A critique on the paper 'Agricultural biotechnology and crop productivity: macro-level evidences on contribution of *Bt* cotton in India'

This paper is a critique of Srivastava and Kolady[1] who reported a macro analysis of the benefits of *Bt* cotton in India using state wide average data. The analysis is in error with respect to the economic benefits, biological underpinnings, and the effects of *Bt* cotton technology adoption on resource-poor farmers growing rain fed cotton. Viable non GMO high density cotton alternatives that increase yields, reduce cost of production, and give higher net average returns were ignored. The authors argue for biotechnology adoption in other crops in India without providing data or analysis.

Unaware of the critical issues in technology impact evaluations, Srivastava and Kolady[1] (S&K) have published a macro-economic analysis of cotton production in India that is totally devoid of understanding the biological underpinnings of the cotton production system, and of the impact of the introduction of *Bt* cotton technology on 62–65% of India's resource-poor subsistence farmers producing rainfed cotton. A good part of their study is the exposé of the biotechnology development and commercialization of the genetically modified organism (GMO), *Bt* cotton in India, indicating how more than 1128 varieties of variable quality could have been developed. This part of the story would be a nice addition to a second edition of Beckert's book titled *Empire of Cotton*[2].

Early in their article, S&K cite highly flawed analyses that conflate all cotton-growing areas to show that there is no evidence linking farmer suicides and adoption of *Bt* cotton[3,4], and then wash their hands of the problem by citing the Governor of the Reserve Bank of India, '….that farmer suicide is a complicated issue and formal finance is the key, a finding reported in the empirical literature'. However, a closer look at the suicide data among farmers of Andhra Pradesh and Maharashtra, most of whom grow rainfed cotton, shows significant increase in farmer suicides with time and when plotted on national totals[5]. Of course, the cotton farmer suicides are not directly related to *Bt* cotton itself, but rather are a proxy for the economic instability that the technology, and prior and ongoing pesticide use have introduced to the rainfed subsistence cotton farmer system. Yet, S&K mention that numerous economic studies worldwide have found high benefits of biotechnology for the poor[6], and then seek to place the Indian situation in a similar positive light. They state that '…agricultural biotechnology … assumes significance in addressing the biotic and abiotic stresses in the agricultural sector…', whatever that might mean. Then they use state-wide macro data to show '…The economy-wide benefits of structural change in cotton production since 2002–03 [*when Bt cotton began to be introduced*] are reflected through the performance of trade and agri-biotech industry in India.' They attempt to place subsistence Indian cotton farmers, most of whom have less than a hectare of land, in a global context claiming that increased yield, reduced cost of production and higher net returns per hectare were the major drivers of rapid widespread adoption of *Bt* cotton by them. This view flies in the face of reality that seed and pesticide costs in low-yield rainfed areas of, say, Maharashtra may vary between 11% and 20% of gross revenues of small farmers resulting in less than one USD per day of income[5]. *Bt* cotton adoption in India was not driven primarily by the factors S&K posit; rather it was the widespread promotion of a false lifeline of promises to poor farmers of increased yield, reduced insecticides use and no pests that were the initial drivers, with the inability to replant saved seed assuring the continued use of *Bt* seed[7]. Some of the field-level studies of *Bt* cotton adoption in India and others they have cited to show economic gains by Indian farmers were based on inappropriate trial plot data that biased the results[8–10], did not control for important inputs such as fertilizer and water[11], used industry data to predict unrealistic estimates of yield gains[12], and ignored important agronomic aspects of the system (e.g. irrigated versus rainfed cotton, density considerations, varieties, pest dynamics), and the effects of weather[5]. Such technology-oriented field-level economic analyses based on survey panel data disregard the underlying agro-ecological principles of yield formation and interactions with the social environment, and produce statistical relationships of little help in the evaluation of multiple causes and effects in complex agricultural systems. Such econometric analyses tell us nothing about the origins of the problem being evaluated or about better alternatives, if any, to the current production system. They provide little insight into what is first a biological problem with socio-economics superimposed, and seldom, if ever, question whether the technology was needed in the first place[5]. All of these points and many others have been covered in detail by Gutierrez *et al.*[5], but were ignored or minimized by S&K.

