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Review Article

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Leaf Reddening Enigma in Bt Cotton: A Review

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A B S T R A C T

The maximum yield potential of *Bt* cotton is yet to be trapped under irrigated conditions which is low for various reasons. Among the different constraints in cotton major reduction in yield is due to leaf reddening which results in 30-60% of yield loss. Leaf reddening in cotton is also known as red leaf disease (*lal patti*). This disorder is an outcome of interaction of location, variety, environmental condition and nitrogen, potassium, magnesium etc. supply. In general, some of the *hirsutum* varieties and a few inter and intra specific tetraploid hybrids are sensitive and vulnerable to this malady. Appearance of red leaf symptom is primarily, due to the accumulation of anthocyanin pigment. Identification of suitable reasons and management of leaf reddening to increase the productivity in cotton is the key for crop potential and hence, the review.

Keywords

Bt cultivars, Time of sowing, Transplanting, Nutrition, Target yield approach.

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Introduction

Cotton (*Gossypium* spp.), 'the king of fibers' also popularly known as 'the white gold' enjoys a pre-eminent position amongst cash crops in the world and in India as well. It is the nature's most precious gift to the mankind, contributed by the genus *Gossypium* to clothe the people all over the world. There is great discontent in different quarters with the cultivars as some varieties are becoming vulnerable to boll worm (mostly due to spurious seed/F2 seed) and/or to many physiological disorders and, hence, yield below par (Venkateshwaralu, 2002) besides producing poor quality fibreas reported in Maharashtra and Gujarat (Hebbar and Mayee, 2011). Leaf reddening malady is the major handicap in achieving potential crop yields, particularly in *hirsutums* in majority of the locations in spite of following best production practices. Leaf reddening could reduce the seed cotton yield to the extent of 30-60 per cent depending on variety and reddening intensity (Pagare, 2011) and time of occurrence. The red colour becomes apparent when the green chlorophyll decomposes with the approaching winter (Anon., 2007) and, therefore, early planting or use of cultivars suitable for late planting to escape hardships of winter assumes significance. Intense light and low temperatures of winter favour the development of anthocyanin pigments. The principle cause of reddening is nitrogen and magnesium deficiencies triggered by lower nutrient availability and /or crop uptake determined by inclement climate and/or poor soil. Supply of nitrogen along with phosphorus and potassium or potassium nitrate and/or magnesium to the leaf at these stages to reduce the formation of anthocyanin and achieve potential yields is critical (Sathyanarayanrao, *et al.,* 2014, Honnali and Chittapur, 2017 and Basavenneppa *et al.,* 2015). This brings-forth the importance of plant nutrition in the management of leaf reddening for achievable harvests hence, this attempt.

Causes of reddening

In India several studies have been carried out on the field to identify the reasons for leaf reddening malady (Table 1). Leaf reddening appears to be a physiological disorder associated with several factors *viz.,* environment, nutrient, soil type, genotype and physiological parameters. Dastur and Bhatt (1956) observed that there was an accumulation of carbohydrates in the leaves when cotton plant had nearly reached the stage of senescence. Das and Leopold (1964) reported that the photosynthetic rate was reduced at senescence. Moore and Lovell (1936) found that in senescent leaves, the leaf chlorophyll content was approximately linearly related to the estimated area of yellow tissue. Interestingly, Burt and Haider (1919) reported this phenomenon in Cawnpore American cotton in United Provinces. They suggested that the red leaf disease was due to an attack of aphids. Kottur (1920) suggested that the jassid might be the vector in carrying the red leaf disease and claimed success in warding off the disease by dusting with sulphur. Evans (1926) reported that the phosphate and potash deficiency in soil and hopper and jassids caused the red leaf disease in cotton at New Guinea. Simultaneously, Sawhney (1932) observed that the red leaf blight of *Buri* cotton has been known in Hyderabad. The red pigment in leaves was reported to be developed as a result of injury caused by jassid. Ramiah and Nath (1945) found that the red colour in *Gossypium hirsutum* leaves occurred uniformly over the whole upper surface. They suggested that itmay also occur in patches on both surfaces due to an attack of jassids.

