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GLOBAL ANALYSIS OF BT COTTON ADOPTION: EFFECTS ON PESTICIDE USE, CROP YIELD, AND SOCIOECONOMIC OUTCOMES

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ABSTRACT

Cotton belongs to family Malvaceae having a genus *Gossypium* is a world's superior fiber. Pakistan ranks second in the world in terms of exports, fourth in terms of yarn production, and seventh in terms of fabric production. Almost 60% of Pakistan's export revenue comes from the sale of cotton goods. Non- *Bacillus thuringiensis* (Bt) cotton was the major reason of low cotton yield in Pakistan. In 1990 China, Australia and USA introduced Bt gene for the management of bollworms which ultimately increase the cotton production, while Pakistan adopted first Bt crop in 2004. The purpose of the present review is to assess the rate of adoption of Bt cotton, as well as its influence on yield and the application of pesticides. The result showed that Bt technology significantly decreased pesticide usage while still increasing yields. It is possible to estimate the significance of having a high cotton yield as well as low crop losses by considering the fact that the production and exports of Pakistan's textile industry are directly dependent on the country's annual cotton production.

Keywords: *Gossypium hirsutum*, Malvaceae, fibrer, textile sector, *Bacillus thuringiensis*, pesticide, yield, socio-economic, adoption, bollworms, natural farming, Bt cotton, not Bt cotton

Agriculture plays a significant role in the economy of the developing countries like Pakistan. Agriculture is a corner stone and also considered as the backbone of Pakistan's economy. Agriculture was formerly a vital economic sector, but it has since declined due to poor results and adverse political, social, environmental, and climatic conditions. So it is now Pakistan's second-biggest sector (Raza et al., 2012). This sector is directly responsible for providing for the needs of the country's population and contributes 26% of the total gross domestic product. Agribusiness provides a business occasion for 44% of the labor force while 62% of rural population relies on agriculture for their livelihood. Business activities and mode of life consolidate together in agricultural sector. The importance of agriculture can be estimated from three perspectives; to give food to country and fibers for domestic industry, methods of earning foreign exchange, provides products and enterprises in domestic industry and global market. Wheat, cotton, rice, sugarcane, fruits and vegetables are the major agricultural crops of Pakistan. The irrigation system of Pakistan is among the world's biggest system to support the agricultural production. Punjab, the irrigated province of Pakistan has major contribution in production system (Azam et al., 2017; Rehman et al., 2015).

Conventional breeding techniques is used to achieve limited by time and space therefore its urgent to develop modern techniques to produce high yield, resistant to insect and with broad spectrum effects. *Gossypium hirsutum* (L.), *G. barbadense* (L.), also known as the "New World Species," *G. herbaceum* (L.), and *G. arboretum* (L.), also known as "The Old World Species," are all commercially important cotton species. Some parts of Africa and Asia still grow Old World cottons, but New World cottons have almost completely replaced them. Most people grow *G. hirsutum* cultivars, which can be found in 45 countries. *G. hirsutum* makes up about 90% of the world's cotton harvest every year (Truscott, 2010). *G. hirsutum* is a natural crop that is increasingly one of the world's most important textile businesses due to its high quality fiber. In a nutshell, this industry contributes at least $600 billion to the global economy every year (Ashraf et al., 2018). China, India, and the United States of America (USA) are the world's top three cotton-producing countries, and their annual cotton output is measured in thousands of metric tons

(Shuli et al., 2018). In Pakistan, cotton is most valuable crop and at fifth in terms of cotton production behind China, India, the United States, and Brazil. Pakistan's agricultural sector and economy would collapse without cotton. Even yet, 10% of Pakistan's Economy comes from cotton and its byproducts, as well as the agricultural value-added (Bakhsh et al., 2009; Sial et al., 2014).