If the field-level economic analyses above fail to inform about the underlying agro-economic social problems of Indian cotton production, what can really be expected from the macro-economic analyses using highly aggregated state-wide data? Yet S&K claim that GMO technologies using *Bt* cotton in India as the prime example '…will provide the Indian farmers upward mobility from poverty'. Such aggregate data tell us noting about how the community of subsistence farmers is doing, and to use *Bt* cotton adoption rates and average state-wide yields as metrics of the success of the technology is academically disingenuous hubris.

The average national data reported by S&K summarize insecticide use and the changing allocation to control different pests. Replotting the data and including average yield during the 2002–2013 period after GMO hybrid cotton was first introduced to India[13], shows three issues of interest (Figure 1): (i) national cotton yields increased to about 510 kg/ha in 2007 when *Bt* cotton adoption was about 70%, but then declined to 504 and 483 kg/ha respectively, in 2014 and 2015 (not illustrated) when 95% of the crop was *Bt* cotton; (ii) insecticide use decreased to its lowest point in 2006 with a concomitant decrease targeting 'American' bollworm (i.e. bollworm) despite *Bt* cotton adoption being only 30%; and (iii) insecticide use increased after 2006 reaching 2002 levels in 2012 and higher in 2013, but now the insecticide targeted new induced sucking hemipteran pests in *Bt* cotton[13,14]. Important asides include: (i) the Finance Ministry in 1993–94 imposes a 10% excise tax on all pesticides at the factory (the 'polluter pays' principle) that likely caused the 35% reduction in pesticide use nationally by 2003, before significant introduction of *Bt* cotton; (ii) after 2003, the Government began to subsidize fertilizers[15] that helped increase yields, and (iii) the cotton economy of India increased significantly as the area under cotton cultivation rose from 76.3×10^5 ha in 2003 to about 120×10^5 ha after 2011 (ref. 13). S&K have side-stepped the issues of how all of these changes impacted small subsistent rainfed cotton farmers who faced high *Bt* cotton seed prices and the costs of continued insecticide use (i.e. the biotechnology and pesticide treadmills), normal costs of production, exorbitant money-lender fees, new induced secondary pests, and highly variable weather that set the limits on the maximum yield potential of all varieties[5]. Instead, they subjected an available limited dataset to a simple statistical analysis for hypothesis testing and then posited a bright future for the transgenic *Bt* technology.

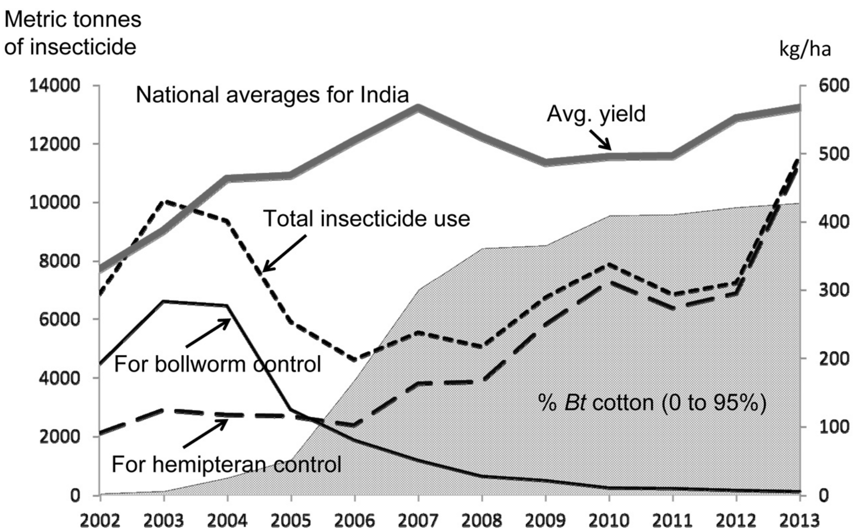

Figure 1. Trends for cotton yield, pesticide use and percentage of total cotton-growing area planted with *Bt* cotton. (Source: K. Kranthi[12,13].)