Garner (1934) reported that nitrogen deficiency causes frenching disease with light green colour of foliage, yellowing and firing of lower leaves of tobacco plant. In cotton Dabral (1938) for the first time reported that the red leaf disease was caused by deficiency of nitrogen and this was cured by the application of various fertilizers containing nitrogen. Deficiencies in the amount of chlorophyll in the cotton plant have also been reported. Balls (1908) made a cross between an upland cotton with light green leaves and a dark green Egyptian cotton. He stated that in the F2 generation, plants with light green leaves and plants with dark green leaves appeared in a 3: 1 ratio. Dastur and Ahad (1941) found that the mineral composition of *desi* cotton was same except that there was less of K_2O compared to American cotton. The mineral content of bolls of *desi* cotton was higher than the American cottons. The concentration of nitrogen in the bolls and leaves in these varieties was found nearly the same. Serry and Wad (1958) observed that the nitrogen deficiency in sand culture was associated with decrease in percentage of P_2O_5 and ash and in the quantities of Ca, Mg, and K absorbed by American cotton. Further, Dastur and Singh (1947) reported that the red leaf was caused by a deficiency of nitrogen in the leaves of plant growing on light sandy soil. The leaves of plant indicated this type of reddening during the fruiting phase and contained significantly less nitrogen than the leaves of plant which were green in colour. Later, Dastur (1967) also reported that high wind velocity causing desiccation injury and low night temperature during November/

December is also responsible for red leaf in cotton.

At Dharwad, Karnataka Prabhakar (1981) observed that leaf reddening was not noticed in October and it was started in November and increased in December and January. Chimmad (1989) also from Dharwad reported that all the genotypes revealed an increasing trend for red leaf index from II fortnight of October (boll development stage) to maturity. Correlations indicated that anthocyanin accumulation was significantly negative with N, P, K, Ca and Mg contents of leaf. The chlorophyll content decreased and anthocyanin content increased as the crop attained maturity. This malady has been found to cause serious losses in the high yielding cultivars of *Hirsutum* and *Barbadenses.* Further, Chimmad and Panchal (1998) opined that the lower leaf nitrogen (<2.5%) content, higher accumulation of anthocyanin content, lower temperature (10^0C) and higher per cent of solar radiation were associated with leaf reddening. Bhatt *et al.,* (1982) also found reddening of cotton leaves is primarily associated with low leaf N concentrations and reduced amino acid levels of prematurely reddened cotton leaves. Simultaneously, Shanmugham (1992) reported that drop in temperature below 21°C stimulates the formation of anthocyanin pigment particularly the sudden fall in night temperature below 15°C stimulates the formation of anthocyanin pigment. The reddened leaves reveal low chlorophyll content with high anthocyanin pigment. This malady has been found to cause serious losses in the high yielding cultivars of *hirsutum* and *barbadenses.* The critical N requirement of leaf is 2.0-2.6% if it falls below this reddening of leaf triggered.

Further, Wright (1999) found that cotton plants with severe reddening symptoms had 55 - 66%, heavier total boll mass and their leaves had only about half the potassium (K) and three quarters the phosphorus (P) concentration of unaffected plants. Hence, affected plants had less leaf K and P to meet the demand of a heavy boll load. Velikova *et al.,* (2002) observed the damage of photosynthetic activity upon reddening may be caused by oxidative stress due to K shortage and corresponding accumulation of Na ions. The oxidative stress in cotton may be partly counteracted by the strong accumulation of anthocyanins having protective antioxidants and antiradical functions.Hebbar *et al.,* (2007) reported that synchronized boll development in *Bt* plants altered the source–sink relationship due to rapid translocation of saccharides and nutrients from leaves to the developing bolls. Kaur *et al.,* (2007) also made similar findings. Adoption of modern cotton varieties is another important factor for K deficiency, since sensitivity of cotton to potassium varies with genotypes. Many reports have indicated that modern cotton varieties with fast fruiting, high yielding or heavy boll load and early maturity seem to be more susceptible to K limitation than traditional varieties. Pagare and Durge (2011a) reported that reduction in the chlorophyll content and accumulation of more anthocyanin content in leaf is responsible for reddening in cotton. Anthocyanin content increased in reddening affected leaves in the range of 4.94 to 5.06 per cent at square formation stage compared to normal leaf. While, Naidu and Mahalakshmi (2011) reported that reduction in the photosynthetic rate, stomatal conductance and transpiration were responsible for reddening of cotton leaves. There was reduction in contents of N, P, K, Ca, Mg, Zn and Mn in reddening leaf with the increase of Na, Fe and Cu.

