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RESEARCH PAPER

Sorghum hybrid (CSH-16) ideotype to cope with projected climate of North Interior Karnataka

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Abstract: Sorghum is grown during both *kharif* and *rabi* seasons in North Interior Karnataka (NIK) of India and CSH-16 hybrid, a nationally released hybrid is grown during *kharif* season. Sorghum yield under projected climate of coming decades in rainfed conditions may decline due to increase in temperature and changes in rainfall patterns, thus need new cultivars that cope with future climate. Hence modelling study was carried out to quantify the effect of climate on yield and to design ideotype of CSH-16 which may aid breeders in their quest for new cultivars for projected climate. Using DSSAT-CERES model in this study already calibrated genetic coefficients of CSH-16 hybrid for current climate were modified in different combinations, and were run under projected climate (2020-2050) in rainfed conditions on two predominant soils across 12 districts of NIK. The combination of modified genetic coefficients surpassing the yield levels of current climate (1988-2018) under projected climate were identified as the ideotype. Increasing the GDD requirement from end of heading to fertilization (PANTH) and from beginning of grain filling to maturity (P5) along with increased partitioning of assimilates to head (G2), all by 5 or 10 %, simulated the best yields under projected climate exceeding the yield loss projected for the period from 2020-2050. This suggests that CSH-16 ideotype with longer duration from heading to maturity coupled with higher harvest index would perform better in coming decades.

Key words: Future climate, Ideotype, Simulation, Sorghum, Yield

Intrduction

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the world's most important nutritional cereal crops and also the major staple food crop of millions of people in semi-arid tropics region (SAT). Among the food crops, sorghum is the fifth major cereal crops in India and is grown during both *Kharif* and *Rabi* seasons. Its major area is concentrated in the Deccan Plateau, Central and Western India apart from a few patches in Northern India. More than 90 % of the total area is rain-fed (Sandeep *et al*., 2017) and about 85 % of total production is concentrated in the SAT region of Karnataka, Maharashtra, Telangana and Andhra Pradesh.The projected climates of coming decades, especially changes in rainfall patterns coupled with rise in temperature will affect crop productivity.

North Interior Karnataka (NIK) is a geographical region consisting of mostly semi-arid plateau from 300 to 730 metres elevation that constitutes the northern part of the South Indian state of Karnataka. It includes 12 districts namely Bagalkote, Belagavi, Ballari, Bidar, Dharwad, Gadag, Haveri, Kalaburagi, Koppal, Raichur, Vijayapura and Yadgir. Total area of this region is 88,361 km^2, which has a population of 24.57 million.This region is largely covered with rich black cotton and red loamy soils, gently sloping lands and plains, summits of plateau and table lands. However, NIK is prone to droughts as monsoon rains are highly unpredictable and erratic in its distribution over time and space, thus affect crop performance. This situation may get even worse in coming decades. Hence this study was conducted to design *kharif* sorghum ideotype of CSH-16 which would perform well under future projected climate. The major challenge of current century is to secure sustainable food supply under a changing climate when food demand by 2050 would roughly double compared to present. Most of this increment has come from cereals. This poses challenges to plant breeders and crop scientists.

A crop ideotype is a model plant which is expected to yield greater quantity or better quality of grain, oil or other useful product when developed as a cultivar. Multi-process based crop simulation models which simulate crop growth and development in interaction among genotype, environment, and management are widely used to assess impacts of climate change on crop yield potentials, phenology, water use, etc. Further, the same models are used to identity sensitive traits for various climatic extremes *viz*., warming, drought, heat waves, long dry and wet spells (Rotter *et al*., 2015). Crop simulation models (CSM) have been successfully used to study the impacts of increasing climate variability and climate change, and assess adapted cultivars. Introduction of changed technology (e.g., improved cultivars) will significantly reduce the climate change effect. One important technique in this regard is design of ideotypes for future climate. In this regard CSM can be used to identify a desirable genetic trait or a combination of genetic traits leading to the design of a crop ideotype for a specific environment (White and Hoogenboom, 2003). Designing ideotype cultivars for the coming decades is a very powerful and extremely useful methodology with the potential to speed up crop improvement, genetic adaptation and breeding by providing selection targets and their suitable combination for enhanced yield under future climates (Senapati *et al*., 2020).