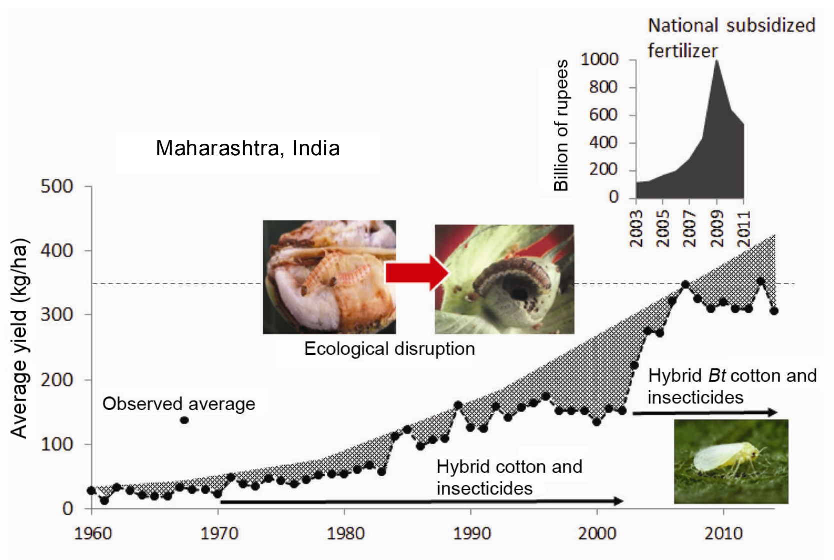

Figure 2. Trends in average yield of cotton in Maharashtra, India (source: Ministry of Agriculture, Government of India (GoI)). (Inset. Upper right) National subsidized fertilizer (Indian rupees). Source: Ministry of Fertilizers and Chemical, GoI). The heavy arrow indicates the transition in pest importance from pink bollworm to bollworm due to insecticide ecological disruption, and the emergence of whitefly as a major pest after the introduction of hybrid *Bt* cotton.

Figure 2 shows the state-wide average cotton yield data for Maharashtra during 1960–2013. Majority of the farmers in Maharashtra grow rainfed cotton on farms that are <1 ha. Observed average yields in the figure show an increasing trend despite dips and plateaus in the pattern. For heuristic purposes, the average potential yield of cotton through time can be viewed roughly as the high points in the data (the upper margin of the shaded area), and the smooth trend can be viewed as the path of yield enhancement progress due to plant breeding and agronomic changes. The trend likely underestimates the true potential under good agronomic conditions and ample rainfall. The shaded area in the figure is the difference between the observed and heuristic trend line of yield, and approximates the yield loss due to weather, poor agronomic practices, induced pests, and other factors. Note the heavy government subsidies for fertilizers (billions of rupees) that began in 2003 and peaked in 2009 (inset (upper right), Figure 2)[15].

A review of the history of cotton culture in India helps explain the data in Figures 1 and 2. Cotton production in India has a 5000 year history with large changes starting in 1790 when New World cottons (chiefly *Gosypium hirsutum* L. and later *Gosypium barbadense* L.) were introduced by the colonial British to feed their developing industrial revolution[2]. Why hybrid cotton (normally *G. hirsutum*) was introduced to India in the 1970s (ref. 16), but nowhere else in the world, is truly a mystery other than to note that it prevents planting saved seed. The introduction of hybrid cotton varieties also ushered in the high use of insecticides and fertilizers[17,18]. As occurred worldwide in cotton, over time excessive insecticide use created and region wide ecological disruption and outbreaks of secondary pests that greatly contribute to yield losses. Prior to high insecticide use, pink bollworm which is native to South Asia, was the major pest in long-season irrigated Indian cotton grown more than 180 days, while bollworm and whitefly were minor pests[5]. However, by 2002, 75% of insecticide use in Indian cotton targeted outbreaks of bollworm and other secondary pests[5,13] (Figure 1), and as occurred in Peru, California, Mexico, Egypt and elsewhere, the damage caused by the secondary pests became greater than that of the original target pest(s). This scenario of insecticide-induced pests in cotton was outlined by van den Bosch[19] in his book *The Pesticide Conspiracy* (also see the supplemental materials in ref. 5). Complicating the insecticide-based cotton production system in India was the development of insecticide resistance in a defoliator in the late 1980s and in other pests, including pink bollworm and bollworm in the 1990s (refs 20, 21). Together, increasing insecticide use and insecticide resistance in India increased the severity of secondary pest outbreaks (e.g. bollworm, whitefly and others), and the resurgence of target primary pests (pink bollworm) from late 1980s to about 2002–03 contributed greatly to reduction in cotton yield (Figure 2)[5]. In cotton (and in other crops), the more one sprays, the more primary pests resurge and more secondary pests outbreaks are induced[19].