Varietal response to leaf reddening

Since 1908 many research workers observed that reddening malady was much pronounced in *Hirsutum* and *Barbadens* than in *Desi* types (Alston, 1959). However, not much further work followed to screen cultivars to leaf reddening or its impact on cultivar performance.

In Karnataka, Chimmad and Panchal (1998) reported that genotypes MCU-5, DCH-32 and lakshmi recorded higher levels of red leaf index, anthocyanin content in leaf at all growth stages and lower seed cotton yield while, RAMPBS-218 and RAMPBS -296 remained green with lower red leaf index, anthocyanin content in leaf and recorded higher seed cotton yield. At Akola, Pagare (2011b) revealed that reddening of leaves was more pronounced in *Gossypium hirsutum* resulting in lower seed cotton yield. Among the tested genotypes MRC- 6301 was more prone to reddening of leaf compared to NSC-145 and TCHH-4. Further, Pagare and Durge (2011a) reported that, healthy cotton leaves has maximum chlorophyll content compared to reddened leaves. The reduction of chlorophyll content in red leaf was more in MRC-6301 *Bt* cotton hybrid. Anthocynin content in red leaves was maximum in all the *Bt* cotton varieties compared to healthy leaves of *Bt* cotton varieties at all the growth stages. Interestingly, Hosmath *et al.*, (2012) at Dharwad, Karnataka reported that, Neeraja (BG II) *Bt* registered significantly higher SPAD value (40.91, 42.98 at 90 and 120 DAS, respectively). chlorophyll 'a' content (0.87, 1.02 mg g^{-1} fresh weight at 90 and 120 DAS, respectively), chlorophyll 'b' content (0.51, 0.54 mg g^{-1} fresh weight at 90 and 120 DAS, respectively) and total chlorophyll content (1.29, 1.61 mg g^{-1} fresh weight at 90 and 120 DAS, respectively) compared to other *Bt* cotton genotypes. Neeraja (BG Il) *Bt* also recorded significantly lower accumulation of anthocyanin content (0.092, 0.187 mg g^{-1} fresh weight at 90 and 120 DAS, respectively) and red leaf index (0.65, 2.0 during 90 and 120 DAS, respectively) compared to other *Bt* cotton hybrids. While from same place Sudha (2011) recorded significantly higher SPAD value (43.10, 44.35 and 42.70 at 90, 120 DAS and at harvesting, respectively) in MRC-6918 *Bt* compared to other *Bt* cotton hybrids and lowest SPAD value was registered in RCH-2 *Bt* (39.30, 38.15 and 37.40 at 90, 120 DAS and at harvest, respectively).

Amelioration of leaf reddening

Several studies have been carried out on the field to identify the reasons for leaf reddening malady. Nageshwara Rao (1976) reported 18-23% increase in yield with 50 to 60% recovery from reddening to greenness by an application of 0.5% $MgSO_4$ spray. There was significant increase in seed cotton yield with foliar application of 2% magnesium and 0.2% zinc and also with combination of zinc and magnesium (Eweida *et al.*, 1979). At Dharwad, Prabhakar (1981) found that foliar application of 2% urea + 1% single super phosphate four times at 15 days interval during November and December helped to control the leaf reddening. Koraddi *et al.*, (1991) studied the effect of nutrients and growth regulators on leaf reddening in cotton. They observed no influence of magnesium in checking leaf reddening. They found that foliar application of 20-10-10 kg NPK ha^{-1} in four equal instalments was effective in checking the leaf reddening with highest seed cotton yield (2465 kg ha^{-1}). Chaudhari *et al.*, (2001) reported that spraying of 2% DAP and 2% urea at 45 and 75 DAS respectively increased bolls $plant^{-1}$ (12.70 and 12.41), yield $plant^{-1}$ (24.48 and 24.30 g) and yield ha^{-1} (10.79 and 10.64 q) and reduced the leaf reddening in cotton over control.

Brar and Brar (2001) opined that foliar application of 2.0% urea or KNO_3 at flower initiation and a week later increased the seed cotton yield by 25.3 and 33.1%, respectively.

