Improving post-rainy season sorghum productivity in medium soils: does ideotype breeding hold a clue?

P. Sanjana Reddy[1,]*, J. V. Patil[1], S. V. Nirmal[2] and S. R. Gadakh[2]

[1]Directorate of Sorghum Research, Rajendranagar, Hyderabad 500 030, India
[2]Mahatma Phule Krishi Vidyapeeth, Rahuri 413 722, India

Improvement in post-rainy sorghum grain yield has been a challenge with M 35-1, a landrace selection released in 1937 dominating the post-rainy (*rabi*) tracts. It led to stagnation of post-rainy sorghum yields until the importance of specific adaptation was realized in lieu of highly variable soil and climatic conditions of post-rainy growing regions. As a result, Phule Maulee and of late Phule Chitra were released for regions of Maharashtra with medium soil depth. These varieties were compared with M 35-1 in medium soil depth under receding soil moisture conditions for grain attributes and physiological traits in order to define a crop ideotype that is suitable for such regions, which will further facilitate rapid breeding process. On evaluation of these three varieties (Phule Maulee, Phule Chitra and M 35-1) along with 13 other varieties for three consecutive years, from 2006–07 to 2008–09 in medium soils, it was found that when compared to M 35-1, double the grain yield can be obtained by selecting for double the per day grain productivity, 50% higher biomass and per day fodder productivity, harvest index above 30, 5–10% more earhead emergence, 5% bolder seed, 5% higher relative water content. These traits can lead to the development of new varieties suitable for medium soil situations. Apart from high panicle dry matter (50% of total dry matter), these varieties should also have efficiency in conversion of photosynthates to the grain.

Keywords: Ideotype breeding, medium soil, specific adaptation, sorghum.

SORGHUM [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop in the world after rice, wheat, maize and barley, and is the dietary staple of more than 500 million people in over 90 countries, primarily in the developing world. In India, it is grown during both rainy (*kharif*) and post-rainy (*rabi*) seasons for multiple uses as a food, feed, fodder and a fuel crop. Sorghum grown in the rainy season is mainly utilized as feed, as the grain is often caught in the rains and the quality is affected due to grain moulds. However, post-rainy sorghum is primarily used as a food owing to its good grain quality and also serves as a main source of fodder, especially during dry seasons. There has been drastic reduction in sorghum area especially in the rainy season, but the area under post-rainy sorghum has remained stable and is grown predominantly in six districts of Maharashtra (Solapur, Ahmednagar, Pune, Beed, Osmanabad and Aurangabad) and three districts of Karnataka (Bijapur, Gulbarga and Raichur), apart from parts of Andhra Pradesh and Tamil Nadu[1].

Post-rainy season-adapted sorghums are characterized by response to shorter daylength (photoperiod sensitivity), flowering and maturity (more or the less same time), irrespective of temperature fluctuations and sowing dates (thermo-insensitivity within the post-rainy season varieties). They are tolerant to terminal moisture stress and resistant to stalk rot/charcoal rot. They usually produce high biomass (grain and stover) and have high lustrous grain with semi-corneous endosperm. Tolerance to shoot fly, lodging (mechanical) and rust is also required[2]. All these characters are exemplified best in M 35-1, a variety selected from a local landrace nearly 75 years ago at Mohol, Maharashtra, which produces high stable yields of grain and stover across different sowing dates. As a result, M 35-1, a landrace selection developed in 1937 still dominates the post-rainy season sorghum areas in India[3].

Developing high-yielding post-rainy season-adapted varieties/hybrids is the main objective in almost all the crop improvement programmes. Though great efforts have been made to develop hybrids with wider adaptability to varied production environments, the results are not encouraging[4]. Productivity depends not only on the moisture availability, but also on the soil types under which it is grown and the genotypes[5]. Also, improvement of post-rainy sorghum did not receive as much emphasis and effort as the rainy sorghum until the nineties. Among the factors influencing adoption of sorghum varieties, farmers rated grain and fodder quality attributes as their first priority[6].