Material and methods

The experimental data of *kharif* sorghum hybrid CSH-16 to calibrate and validate DSSAT-CERES-Sorghum were collected from the experiment carried out in AICRP- Sorghum scheme during *kharif* season of 2016-17 and 2017-18, on deep black soils at Main Agricultural Research Station of University of Agricultural Sciences, Dharwad located at 15°26' N latitude, 75°07' E longitude and at an altitude of 678 m above mean sea level, which comes under Northern Transition Zone (Zone-8) of Karnataka. The data on daily weather parameters required to build weather file within the DSSAT model were recorded from Meteorological Observatory of the University for the experimental years. The historical weather data from 1988-2018 (31 years) for all 12 districts were downloaded from NASA power web portal (*www.power.larc.nasa.gov*) and were superimposed with projected changes in rainfall and temperature at district level for subsequent seasonal analysis. Yearly weather files for 2016-17 and 2017-18 were built as well as one combined file for the period of 1988-2018 (31 years) using WeatherMan software within the DSSAT ensemble. Soil profile data of both black and red soils up to a depth of 125 cm and 35 cm respectively, for all 12 districts were collected from ICAR Krishi Geoportal website (http://geoportal.icar.gov.in) to build soil modules within the model. The N, P, K (kg ha^{-1}) and texture data of both type of soils from all the 12 districts were collected from soil health card web portal of the Ministry of Agriculture and Farmers Welfare, Govt. of India (*https://soilhealth2.dac.gov.in / Health Card*) to build soil module. All these files were used to run the model for calibration (2016-17) and validation (2017-18), and also sequential analysis for 31 years (1988-2018) superimposed with projected changes in temperature and rainfall (Table 1). Standard production practices recommended by UAS Dharwad for *kharif* sorghum in NIK were added in the X-file to run simulations. A total of 11 genetic coefficients were optimised using GenCalc program (Hunt *et al*., 1993) built within the DSSAT-CERES model for *kharif* sorghum hybrid CSH-16 and are represented in Table 2. Earlier calibration and validation study taken by Sannagoudar *et al.* (2019 and 2020) on four *kharif* sorghum cultivars at Dharwad location were used for this work as well. Further, already calibrated genetic coefficients which govern the main plant functions of the hybrid CSH-16 were modified in different combinations to design ideotypes (Table 3) and were run under projected climate (2020-2050) for 31 years in rainfed conditions. The best combination of genetic coefficients surpassing the yield levels of current climate (1988-

Table 1. Projected annual average temperature and rainfall for the period from 2020-2050 for each of 12 districts of NIK.

Districts	Temperature (°C)		Rainfall (mm)
	T max.	T min.	
Bagalkote	34.9	22.1	644.7
Ballari	34.7	22.5	657.7
Belagavi	33.8	22.0	852.0
Bidar	34.8	22.4	1065.6
Vijayapura	35.7	22.9	577.8
Dharwad	33.6	21.8	994.2
Gadag	34.3	21.9	695.1
Kalaburagi	35.6	22.9	752.3
Haveri	33.4	22.1	870.0
Koppal	34.9	22.3	595.5
Raichur	36.0	23.3	606.4
Yadgir	35.9	23.0	621.0

Table 2. Optimized genetic coefficients of sorghum hybrid CSH-16 after calibration along with coefficient codes and description.

Coefficient Code	Description	GCs
P1	Thermal time (TT) from emergence to end of juvenile phase	14.10
P2	TT from end of juvenile stage to tassel initiation under short days	80.0
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at the maximum rate	12.46
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O	88.16
PANTH	TT from end of heading to fertilization	580.5
P3	TT from end of flag leaf expansion to fertilization	133.0
P4	TT from fertilization to beginning of grain filling	92.0
P5	TT from beginning of grain filling to physiological maturity	656.0
PHINT	Interval in TT between successive leaf tip appearances	54.02
G1	Scale for relative leaf size	7.261
G2	Scale for partitioning of assimilates to the ear head	5.652

Table 3. Combinations of genetic coefficients (GCs) of the *kharif* sorghum hybrid CSH-16 tested to run simulations to identify the best performing ideotype for the period 2020 to 2050 (P1, P2, P2O, P2R, P3, P4, PHINT, G1 retained same as in Table-2).