Genetically modified hybrid *Bt* cottons were introduced in 2002, and by 2012 more than 1128 *Bt* varieties were planted on 92% of the cotton area[22,23], virtually eliminating non-GMO Desi and North American varieties from the marketplace. The *Bt* technology is not yield-enhancing; rather it is designed to protect the yield potential of the variety that carries the trait against some pests, and the hybrid seed prevents seed saving by resource-poor farmers. The incorporation of *Bt* technology in hybrid cotton initially controlled pink bollworm and bollworm, and an initial decline in insecticide use occurred. However, by 2013, insecticide use surpassed 2002 levels (Figure 1) as farmers attempted to suppress new induced outbreaks of pests refractory to *Bt* cotton (whitefly, mealy bug, jassid) and the diseases they vector[24]. The inescapable fact is that *Bt* cotton was introduced to India to solve an induced bollworm problem created by ecological disruption due to insecticide misuse, and the outbreaks of new induced sucking pests in *Bt* cotton have similar insecticide-based causes[5]. Yet, S&K posit these new pest problems can be solved with additional biotech fixes. We suspect this is rather analogous to a technological dog chasing its tail.

Such problems are not new, as technology and a pesticide-driven fiasco occurred in the green revolution rice in Asia, where insecticides were initially used to control rice stem borer, and induced massive outbreaks of the heteropteran rice brown plant hopper (RBPH; and the virus disease it vectors). This led researchers at the International Rice Research Institute (IRRI), Philippines to begin breeding rice varieties resistant to RBPH. Unfortunately, the genetic capacity for breaking the resistance to the new varieties was already present in RBPH populations before the new varieties were released, leading to rapid failure of the new varieties[25,26]. The solution to the RBPH problem was to greatly reduce the use of insecticides in rice – to utilize the regulatory power of nature in the rice system.

Though the details for rice are different, the scenario is surprisingly similar to that being played out in GMO cotton in India, as increasingly more lepidopterous pests are targeted, but not controlled by new constructs of *Bt* and in response more insecticides are used that induce massive outbreaks of heteropteran pests. In addition to insecticide resistance, rapid resistance to *Bt* varieties has occurred in pink bollworm in India[27] and will likely occur in bollworm and defoliators as has occurred in maize in USA. The solution to this downward insecticide-biotechnological spiral in Indian irrigated and rainfed cotton is short-season high-density non-hybrid non-GMO cotton with minimal insecticide use[5,13], the potential of which has been demonstrated by Indian scientists at the Central Institute for Cotton Research, Nagpur[28] (see also http://www.thehindubusinessline.com/blink/know/fly-in-the-face-of-bt-cotton/article8561303.ece), and by organic cotton growers in India. These varieties and practices are viable alternatives for resource-poor farmers. Yet, the GMO industry and its academic and government supporters (e.g. S&K) fail to recognize this, and the obvious question is why? The development of these new varieties is in the interest of small, resource-poor farmers especially, but all Indian cotton farmers in general, and in the aggregate the national economy and nature itself. The requisite bio-economic field trials of these advanced non-hybrid varieties must cover the full spectrum of appropriate possibilities, including organic and GMO cottons, with and without insecticides. Plant breeders must also take into account that sustainability considerations call for developing locally adapted varieties. Furthermore, as shown in California[5] (supplemental materials), the studies must be conducted in large, ecologically undisturbed areas, say where organic cotton is currently grown.