A. Cotton adoption and production

Pakistan's output is 685 kg/ ha, higher than the global average of 575 kg/ ha but 34% below its needs, according to the US Department of Agriculture (2018). Cotton is Pakistan's most valuable crop. Over 15% of all farmland in Pakistan is devoted to growing cotton, and about 26% of all farmers grow the crop. Cotton is mostly grown in Punjab (79%) and Sindh (20%) during the Kharif season. (Monsoon). Baluchistan and Khyber Pakhtoon Khawah are two more provinces that cultivate it as in (Table 1). From the 9th country Pakistan to adopt Genetically Modified Organisms (GMOs), with Bt cotton representing as the country's only formally commercialized GM crop. With Bt cultivation, countries saw increased yields and lower production costs due to reduced pesticide use (Frisvold et al., 2006, Subramanian and Qaim, 2009; Shankar and Thirtle, 2005). About 94% of farmers in China and Australia use Bt cotton to increase yields and reduce crop losses, making these countries the world's leading cotton producers. Cotton picking is a labor-intensive task that offers additional employment and income options to rural households that are not involved in farming (Cororaton and Orden, 2008). A total of 24.9 million hectares were grown with biotech cotton in 2017, which is a decrease of 3% compared to the previous year. Insect-resistant/herbicide-tolerant cotton's rising global market value and widespread acceptability contributed to a 3% gain in the biotech cotton market as a whole in 2018 as in (Fig. 1).

Table 1. Province wise production of cotton from 2013-14 to 2017-18 (000 tons)

Year	Pakistan	Punjab	Sindh	Balu-chistan	KPK
2013-14	2171.86	1555.47	599.30	16.96	0.14
2014-15	2374.39	1748.01	607.65	18.22	0.51
2015-16	1686.85	1078.88	591.16	16.60	0.20
2016-17	1814.96	1186.89	611.80	16.18	0.10
2017-18	2031.83	1373.82	642.23	15.70	0.09

Source: Agricultural statistics of Pakistan

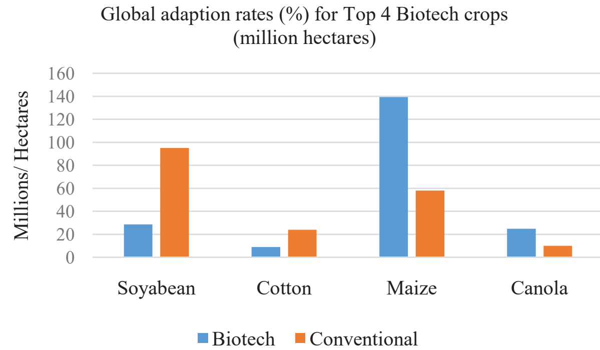

Fig. 1. Rates of adaptation (%) for the world's top four biotech crops (Million Hectares)
Source: ISAAA, 2018

B. Application of pesticides

Pesticides have been used to protect Pakistan's cotton crop from sucking and chewing insects over the previous three decades as in (Fig. 2). Pesticides play a significant role in the cotton production and account 33 % of capital costs (Farooqi, 2010). Overuse has also resulted from a lack of awareness about effective pesticide use, techniques, and safety precautions. It has also had negative effects on the people and society of Pakistan, such as less biodiversity, more air pollution, toxic residues in food items, and direct exposure of farm workers and cotton pickers to serious health hazards, all of which have contributed to the rise in the price of cotton production (Nazli & University of Guelph, 2010). Diseases and insect attacks affect cotton production in developing countries like Pakistan. Pest infestation is more dangerous for small farms, which are major part of Pakistan's agriculture because the poor farmers cannot face any form of financial loss (Farooqi, 2010).

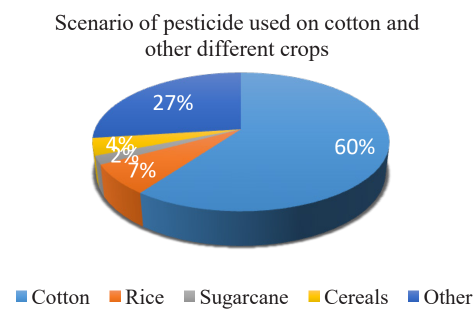

Fig. 2. Pesticides used on cotton

C. Genetically modified cotton

Various strategies have been implemented to develop inbuilt resistance to bollworms, however, the only effective strategy for addressing insect resistance is the use of Bt toxin, a toxin family originally generated from soil bacteria (Bakhsh, 2017; Ahsan et al., 2009;

PARC, 2007).

The process of producing a GM crop plant is divided into six phases (Mannion, 2008; Monsanto, 2007).

