision of Dr. Y Singh.

18. Meenakshi Rana. 2016. Variability in *Colletotrichum graminicola* causing anthracnose of sorghum and its management submitted for Ph.D. to GBPUAT under supervision of Dr. Y Singh.

19. Mamta. 2017. Variability in *Gloeocercospora sorghi* causing zonate leaf spot of sorghum and its management submitted for Ph.D. to GBPUAT under supervision of Dr. Y Singh.

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4. Future Thrusts:

- Screening of germplasm for disease resistance
- Isolation, characterization and establishment of a repository of native Bio-control Agents (BCAs) from rhizosphere of sorghum
- Management of foliar diseases and bacterial stalk rot through Bio-control agents
- Studies on expression of defense genes in plants treated with BCAs
- Study of variability in *C. graminicola* causing anthracnose of sorghum

C. Sorghum Agronomy:

1. Significant Achievements:

The yield evaluation trials of pre-released varieties and hybrids of single cut and multicut forage sorghum for their response to different fertility levels are being conducted for developing cost effective cultivation practices for fodder purpose. Work has also been initiated on assessment of different forage crops as potential source of bio energy production under different cropping systems.

✓ The varieties S 540 for green fodder yield and S 541 and

UTFS 49 for dry matter yield were found significantly better. Green forage as well as dry matter yield increased significantly with increase in nitrogen levels from

0 to 100 Kg/h.

✓ Green forage as well as dry matter yield increased significantly with increasing dose of nitrogen up to 80Kg N/ha and phosphorus up to 40Kg P_2O_5/ha. The combination of fertilizer N_{80} P_{40}, being *at par* with N_{120} P_{60}, caused significantly higher green forage and dry matter yield as compared to other combinations.

✓ Inoculating sorghum seeds with *Azospirillum* caused significant increase in green forage and dry matter yield as compared to non-inoculation. The economic analysis indicated that application of 100% RDF and seed inoculation with *Azospirillum* caused significant increase in net return as well as rupees per rupee invested.

✓ The varieties UTMC 532, GK 909 and SSG 59-3 (check) and hybrids UTMCH 1302, UTMCH 1304, SPH 1626, SPH 1627, CSH 20 MF(check) and CSH 24 MF(check) gave significantly highest total green fodder yield. A dose of 150 Kg N/ha was found to cause significantly more fodder yields as compared to remaining nitrogen levels. Green as well as dry fodder yields, increased significantly with each increasing level of nitrogen with highest at 150 Kg N/ha as well as net monetary returns.

✓ 75% of recommended N + *Azospirillum* inoculation and 75% of recommended N + 25% N through FYM were best for green as well as dry fodder yield and net return in terms of Rs./ ha. 50 0% RDF + 25% N through FYM + *Azospirillum,* 75% RDF + 25% N through FYM) and 50% RDF + 50% N through FYM were other good INM practices.

✓ Integrated nutrient dose of 100% RDF + 25 Kg Zinc Sulphate/ha was best for green as well dry fodder yield besides various growth parameters like leaf stem ratio and plant height.

✓ Inter cropping of 1:1 sorghum with *Pillipesara* gave highest net return and benefit cost ratio followed by 2:2 sorghum intercropping with *Pellipesara* (Rs.19, 625/ha). Besides, 2:1 inter cropping of sorghum with *Phillipesora* gave highest dry fodder yield.

✓ Plant spacing of 45x15cm gave maximum green cane yield, fodder yield and juice yield. Application of 120 Kg N/ha gave maximum and significantly highest green cane and fodder yield however, for juice yield this treatment was *at par* with 90 Kg N/ha. Plant spacing did not exert any significant effect on juice yield however, it increased significantly with increased Nitrogen level from 30 to 90 Kg N/ha.

✓ 150% RDF gave highest yield. The genotype SPV

1754 gave highest green as well as dry fodder yield. SPV 1754 responded as significantly best genotype at 150% RDF for green fodder yield (740.74 q/ha). For dry fodder, SPH 1467 gave highest yield at 100% RDF but was *at par* with SPV 1754 at 50% and 100% RDF, and with SPV 1753, SPV 1754 and SPH 1467 at 150%RDF. Stem girth increased significantly with increasing doses of RDF.

- ✓ No significant yield difference as compared to Control (conventional tillage + RDF) was observed under different tillage practices and INM doses. Conventional tillage with 100% RDF was best for GFY.
- ✓ Soil application of 100% RDF +15 Kg Zn + 15 Kg Fe gave highest GFY, DFY, net monetary returns and crude protein %.
- ✓ 150% more RDF gave significantly highest yield of green fodder as well as grain. The variety SPSSV 40 was significantly best for grain yield.
- ✓ The sweet sorghum variety CSV 19SS gave significantly highest green and dry fodder yield. The application of N@120Kg/ha was significantly best treatment for yield and net monetary returns. Sowing of sweet sorghum genotypes at seed rate of 60 Kg/ha gave good yield of highly digestible fodder
- ✓ Sowing on 15th April gave highest cane yield, juice yield and juice quality. High brix and high sucrose content was recorded in 15th May sowing.
- ✓ Millable cane yield increased significantly with increase in nitrogen levels, however, sowing done at 30 x 15 cm spacing yielded significantly more millable canes. Juice% and Brix (%) Increased significantly by application of 100 Kg N/ha. Wider spacing though increased the brix but spacing did not influence significantly the juice and brix per cent.
- ✓ Application of 150% more dose of fertilizers than recommended dose of fertilizer (RDF) resulted in significant increase in grain and green fodder yield, cane yield, stover yield, juice yield, cost benefit ratio and net monetary return.
- ✓ Application of 120 Kg N/ha gave significantly highest green (598.5q/ha) and dry fodder (148.4q/ha) yield along with net monetary returns and cost: benefit ratio.
- ✓ At both the cutting green fodder and dry fodder yield increased significantly with increasing fertility levels. There was a increasing trend in green and dry fodder yields from 50% to 125% RDF. Nitrogen content and nitrogen uptake, net return and B: C ratio increased significantly with increasing dose of fertility.
- ✓ Full package of practices (FPP) produced significantly highest green fodder and dry fodder yield. Important management component had greater influence on green fodder yield and dry fodder yield. In order of importance, most important component was fertilizer application followed by weed management.
- ✓ The green fodder yield increased significantly with increase in nutrient supply. 100% RDF gave significantly highest green fodder yield. Intercropping systems of sole cowpea gave significantly highest green fodder yield (628.6 q/ha) while intercropping of sole cluster bean had significantly highest digestibility percent.