Genetic coefficients	PANTH	P5	G2
Calibrated GCs	580.5	656.0	5.652
PANTH 5% + P5 5% + G2 5%	609.5	688.8	5.932
PANTH 5% + P5 5% + G2 10%	609.5	688.8	6.213
PANTH 5% + P5 5% + G2 15%	609.5	688.8	6.499
PANTH 5% + P5 10% + G2 5%	609.5	721.6	5.932
PANTH 5% + P5 10% + G2 10%	609.5	721.6	6.213
PANTH 5% + P5 10% + G2 15%	609.5	721.6	6.499
PANTH 5% + P5 15% + G2 5%	609.5	754.4	5.932
PANTH 5% + P5 15% + G2 10%	609.5	754.4	6.213
PANTH 5% + P5 15% + G2 15%	609.5	754.4	6.499
PANTH 10% + P5 5% + G2 5%	638.5	688.8	5.932
PANTH 10% + P5 5% + G2 10%	638.5	688.8	6.213
PANTH 10% + P5 5% + G2 15%	638.5	688.8	6.499
PANTH 10% + P5 10% + G2 5%	638.5	721.6	5.932
PANTH 10% + P5 10% + G2 10%	638.5	721.6	6.213
PANTH 10% + P5 10% + G2 15%	638.5	721.6	6.499
PANTH 10% + P5 15% + G2 5%	638.5	754.4	5.932
PANTH 10% + P5 15% + G2 10%	638.5	754.4	6.213
PANTH 10% + P5 15% + G2 15%	638.5	754.4	6.499
PANTH 15% + P5 5% + G2 5%	667.5	688.8	5.932
PANTH 15% + P5 5% + G2 10%	667.5	688.8	6.213
PANTH 15% + P5 5% + G2 15%	667.5	688.8	6.499
PANTH 15% + P5 10% + G2 5%	667.5	721.6	5.932
PANTH 15% + P5 10% + G2 10%	667.5	721.6	6.213
PANTH 15% + P5 10% + G2 15%	667.5	721.6	6.499
PANTH 15% + P5 15% + G2 5%	667.5	754.4	5.932
PANTH 15% + P5 15% + G2 10%	667.5	754.4	6.213
PANTH 15% + P5 15% + G2 15%	667.5	754.4	6.499

2018) under projected climate were identified as the best ideotype suitable for both black and red soils, under future climates of NIK.

Results and discussion

The yield simulated under projected climate (2020-2050) for CSH-16 with the combination of modified genetic coefficients as in table 3 either surpassing or coming closer to the yield simulated with calibrated genetic coefficients as in table 2 under current climate (1988-2018) were identified as the best ideotype separately for black clay and red loamy soils. The simulated values on phenology (days to anthesis and maturity), grain yield and total above-ground biomass are presented in Table 4 to 7 are the average values derived out of 31 years' simulation runs done separately for red loamy and black clay soils across 12 districts and seven dates of sowing at weekly interval with a total number observations of 2976. A total of 27 combinations were derived out of changes to three GCs (PHANT, P5, G2) each by 5, 10 and 15 % levels (3 x 3 x 3) and the simulations were run for projected climate (2020-2050) with all these 27 GC combinations (Table 3) separately, but only the best five GC combinations which simulated the yield either comparable to or exceeded the yield simulated under current climate (1988-2018) with calibrated GCs (Table 2) were presented in Table 4 to 7.

On the black clay soils of NIK under projected climate (2020-2050) increasing the GDD from end of heading to fertilization (PANTH) from beginning of grain filling to physiological maturity (P5) both by 15 %, and increasing the partitioning of assimilates to the head (G2) by 5 or 10 or 15 % (modified GCs) would increase the days to anthesis by just three days, days to maturity by maximum one day and the yield levels by ±2.5 % compared to the yields under current climate (1988-2018) with calibrated GCs (Table 4 and 5). Such studies have been carried elsewhere, especially in Europe for Wheat and Barley, using crop simulation models. For example, one such study by Senapati *et al.*, (2020) reported that canopy structure, crop phenology and water uptake pattern, heat and drought tolerance at flowering and / or seed filling are few traits identified to achieve genetic yield potentials.