1. Gene mapping is a method for locating and isolating the gene that has the desired characteristics.
2. A procedure known as polymerase reaction (PCR) is used to make multiple copies of the isolated gene.
3. Transformation of genetic material from the isolated material can be achieved by three ways: using a soil bacterium that has been injected with the required genetic material, a protoplast or through a gene gun.
4. Under laboratory condition, the genetic material that has transformed is allowed to develop into a plant.
5. The plant is assessed in an experimental context to see if it displays desired characteristics.
6. To produce hundreds of seedlings with the desired features, tissue culture, the growth of plant tissue rather than the entire organism, and cloning can be used.

In the case of genetically modified (GM) plants, the Bt genes are the result of the modification. Cotton is one of the many key agricultural and economic crops where the use of these Bt genes has been permitted for commercialization (Xiao et al., 2019). The first GM crop to go on sale to the public was cotton in 1996 (Raman, 2017). This plant is mostly planted today for pest management against coleopteran, lepidopteran, and hemipteran insects.

Cry 1 Ac was used early on in the history of genetically engineered cotton to decrease populations of *Helicoverpa armigera* and *Pectinophora gossypiella* (Wu et al., 2005). Cotton that has been cultivated for an extended period of time with only one copy of the Bt gene runs the risk of developing gene resistance to multiple different toxin combinations over time. The latter half of the 20th century saw the development and testing of these various mixtures of toxins. In a number of countries, Cry1Ab+Cry2Ab2 has replaced with a single copy of the Bt gene (Xiao et al., 2019). In comparison to cotton that did not include Bt, cotton that contained a mixture of two toxins resulted in a lower number of cotton bollworm larvae. The cotton bollworm and other lepidopteran pests have been controlled, but the mirid bug, which was not one of the targets of the eradication effort, has become the dominating pest (Lu et al., 2010). Monsanto discovered the insecticidal effects of Cry51Aa2 against mirid nymphs. The mosquitocidal toxin known as Cry51Aa2 has a unique chemical structure in comparison to the more common toxin known as Cry 1A (Baum et al., 2012). In today's world, chemical pesticides are typically used in order to get rid of mirids. The Cry51Aa2 gene, when combined with another Bt toxin gene, has the potential to lower the risk of an outbreak of mirids as well as the environmental damage caused by the use of pesticides.

Single Bt-gene cultivar (Ingard) was replaced by two-Bt gene cultivar (Bollgard II). Bollgard II has now almost replaced conventional non-Bt cultivars in Australia (Wei et al., 2014). Pyke, 2000 reported that the average use of insecticides has reduced two-fifth and four-fifth by implementation of Ingard and Bollgard II, respectively. Bollgard II is more effective as compared to Ingard for the management of Helicoverpa spp. Due to low need of chemical spray, worker safety and lifestyle benefits farmers prefer to plant the Bollgard II cotton.

When Chinese farmers switched to Bt cotton, they used less pesticides, saved money on labor costs, and were less likely to be exposed to especially dangerous pesticides, according to comparisons between Bt cotton and other types of cotton and surveys of farmers (Wei et al., 2014).

D. Significant Bt cultivation

In Pakistan, the establishment of a refugee is not required, and instead, a natural refuge strategy is applied for Bt cotton. This is similar to the method utilized in China. It has been determined that the *Helicoverpa armigera* population, which is highly susceptible to extinction, may be maintained with the help of a number of different host crops. These include maize, sorghum, maize and sunflowers amongst others. China and Pakistan both have cotton growing regions, but their respective landscapes couldn't be more contrasting. The agricultural land in China is extremely fragmented, and there are a myriad of different crop patterns and weed hosts to contend with. Pakistan's cotton crop season includes alternative host crops, but their acreage is little compared to cotton, especially in Punjab's cotton zone. The cotton zone spans the entirety of both the Punjab and Sindh provinces (Ali et al., 2013).

In 2012-2013, Bt cotton was planted on over 2.56 million hectares (62.59%) of the total area used for

Kharif (summer) crops. Almost 80% of Punjab's cotton acreage is concentrated in the key cotton districts of Bahawalpur, Bahawalnagar, Vehari and Rahim Yar Khan. Because of the extensive cultivation of Bt cotton in these regions, the overlapping cultivation of other key host crops is significantly smaller than that of Bt cotton.