From a technical standpoint, in the absence of *Bt* cotton, average national cotton yields in India could have increased using: (i) proven low-cost, high-density planting of non-GMO, non-hybrid, short-season varieties grown during monsoon that avoid pests such as pink bollworm, and allow seed saving and replanting; (ii) availability of modern agronomic inputs such as government subsidized fertilizer that began 2003, and (iii) sound integrated pest management that minimizes the use of insecticides and largely eliminates secondary pest outbreaks[5,13], and reduces risk. (The seed cost for high-density plantings of *Bt* hybrid varieties would increase 5–6-fold based on current seed costs)[5]. The changes to non-GMO varieties would have positive outcomes for small, rainfed cotton farmers that paraphrasing S&K would increase yield, reduce cost of production, and result in higher net average returns per hectare given the background effects of variable rainfall in Central India. A useful tool for rapid analysis and to separate the effects of weather, agronomic practices and pests on yield is the use of physiologically based demographic modelling of the cotton crop systems[5].

von Hayek in his 1974 Nobel Prize in Economics lecture titled 'The pretence of knowledge' concerning larger economic issues stated '…[economists]…have… little cause for pride: as a profession [we] … made a mess of things'[29]. In agricultural biotechnology, agricultural economists have pushed forward agendas without understanding the ecological bases of the crop production problem and in the process have often wrongly filled the information gaps created by corporate intellectual property constraints on field research on GM crops[5]. Albert Schweitzer is quoted in Rachel Carson's famous book *Silent Spring*[30]: 'Man has lost the capacity to foresee and to forestall. He will end by destroying the earth'. India has the research talent, and hopefully will find the political will to forestall the evolving GMO-driven ecological, economic and social disasters in cotton and in other food crops.