When the CSH-16 hybrid with five best modified GC combinations i.e., identified as potential ideotypes were ran under current climate (1988-2018) on black soils in order to check the performance of these under current climate, the yield

Table 4. Simulated average days to anthesis and maturity (SE± n=2976) of *kharif* sorghum hybrid CSH-16 in rainfed conditions on *black clay soils* with calibrated and modified genetic coefficients for the best five combinations under current climate (1988-2018) and projected climate (2020-2050)

Modified Genetic Coefficients	Days to anthesis					Days to maturity				
	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (days)	B-A (days)	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (days)	B-A (days)
PANTH 15% + P5 10% + G2 10%	66 (±0.4)	68 (±0.5)	69 (±1.3)	-2	3	107 (±1.2)	116 (±1.4)	107 (±1.9)	9	0
PANTH 15% + P5 10% + G2 15%	66 (±0.4)	68 (±0.5)	69 (±1.3)	-2	3	107 (±1.2)	116 (±1.4)	107 (±1.9)	9	0
PANTH 15% + P5 15% + G2 5%	66 (±0.4)	68 (±0.5)	69 (±1.3)	-2	3	107 (±1.2)	117 (±1.5)	108 (±2.0)	10	1
PANTH 15% + P5 15% + G2 10%	66 (±0.4)	68 (±0.5)	69 (±1.3)	-2	3	107 (±1.2)	117 (±1.5)	108 (±2.0)	10	1
PANTH 15% + P5 15% + G2 15%	66 (±0.4)	68 (±0.5)	69 (±1.3)	-2	3	107 (±1.2)	117 (±1.5)	108 (±2.0)	10	1

Table 5. Simulated average yield and total biomass (SE± n=2976) of *kharif* sorghum hybrid CSH-16 in rainfed conditions on *black clay soils* with calibrated and modified genetic coefficients for the best five combinations under current climate (1988-2018) and projected climate (2020-2050)

Modified Genetic Coefficients	Grain yield (kg ha^{-1})					Total biomass (kg ha^{-1})				
	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (%)	B-A (%)	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (%)	B-A (%)
PANTH 15% + P5 10% + G2 10%	2272 (±215)	3138 (±282)	2218 (±227)	27.5	-2.4	5284 (±469)	6505 (±548)	4807 (±459)	18.7	-9.9
PANTH 15% + P5 10% + G2 15%	2272 (±215)	3140 (±280)	2260 (±231)	27.6	-0.5	5284 (±469)	6438 (±537)	4808 (±459)	17.9	-9.9
PANTH 15% + P5 15% + G2 5%	2272 (±215)	3150 (±282)	2247 (±230)	27.8	-1.1	5284 (±469)	6580 (±551)	4898 (±468)	19.6	-7.8
PANTH 15% + P5 15% + G2 10%	2272 (±215)	3197 (±285)	2294 (±234)	28.9	0.9	5284 (±469)	6571 (±549)	4903 (±468)	19.5	-7.7
PANTH 15% + P5 15% + G2 15%	2272 (±215)	3236 (±288)	2335 (±238)	29.7	2.6	5284 (±469)	6560 (±548)	4902 (±468)	19.4	-7.7

Table 6. Simulated average days to anthesis and maturity (SE± n=2976) of *kharif* sorghum hybrid CSH-16 in rainfed conditions on *red loamy soils* with calibrated and modified genetic coefficients for the best five combinations under current climate (1988-2018) and projected climate (2020-2050)

Modified Genetic Coefficients	Days to anthesis					Days to maturity				
	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (days)	B-A (days)	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (days)	B-A (days)
PANTH 15% + P5 10% + G210%	65 (±0.3)	67 (±0.3)	68 (±0.9)	2	3	108 (±0.5)	117 (±0.5)	107 (±0.9)	9	1
PANTH 15% + P5 10% + G215%	65 (±0.3)	67 (±0.3)	68 (±0.9)	2	3	108 (±0.5)	117 (±0.5)	107 (±0.9)	9	1
PANTH 15% + P5 15% + G2 5%	65 (±0.3)	67 (±0.3)	68 (±0.9)	2	3	108 (±0.5)	119 (±0.5)	108 (±0.9)	11	0
PANTH 15% + P5 15% + G210%	65 (±0.3)	67 (±0.3)	68 (±0.9)	2	3	108 (±0.5)	119 (±0.5)	108 (±0.9)	11	0
PANTH 15% + P5 15% + G215%	65 (±0.3)	67 (±0.3)	68 (±0.9)	2	3	108 (±0.5)	119 (±0.5)	108 (±0.9)	11	0