Further, they opined that application of KNO_3 containing both potassium and nitrate, applied at critical growth period helped in the retention and development of the bolls on the plant which significantly contributed to increase of seed cotton yield. Similarly, Singh (2004) observed that foliar application of urea (2-4%) with 15-20 ppm chlormequate chloride) and 0.1% citric acid, 2-3 times at weekly intervals resulted in 70-80% amelioration. While, application of $MgSO_4$ at 20-25 kg ha^{-1} to soil or as foliar spray with 5% $MgSO_4$ and 1% urea as soon as the reddening symptoms appear in leaf reduces this disorder (Ikisan, 2004).

Table.1 Reason for leaf reddening in cotton

Reasons	References
Accumulation of carbohydrates, stomata conductance and senescence of leaves	Dastur and Bhatt (1956), Das and Leopold (1964), Moore and Lovell (1936)
Sucking pest	Burt and Haider (1919), Kottur (1920), Sawhney (1932) and
Nutrient deficiency	Dabral (1938), Dastur and Ahad (1941), Serry and Wad (1958), Dastur and Singh (1947), Wright (1999), Bhatt *et al.*, (1982), Wright (1999), Velikova *et al.*, (2002),). Hebbar *et al.*, (2007) and Kaur *et al.*, (2007)
Environment	Dastur (1967), Prabhakar (1981), Chimmad and Panchal (1998) and Shanmugham (1992)
Reduction in chlorophyll and accumulation of anthocyanin	Pagare and Durge (2011)

In Karnataka, application of 2% urea or 2% DAP or 1% $MgSO_4$ at 90 and 110 DAS for control of leaf reddening has been recommended from the University of Agricultural Sciences, Dharwad (Anon., 2005). Subsequently, at Dharwad, while studying effect of foliar feeding of nutrients on *Bt* cotton it was found that foliar application of $MgSO_4$ (1.0%) at flowering and boll development stage + DAP (2%) at boll development stage significantly increased the seed cotton yield (2399 kg ha^{-1}) and reduced the leaf reddening in cotton over control treatment (2245 kg ha^{-1}) (Anon., 2010). Similarly in another study at Dharwad, it was found that combined foliar sprays of KNO_3 (2%) at 80 and 100 DAS + $MgSO_4$ (1%) at 80, 100 and 120 DAS (3371 kg ha^{-1}) registered on par seed cotton yield with $MgSO_4$ (1%) spray (3235 kg ha^{-1}) at 90 and 110 DAS besides less reddening incidence (Anon., 2010). In Bhanswara, Sharma and Singh (2007) observed response of cotton to 2% foliar application of potassium (K_2O @ 5 kg ha^{-1}) in potash deficient soils. Praharaj *et al.*, (2010) reported that the low leaf N and potash resulting in reddening of leaves could be augmented through combined spray of 1% $MgSO_4$, 1% urea and 0.1% zinc sulphate at 50^{th} and 80^{th} days. Patel *et al.*, (2011) indicated that application of recommended dose of fertilizer based on soil test value along with one spray each of urea (2%) and $MgSO_4$ (1%) during flowering to boll development stage significantly reduced incidence of leaf reddening of *Bt* cotton and also increased the cotton yield and monetary returns. In Karnataka working in the Upper Krishna irrigation command, Upperi and Kuligoud (2011) indicated that the application of 100% RDF + 20 kg $MgSO_4$ ha^{-1} significantly lowered anthocyanin (0.1 mg

g^{-1}) content and increased chlorophyll content (4.37 mg g^{-1} fresh weight) compared to 50% RDF (0.25 mg g^{-1} and 3.68 mg g^{-1} fresh weight).

Perane *et al.,* (2011) revealed maximum of 46.53% reddening where the fertilizers were not applied. The maximum reduction 49.83% in leaf reddening and improvement in seed cotton yield was observed with application of 10 t ha^{-1} FYM + 125% RDF (125:63:63 NPK ha^{-1}) + two sprays of micro nutrients. Ambati and Soniya (2012) reported that application of 150% RDF along with soil application of $MgSO_4$ at 25 kg ha^{-1} in shallow soil significantly reduced the formation of red leaves in the month of October. Increased splits of nitrogen also appears to be promising as Gawade and Bhalero (2012) reported that application of nitrogen at six splits recorded significantly lower leaf reddening and maximum seed cotton yield (34% and 6.86 q ha^{-1}) over other split application. Similarly, Giri *et al.,* (2013) also revealed that application of nitrogen at six split recorded significantly lower leaf reddening at 90, 120 and 150 DAS and seed cotton yield (3015 kg ha^{-1}).