Several strategies were suggested to improve the yields of post-rainy sorghum. A multidisciplinary approach was one of them[7]. However, conventional crop breeding techniques emphasized selection for yield per se or improvement of crop cultivars through incorporation of resistance to biotic and abiotic stresses. Donald[8] proposed the ideotype approach to plant breeding in contrast to the empirical breeding approach of defect elimination and selection for yield per se. Ideotype breeding involves defining a crop production environment, designing a plant model, from morphological and physiological traits known to influence performance in that environment, and combining the traits into one plant type. Through a comparative analysis of phenology, growth and yield for three genotypes (Phule Chitra, Phule Maulee and M 35-1), we sought to characterize the traits which can be used for the development of ideotype concepts for breeding.

Much of the post-rainy season sorghum is grown on residual and receding soil moisture on shallow and

*For correspondence. (e-mail: sanjana@sorghum.res.in)

medium-deep soils. Germplasm lines suitable to both the soil conditions and also to specific soils were identified by Pawar *et al.*[9]. Under shallow soils, the hybrids were shorter, flowered and matured early and in medium-deep soils, mean leaf area, grain number and 1000 grains mass, grain and fodder yields were higher[10]. Therefore, there is a need for the development of varieties adapted to specific soil situation in post-rainy season to enhance production and productivity levels. Hence, the present study was undertaken to evaluate the relative performance of post-rainy sorghum varieties for their productivity and to identify ideal plant types suited to medium black soils.

The genetic material included three distinct post-rainy sorghum genotypes, Phule Chitra (SPV 1546), Phule Maulee and M 35-1, and 13 newly bred varieties. Phule Chitra (SPV 655 × RSLG 112) is a new variety released for cultivation in medium-type soils in 2006 for Maharashtra (in the name of Phule Chitra). Phule Maulee (RSLG 262) was released for cultivation in shallow to medium-type soils of Maharashtra in 1999. M 35-1, a selection from landrace Maldandi is a popular variety grown by farmers during post-rainy season, known for stable performance under varied environmental situations in post-rainy season.

The performance of Phule Chitra over Phule Maulee for agronomic and physiological traits will reveal the traits that need to be improved for yield improvement in medium soils, whereas the performance of Phule Chitra and Phule Maulee over M 35-1 will help in the development of ideotype for enabling breeding post-rainy sorghum suitable for cultivation in medium soils.

Preliminary field experiments were conducted during post-rainy season (from September to January) at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, located at 19.38°N lat. and 74.65°E long. Sixteen varieties (13 newly bred varieties, Phule Chitra, Phule Maulee and M 35-1) were evaluated in the medium-type soils (up to 60 cm) for three consecutive years from 2006–07 to 2008–09 in a randomized block design replicated three times. Fertilizer inputs were 60 kg N and 30 kg P_2O_5 as basal application and 30 kg N as top dressing applied at 30 days after sowing. Plant protection included hand weeding as required, as well as insecticide treatments following standard recommendations. The seeds were sown manually with a spacing of 45 cm between rows and 15 cm between plants in a row with more than two seeds per hill and thinned to one per hill at 15 days after sowing. The gross plot size was 13.5 sq. m and net plot size was 7.92 sq. m.

All physiological observations were recorded at 50% flowering and at physiological maturity, whereas yield and yield components were recorded at harvest (10 days after physiological maturity).