2. Research Publications:

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3. Verma SS, Singh V, Joshi YP and Yadav MS 2003. Integrated weed management in forage sorghum in north region of Uttar Pradesh. *J. Farming Sys. Res. & Dev.* 8(1): 69-73.

4. Chandra R, Joshi YP and Malik HPS 2003. Response of forage sorghum (*Sorghum bicolor*) genotypes to cutting intervals. National symposium on sustainability, advancement and future thrust areas of research. held at CCS.HAU. Hisar, March, 5-6, 2003. pp-115.

5. Verma SS, YP Joshi and Singh Virendra 2003. Response of sorghum to bio- fertilizer and nitrogen. *Pantnagar Journal of Research.* 1 (2): 13-16.

6. Chandra R, Joshi YP and Verma SS 2004. Response of multicut forage sorghum [*Sorghum bicolor* (L.) Moench] to cutting intervals. *J. Farming Sys. Res. & Dev.* 10(1&2): 128-129.

7. Verma SS, Singh B, Joshi YP and Jaiswal RS 2004. Effect of nitrogen levels on seed production of forage sorghum genotypes. *J. Farming Sys. Res. & Dev.* 10(1&2): 111-112.

8. Verma S S, Joshi YP, Saxena SC and Bhardwaj AK 2004. Effect of special arrangement on growth, yield and economics in pigeon pea, fodder sorghum inter cropping system under rainfed condition of north India. *Journal of Rural & Agril. Research.* 4(1&2): 22-24.

9. Verma SS, Joshi and Saxena SC 2005. Effect of row ratio of fodder sorghum (*Sorghum bicolor*) in pigeon pea (*Cajanus cajan*) intercropping system on productivity, competition functions and economics under rain fed conditions of North India. *Indian Journal of Agronomy.* 50: 123-125.

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11. Verma SS, Chandra R, Joshi YP, Saxena SC and Singh VP 2005. Comparison of serials and fodder cropping sequences under integrated fertilizer management with organic and inorganic fertilizer in *Tarai* condition of Northern India. *Pantnagar Journal of Research.* 3 (1): 4-8.

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14. Joshi Y P, Chandra R and Verma SS 2007. Response of multi cut forage sorghum [*Sorghum bicolor* (L.) Moench] to different cutting intervals. *Forage Res*. 32 (4): 262 - 263.

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2. Verma SS and Chandra R 2004. ज्वार के साथ लोबिया की मिलवा खेती की उन्नत विधि. *Kisan Bharti.* 36 (11) :37-38.

3. Verma SS and Chandra R 2005. किसान अधिक लाभ के लिए धान–गेहूं–ज्वार/लोबिया (चारा) फसल–क्रम को अपनायें. *Kisan Bharti.* 36 (12): 13-14.

3. Thesis Research:

1. R. Chandra. 2000. Studies on yield capability of different sorghum (*Sorghum bicolor*) genotypes at varying levels of N and P submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. O.P. Singh.

2. Vineet Kumar. 2000. Response of nitrogen on different varieties of forage sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. H P S Malik.

3. Baljeet Singh. 2000. Effect of nitrogen on seed production of forage sorghum varieties submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. S S Verma.

4. Navaneet Singh. 2002. Effect of nitrogen and zinc on grain and stover yield of sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of

Dr. S S Verma.

5. Vikas Ghanghas. 2004. Effect of zinc levels on growth and yield of forage sorghum [*Sorghum bicolor* (L.) Moench] submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. S S Verma.
6. D.K. Maurya. 2008. Studies on intercropping in sweet sorghum submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. Kewalanand.
7. Shyam Singh. 2009. Studies on integrated nutrient management in sweet sorghum and *Phillipesar*a intercropping system submitted for Ph.D. to GBPUAT under supervision of Dr. Kewalanand
8. Amit Prasad Timilsina. 2010. Effect of row spacing and sowing time on performance of sweet sorghum varieties submitted for M. Sc. Ag. to GBPUAT under supervision of Dr. Kewalanand.
9. Pramod Kumar Dubey. 2012. Response of sweet sorghum [*Sorghum bicolor (*L.) Moench] varieties to different seed rates and nitrogen levels submitted for Ph.D. to GBPUAT under supervision of Dr. Kewalanand

4. Future Thrusts:

- ✓ Evaluation of improved agronomic management practices for cost effective fodder production under different cropping systems
- ✓ Evaluation of forage crops for bio energy potential under different fertility levels of organic and inorganic fertilizers.