While studying the management of leaf reddening in *Bt* cotton through nutrients under irrigated condition, application of 125% RDF based on soil test values recorded higher values of plant height (116.6 cm), number of sympodia (22.2 $plant^{-1}$), number of bolls (27.4 $plant^{-1}$), boll weight (4.8 g) and seed cotton yield $plant^{-1}$ (98.5 g) and seed cotton yield (1718 kg ha^{-1}) compared to RDF alone (111.9 cm, 20.9 $plant^{-1}$, 25.0 $plant^{-1}$ and 4.61 g, 98.0 g $plant^{-1}$ and 1585 kg ha^{-1}) (Anon., 2012b). The number of reddened leaves with 125% RDF at 90 and 120 DAS was 4.06 $plant^{-1}$ and 5.20 $plant^{-1}$ as against 4.73 and 5.53 $plant^{-1}$ with RDF application. Santhosh *et al.,* (2015) reported that leaf reddening index was significantly reduced with higher NPK fertilizers (150% RDF) and also with foliar spray of $MgSO_4$ + KNO_3 thrice combined with initial soil application of $MgSO_4$ at 25 kg ha^{-1}. In UKP irrigation command, Shivaraja (2015) obtained 4209 kg ha^{-1} seed cotton yield with basal application of $MgSO_4$ @ 25 kg ha^{-1} along with foliar spray of MgSO 4 + 19:19:19 @ 1% each for leaf reddening management (LRM) which was significantly superior over control with no LRM practices (3893 kg ha^{-1}). Further, the leaf reddening index (LRI) recorded was significantly lower in former treatment of LRM practices (0.69, 1.07 and 1.72 at 60, 90 and 120 DAS, respectively) compared to control (0.78, 1.25 and 1.84 at 60, 90 and 120 DAS, respectively). In Karnataka foliar spray of $MgSO_4$ and 19:19:19 NPK is now recommended for general practice (Sathyanarayanrao *et al.*, 2014 and Anon., 2016) for the management of leaf reddening While, Honnali and Chittapur (2017) reported that 25% extra RDF 150 (4 splits at monthly interval):75:75 kg ha N, P_2O_5 and K_2O along with soil application of 25 kg ha^{-1} $MgSO_4$ at planting followed by foliar spray thrice each of 1.0% $MgSO_4$ and 19:19:19 NPK at 80, 105 and 130 days after sowing coinciding with square formation, peak flowering and boll development recorded lower scores for leaf reddening (0.67) and higher seed cotton yield (2.07 t ha^{-1}), sustainability yield index (90.59%) and economics (` 73,630 and 2.65 net returns and B:C ratio, respectively) in comparison to application of recommended dose of fertilizer (0.87,1.63tha^{-1},70.41%, Rs. 57,380 and 2.38, respectively).

Thus, the foregoing review reveals that cotton leaf reddening symptoms which appear towards peak flower to boll development result in reddening of leaves and cracking of bolls leading to lower yields; half of the normal yields in uncontrolled situation. Being a complex disorder attributed to many reasons as differential uptake of cations, sudden lowering of night temperature, excessive boll load, low soil nitrogen supply, abiotic stress like water shortage or stagnation, biotic stress due to jassids, synthesis and accumulation of anthocynin pigments etc. resulting in reddening of leaves, petiole, and then stem starting from the lower canopy extending to terminal portion with passage of time. At grand growth phase (flowering and boll development) any hindrance in the assimilate production, translocation and distribution intensifies the leaf reddening effect. Since, leaf reddening is an irreversible process occurring at later stages of crop growth in response to growing conditions corrective measures need to be initiated at appropriate stages.

Reddening is a complex phenomenon and there is no single reason why leaves turn red. The survey data on constraints of Bt cotton cultivation indicated that 93% of farmers facing the problem of leaf reddening and majority of the farmers not adapted the control measures. Now a day's majority of the cotton growers in India as well as Karnataka have expressed that bt cotton was very susceptible to leaf reddening and also they touching the doors of agriculture university and extension agencies for the reason and efficient control of leaf reddening hence there is a need to intensified research work on finding the exact reason and management of leaf reddening and to give the crop condition in parcel basis in necessary.

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