Grain maturity is indicated by the appearance of a black spot on the region where the grain is attached to its supporting branch of the panicle (hilum). A panicle was considered mature when all the grains show black spots at the hilum, and the time taken from sowing to attain this stage is noted as days to maturity. Emergence of earhead is affected when sorghum is grown under residual soil moisture conditions. Hence, the number of earheads emerged was counted and expressed as percentage. All the panicles from the net plot were sundried, threshed and cleaned, and weight of the grains was recorded and expressed as kilograms per plot and converted to kilograms per ha to obtain grain yield. Thousand grains from the seeds collected from five randomly selected plants were taken for 1000-grains count. The weight of 1000-grains was recorded separately and expressed in grams. To obtain grain number per panicle, the grain weight per panicle was divided by the corresponding 1000-grains weight and then multiplied by 1000. Biological yield was calculated as the sum of panicle dry weight and dry straw weight. Percentage of grain yield of a plant to the biological yield gave harvest index. Per day grain/fodder productivity (kg ha^{-1} day^{-1}) was calculated as the ratio of grain weight or fodder weight (in kg ha^{-1}) to the number of days required for maturity.

The biophysical parameters, viz. relative water content (RWC), and stomatal frequency were recorded according to Mata and Lamattina[11], and Quarrie and Jones[12]. Leaf area index (LAI) was obtained by dividing leaf area by land area. Chlorophyll stability index (CSI) was worked out by following the method suggested by Dhopte and Livera[13] as: Percentage of (total chlorophyll content in control – total chlorophyll content after heating at 56°C)/ Total chlorophyll content in control. Leaf temperature was recorded using an infrared thermometer. The average data of three years were subjected to basic statistics and correlation analysis using statistical software packages of SPSS, version 12.

Crop yield is mainly dependent on the interplay of various physiological and biochemical functions of the plants, in addition to the impact of the environment. The cause and effect relationship is difficult to understand mainly because of the complexity in understanding the interplay of several processes and functions under limited water-supply conditions.

In the Rahuri experiment, the varieties were grown on receding soil moisture as there was no rainfall during the crop growth period (Table 1) as normally observed in the

Table 1. Soil moisture status (%) during crop growth

Crop age	Soil depth (cm)	
	0–30	30–60
At planting	31.47	28.87
At panicle initiation	24.00	21.23
At 50% flowering	20.40	18.93
At physiological maturity	14.93	15.60

post-rainy season[14]. The soil moisture was comparatively more at greater depths, thereby implying that a genotype with deep penetrating roots is more suitable for cultivation under receding soil moisture conditions. Similar observations were made by other workers[15,16].

Phule Chitra had the highest grain yield of 2531 kg/ha in medium soils compared to Phule Maulee (1953 kg/ha) and M 35-1 (1285 kg/ha). The grain yield in medium soils was significantly and positively correlated with biological yield (0.53), harvest index (0.80), 1000-grains weight (0.44), percentage earhead exertion (0.38), per day grain production (0.91), per day fodder production (0.57) and total panicle dry matter at physiological maturity (0.50). Phule Chitra was also significantly superior for biological yield (8630 kg/ha) compared to Phule Maulee (6480 kg/ha) and M 35-1 (5917 kg/ha). There were significant differences among the varieties for harvest index. Phule Chitra (29.3%) and Phule Maulee (30.1%) exhibited higher harvest index than M 35-1 (21.7%). Ludlow and Muchow[17] observed that harvest index ranged from 38% to 40% under no stress and 30% to 36% under stress conditions, which shows that there is further scope for improvement in the harvest index. The per day grain production of Phule Chitra (19.8) was double that of M 35-1 (9.7) and 28% superior to Phule Maulee (15.5). This trait also had the highest correlation to grain yield among all the traits. Per day fodder production of Phule Chitra was 52% superior compared to M 35-1 and 62% superior compared to Phule Maulee. From this it can be seen that increased grain yield in Phule Chitra, a recently released variety for medium soils, is possible through improvement in total biomass. Of the total dry matter, Phule Chitra showed superior stem and panicle dry matter over Phule Maulee and was on par with M 35-1, whereas the varieties did not differ significantly for leaf dry matter production. From this, it can be inferred that though M 35-1 had comparatively good dry matter production, it had low-grain yield due to poor mobilization of photosynthates to the sink in medium soils, which needs to be tested further. This was reflected in low harvest index, which indicates the partitioning ability of total dry matter to the developing grains. Maintenance of higher harvest index by means of channelling assimilates to the developing ear was identified as an important drought-resistant mechanism in sorghum[18]. However, only panicle dry matter had contributed significantly to grain yield. Similarly, Sriram and Rao[19] also reported the importance of panicle dry matter contribution to grain yield in sorghum. Kusalkar *et al.*[20] conducted an experiment to identify the key physiological parameters governing the yield potential of post-rainy sorghum on medium soils, and three years of study revealed that RSLG 262 recorded significantly superior grain yield (1449 kg ha^{-1}) over Sel-3 (1133 kg ha^{-1}), which was due to higher dry matter production in different plant parts and its higher translocation to the earhead at physiological maturity in rainfed situation[21] (Table 2).