Table 7. Simulated average yield and total biomass (SE± n=2976) of *kharif* sorghum hybrid CSH-16 in rainfed conditions on *red loamy soils* with calibrated and modified genetic coefficients for the best five combinations under current climate (1988-2018) and projected climate (2020-2050)

Modified Genetic Coefficients	Grain yield (kg ha^{-1})					Total biomass (kg ha^{-1})				
	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (%)	B-A (%)	1988-2018 Calibrated GCs (A)	1988-2018 Modified GCs (C)	2020-50 Modified GCs (B)	C-A (%)	B-A (%)
PANTH 15% + P5 10% + G2 10%	3195 (±117)	4181 (±150)	3195 (±138)	23.5	0	7426 (±234)	8769 (±262)	6935 (±259)	15.3	-7.0
PANTH 15% + P5 10% + G2 15%	3195 (±117)	4182 (±153)	3255 (±139)	23.5	1.8	7426 (±234)	8669 (±265)	6941 (±258)	14.3	-6.9
PANTH 15% + P5 15% + G2 5%	3195 (±117)	4187 (±159)	3222 (±139)	23.6	0.8	7426 (±234)	8124 (±270)	7052 (±265)	8.5	-5.3
PANTH 15% + P5 15% + G2 10%	3195 (±117)	4253 (±160)	3297 (±142)	24.8	3.0	7426 (±234)	8828 (±273)	7066 (±264)	15.8	-5.0
PANTH 15% + P5 15% + G2 15%	3195 (±117)	4309 (±161)	3357 (±144)	25.8	4.8	7426 (±234)	8718 (±272)	7071 (±263)	14.8	-5.0

increased by 27.8-29.7 % and total biomass by 17.9-19.6 %, compared to the yields with calibrated GCs under current climate (Table 5). Though, no much difference was observed in simulated days taken to reach anthesis, but the time taken to reach maturity was delayed by 9-10 days under current climate (1988-2018) due to increased GDD requirement with modified GCs i.e., mainly P5, which govern the crop's thermal time requirement from grain filling to physiological maturity.

On the red loamy soils under projected climate (2020-2050) increasing PANTH by 15 %, P5 by 15 %, and G2 by 5 or 10 or 15 %, increased the days to anthesis by three days, days taken to maturity maximum by one day, like on black clay soils, and the yield levels simulated were at par or higher by 4.8 % of the yields under current climate (1988-2018) on red loamy soil with calibrated GCs (Table 6 and 7). When the successfully identified ideotype were run to check the performance under current climate, the yield and total biomass on red loamy soils increased by 23.5-25.8 % and to 8.5-15.8 % respectively, compared to the yield under current climate (1988-2018) using calibrated GCs (Table 6 and 7). As in black clay soil no much difference was observed in days taken to reach anthesis, but the time taken to reach maturity was delayed by 10 days under current climate (1988-2018) due to increased GDD of P5 coefficient which govern thermal time requirement from grain filling to physiological maturity. A study by Stratonovitch and Semenov (2015) used the Sirius wheat model to optimize wheat ideotypes for CMIP-5.0 based climate scenarios for 2050 at six diverse sites across Europe. They found that yield potential for heat-tolerant ideotypes can be significantly enhanced in the future by selecting an optimal combination of wheat traits, viz., optimal phenology and extended duration of grain filling among the current cultivars.

Conclusion

This simulation modeling study with *kharif* sorghum hybrid CSH-16 showed that to compensate the yield loss expected under future warmer climates, besides agronomic management strategies, changes to important crop traits needs to be made to come up with ideotypes suited for future climates. Under warmer climate crop development process is hastened, thus the total duration of crop is shortened which directly reduces yield. In that regard, this simulation study showed that the crop duration vis-à-vis GDD from end of heading to fertilization

(PANTH) and from beginning of grain filling to physiological maturity (P5) needs to be increased by at least 15 % of current GDD requirement to compensate the crop duration loss expected with rising temperature. This study also further showed that partitioning of assimilates to the ear head (G2) needs to be enhanced by at least 5 % of current rate to maintain the current yields under future climates. Hence, breeding efforts in sorghum need to focus on these selected potential traits.

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