1. Srivastava, S. K. and Kolady, D., *Curr. Sci.*, 2016, **110**(3), 311–319.
2. Beckert, S., *Empire of Cotton: A Global History*, Alfred A. Knopf, New York, USA, 2014.
3. Gruère, G. P., Mehta-Bhatt, P. and Sengupta, D., IFPRI Discussion Paper 00808, 2008; http://www.ifpri.org/publication/bt-cotton-and-farmer-suicides-india (accessed on 25 February 2014).
4. Gruère, G. and Sengupta, D., *J. Dev. Stud.*, 2011, **47**(2), 316–337.
5. Gutierrez, A. P., Ponti, L., Herren, H. R., Baumgärtner, J. U. and Kenmore, P. E., *Environ. Sci. Eur.*, 2015, **27**(12), 17; doi:10.1186/s12302-015-0043-8
6. Qaim, M., *New Biotechnol.*, 2010, **27**(5), 552–557.
7. Peled, M. X., *Bitter Seeds* (film), Teddy Bear Films, San Francisco, USA, 2012; http://teddybearfilms.com/2011/10/01/bitter-seeds-2/ (accessed on 27 March 2015).
8. Qaim, M., *World Dev.*, 2003, **31**(12), 2115–2127.
9. Bambawale, O. M. *et al.*, *Curr. Sci.*, 2004, **86**(12), 1628–1633.
10. Naik, G., Qaim, M., Subramanian, A. and Zilberman, D., *Econ. Polit. Wkly*, 2005, **40**(15), 1514–1517.
11. Narayanamoorthy, A. and Kalamkar, S. S., *Econ. Polit. Wkly*, 2006, **41**(26), 2716–2724.
12. Qaim, M. and Zilberman, D., *Science*, 2003, **299**(5608), 900–902; doi:10.1126/science.1080609.
13. Kranthi, K. R., *Cotton Statistics and News*, 16 December 2014, pp. 4–7.
14. Kranthi, K., *Cotton Statistics and News*, 5 April 2016, pp. 1–6.
15. Konduru, S., Yamazaki, F. and Paggi, M., *J. Agric. Sci. Technol. B*, 2012, **2**, 1016–1028.
16. Kranthi, K. R., *Bt Cotton: Questions and Answers*, Indian Society for Cotton Improvement, Mumbai, 2012.
17. Basu, A. K. and Paroda, R. S., *Hybrid Cotton in India: A Success Story*, Asia-Pacific Association of Agricultural Research Institutions, FAO Regional Office for Asia & the Pacific, Bangkok, Thailand, 1995.
18. Prasad, C. S., *Econ. Polit. Wkly*, 1999, **34**, 12–21.
19. van den Bosch, R. *The Pesticide Conspiracy*, University of California Press, Berkeley, 1978.
20. Kranthi, K. R., Jadhav, D. R., Kranthi, S., Wanjari, R. R., Ali, S. S. and Russell, D. A., *Crop Prot.*, 2002, **21**, 449–460.
21. Kranthi, K. R. *et al.*, *J. Econ. Entomol.*, 2002, **95**(1), 134–142.
22. Kranthi, S., Kranthi, K. R. and Lavhe, N. V., *Crop Prot.*, 1999, **18**, 551–555.
23. Blaise, D. and Kranthi, K. R., *Curr. Sci.*, 2011, **101**, 783–786.
24. Kranthi, K. R., *Cotton Statistics and News*, 8 September 2015, pp. 1–3.
25. Gallagher, K., Effects of host resistance on the micro-evolution of the rice brown plant hopper, *Nilaparvatalugens* (Stal). Ph D dissertation, University of California, Berkeley, 1988.
26. Kenmore, P. E., Ecology and outbreaks of a tropical insect pest in the green revolution: the rice brown plant hopper, *Nilaparvatalugens* (Stal), Ph D dissertation, University of California, Berkeley, 1980.
27. Tabashnik, B. E. and Carrière, Y., *Southwest. Entomol.*, 2010, **35**(3), 417–424; doi:http://dx.doi.org/10.3958/059.035.0326
28. Venugopalan, M. V., Prakash, A. H., Kranthi, K. R., Deshmukh, R., Yadav, M. S. and Tandulkar, N. R., In World Cotton Research Conference (eds Kranthi, K. R. *et al.*), International Cotton Advisory Committee, Mumbai, 2011, pp. 341–346.
29. von Hayek, F., *Nobel Prize Lecture*, 1974; http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/1974/hayek-lecture.html (accessed on 27 March 2015).
30. Carson, R. *Silent Spring*, Houghton Mifflin Company, Boston, MA, USA, 1962.

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Arenaria thangoensis W.W.Sm. (Caryophyllaceae), a threatened species hitherto considered endemic to Sikkim rediscovered from the Western Himalaya, India

The genus *Arenaria s.l.* is represented by about 210 species of annual or perennial herbs distributed in the temperate and arctic areas of Asia, Europe, northern Africa, North America and South America[1]. In India, it is represented by 24 species[2] mainly confined to the Himalaya of which *Arenaria curvifolia* Majumdar, *Arenaria ferruginea* Duthie ex F. Williams and *Arenaria thangoensis* W.W.Sm. are listed as Indian endemics and 'endangered'/'vulnerable' species in the 1997 IUCN Red List of Threatened Plants[3] and Red Data Book of Indian Plants[4]. *A. curvifolia* was rediscovered after 121 years in its type locality, i.e. Kuari Pass, Uttarakhand nearly a decade ago[5], but *A. ferruginea* and *A. thangoensis* still elude the taxonomists.

A. thangoensis W.W.Sm. was described[6] in 1911 based on the collection of plant specimens by Smith & Cave (2572 CAL!) in 1909 from Thangu ('Tangu') area of Sikkim in the Eastern Himalaya. This species was also collected from Chugya (Eastern Himalaya) by Rohmoo Lepcha (285 CAL image!), but never recollected either from the type locality or anywhere in the Himalaya or Tibet. It has also been mentioned as known by the type collection only[7].

During a floristic exploration in the Kuari Pass alpine zone (Chamoli district,