Phule Chitra also recorded significantly lesser number of grains and more 1000-grains weight than M 35-1. Though significant positive correlation of 1000-grains weight and grain number per plant with grain and fodder yield was observed by earlier workers in post-rainy sorghum grown under residual moisture conditions[22–24], only increase in grain boldness seemed to contribute to higher grain yield in medium soils as observed by significant correlation from the current study. However, this needs to be further confirmed. Ludlow *et al.*[25] were also of the opinion that higher yield under drought condition was due to larger grains, and higher harvest and distribution indices. Though time taken to maturity did not influence grain yield, Phule Chitra matured five days earlier than M 35-1 and two days later than Phule Maulee.

Higher stomatal frequency was found to be associated with higher water-use efficiency. In the present study, higher stomatal frequency was found on the abaxial surface compared to the adaxial surface in all the varieties. Phule Chitra and Phule Maulee had significantly lower stomatal frequency on both the leaf surfaces compared to M 35-1. However, this trait may not be contributing to yield improvement in medium soil conditions, as seen by non-significant correlation with grain yield. Shawesh *et al.*[26] observed higher number of stomata on the abaxial surface than on the adaxial surface. They also found higher stomatal frequency for drought-tolerant genotypes than susceptible genotypes in sorghum. On the contrary, in the present study, the medium soil-adaptable genotypes had lower stomatal frequency than M 35-1.

LAI can be considered as the ability of the plant to produce grain yield. But, moisture stress during flowering reduces the LAI and grain yield per plant[27]. Sorghum hybrids have larger LAI and leaf area duration (LAD) than the local cultivars, which maintained better water status[28]. The poor plant water status of hybrids was partially ascribed to their larger LAI. The glossy genotypes possessed higher LAI values even under water stress compared to non-glossy ones[29]. The high LAI and LAD of a genotype which produced high dry matter could be considered as an indicator of grain yield[30]. However, in the present study, LAI was poorly but positively correlated with grain yield ($r = 0.05$) and the varieties showed non-significant differences for LAI that ranged from 3.1 to 3.4.

There were non-significant differences in CSI among the varieties, indicating that the trait may not be contributing to soil-specific adaptation. CSI has shown negative association with grain yield, though non-significant; indicating that the less stable chloroplast has resulted in higher photosynthetic rate under water-deficit condition. These results are in conformity with those obtained by Kadam *et al.*,[30] Awari *et al.*[24] in sorghum and Sairam[31] in wheat. CSI is associated with desiccation tolerance under terminal water-deficit condition and can be used as one of the reliable selection criteria in rapid screening for post-rainy-adapted genotypes for drought tolerance.

Table 2. Comparison of Phule Chitra with a medium soil check, Phule Maulee and a popular check, M 35-1 for agronomic and physiological traits grown on medium soil depth from 2003 to 2005 post-rainy seasons, Rahuri, Maharashtra, India

Trait	Phule Chitra	Phule Maulee	M 35-1	lsd (at $P \leq 5\%$)	Correlation
Grain-yield related traits					
Days to maturity	128	126	133	3	0.32
Earhead exertion (%)	80	75	72	8.5	0.38*
Grain yield (kg ha^{-1})	2531	1953	1285	153.7	1.00
Biological yield (kg ha^{-1})	8630	6480	5917	232	0.53**
Harvest index (%)	29.3	30.1	21.7	14.8	0.80**
Grain number/panicle	1848	2032	2183	189	0.18
1000-grains weight (g)	40	39	37	3.4	0.44*
Per day grain production (kg/ha/day)	19.77	15.5	9.66	15.2	0.91**
Per day fodder production (kg/ha/day)	24.11	14.87	15.74	19.8	0.57**
Total dry matter at physiological maturity (g/m^2)	656.7	549	680.5	89.8	0.59**
Leaves dry matter at physiological maturity (g/m^2)	53	52.3	55.1	5.1	0.03
Stem dry matter at physiological maturity (g/m^2)	274.7	203.7	306.7	26.2	0.10
Panicle dry matter at physiological maturity (g/m^2)	329	293	318.7	29.1	0.50**
Physiological traits					
LAI	3.4	3.1	3.2	1.0	0.05
RWC (%)	87	72	82	3.2	0.38*
CSI	0.21	0.23	0.23	0.08	–0.14
Leaf temperature (°C)	–3.1	–2.6	–1.9	0.1	–0.59**
Stomatal frequency (mm^2) on adaxial surface	123	121	132	9.0	–0.14
Stomatal frequency (mm^2) on abaxial surface	150	140	162	11.3	–0.04

*Significant at $P \leq 0.05$. **Significant at $P \leq 0.01$. lsd, least significant difference.
LAI, Leaf area index; RWC, relative water content; CSI, chlorophyll stability index.

Among the physiological traits studied, RWC exhibited significant correlation with grain yield ($r = 0.38^*$). RWC is the ability of a plant to maintain high water in the leaves under moisture stress conditions and has been used as an index to determine drought tolerance in crop plants[32]. Blum *et al.*[33] reported that higher leaf RWC allows the plant to maintain turgidity, and this would exhibit relatively less reduction in biomass and yield. Among the three varieties, Phule Chitra had the highest RWC of 87% and was also the highest grain yielder. However, on the contrary, Phule Maulee had the lowest RWC of 72%. Hence, from the present study, the importance of RWC has been realized; the soil-specific importance needs to be further studied.

The physiological parameters measured above did not seem to have much influence on grain yield, except for relative water content and leaf temperature. Perhaps, evaluation for root traits may reveal more information on grain yield-contributing mechanisms. The physiological parameters such as LAI, RWC, leaf temperature, CSI, stomatal frequency, harvest index, grain size and earhead exertion of the variety Phule Chitra were superior compared to the other varieties under receding moisture conditions, indicating its suitability for cultivation in medium-type soils during post-rainy season.

Broad adaptation in post-rainy sorghum varieties may not fetch the desired results, as the post-rainy environment is highly variable in terms of soil and climate. Breeding for specific soil depths has been undertaken in various public-sector programmes and significant progress has been achieved, one being the release of Phule Chitra for medium soils. On comparison of yield attributes and physiological traits of Phule Chitra with M 35-1, a widely cultivated post-rainy season variety with broad adaptation and Phule Maulee, a variety suitable for medium soils, the ideotype was reflected in the following traits when grown in medium soils under residual moisture conditions:

- Higher grain yield and per day grain productivity (at least double that of M 35-1).
- Higher biomass and per day fodder productivity (50% higher biomass than M 35-1).
- Harvest index greater than 30 (10% greater than M 35-1).
- Greater earhead exertion (5–10% more than M 35-1).
- Bolder seed (5% bolder than M 35-1).
- Panicle dry matter constituting 50% of total dry matter.
- Higher relative water content (5% higher than M 35-1).

Hence, while breeding for new varieties adaptable to medium soils, these traits have to be considered. However, there is further need to study the root characteristics of these varieties in controlled conditions to identify if any specific root trait contributes to the soil-specific adaptation of these varieties.

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