E. Effect of bt cotton on pesticides use

Field experiment data from 2005–2015 in the eastern and central United States Cotton Belts were analyzed by Fleming et al. (2018) to determine the effectiveness of Bt cotton. This cotton used less insecticide, had less damage, and produced more, but the effectiveness of Wide strike and Bollgard II in the Midsouth decreased over the trial period. New Bt toxins, like the ones in Twinlink and Widestrike 3 can help Bt crops keep their benefits for a long time. Using data from farm surveys, Kouser et al. (2015) examined how the introduction of Bt cotton in Pakistan might affect crop output, pesticide application, and resource efficiency. Chemical pesticides harm the environment and health, as measured by the environmental risk quotient. Cotton yields are higher on Bt-adopting farms, which use less pesticide and do less environmental harm. Bt farms are more effective both environmentally and economically than non-Bt farms. The use of Bt improves environmental efficiency by 37%. Traditional cotton producers will lose US$ 54/ acre in production and sales to reduce environmental and health concerns without Bt (7% of total revenues). It is clear from our research that Bt technology has the potential to aid in the advancement of sustainable farming practices.

The effects of Bt cotton technology on pesticide application were investigated in a study by Veettil et al. (2014). Using detailed panel data from smallholder farmers in central and southern India, an environmental impact quotient (EIQ) was developed to quantify the negative environmental and health implications of pesticide use. Throughout the manufacturing phase, the potential for pesticide harm to the environment is seen as an undesirable byproduct. Compared to conventional cotton, Bt cotton produces fewer external effects. Increases in Bt adoption have been linked to a steeper fall in EIQ, from 39% in 2002-2004 to 68% in 2006-2008. Researchers found that the quality of Bt seeds is connected to their efficiency in protecting the environment, with higher quality seeds being associated with better results than lower quality ones.

The impact of this cotton on pesticide toxicity in smallholder agriculture was studied by Kouser et al. (2011). Bt cotton has decreased the use of pesticides by 70%, with the biggest reductions occurring in the most dangerous pesticides. The incidence of acute pesticide poisoning among cotton farmers has fallen dramatically after the introduction of Bt, as shown by the results of a fixed-effects poison model. These effects have intensified as the percentage of people who embrace new technologies has grown. Qaim et al. (2005) analyzed the technology decreases toxic chemical application rates by 50% while dramatically increasing yields. The efficacy of Bt versus chemical pesticides is measured using a damage control framework, and technical effects are predicted for various farm types. Rapid resistance development and subsequent insect outbreaks seem impossible if minimum non-Bt refuge areas are maintained. As a result, encouraging the widespread use of Bt cotton could intensify the efficiency and environmental gains.

F. Impact of Bt cotton on yield

Mansoor et al. (2020) determined an estimate of the farmers' standard of living by contrasting the per capita income of farmers with the federal poverty threshold. Results from a panel study show that compared to traditional cotton, Bt gene cotton results in a 33-37.5% increase in overall yield. Nonetheless, the average Bt cotton production in Punjab districts is 13% greater than in Sindh districts, leading to a significant disparity in the per capita incomes of Bt farmers in the two provinces. In comparison, as opposed to conventional cotton farmers, Bt gene growers have relatively low pesticide applications.

Nazir et al. (2020) investigated how combining ability and gene activity affect upland cotton yield and yield-contributing traits. Four different varieties of upland cotton were cultivated and then crossed with one another in an experiment using a complete diallel mating strategy. These were MARVI, FH-458, MNH-996, and VH-333. The FH-458 genotype has showed the greatest improvement in fiber length. It was discovered that MARVI is the best general combiner for determining the fineness numbers of fibers, and that VH-333 is the best general combiner for determining the strength of fibers. In terms of the average fiber strength, MNH-996 exhibited the best general ability to mix with other materials. MARVI FH-458 and FH-458 MARVI both had substantial basic combining ability effects for fiber fineness in the F1 hybrids, whereas FH-458 MARVI shown high basic combining ability effects for fiber length.

Khumalo et al. (2019) conducted their research to investigate the impact that Bt cotton had on crop yields. Alba Plus QM 301 and JKC 724, both of which are non-Bt local variations, were put through their paces against the Bt JKCH 1947 Bt and JKCH 1050 Bt cotton kinds. Both of the indigenous cultivars that did not contain Bt came out on top. In its first year of production, the JKCH 1947 variety produced 3070 kg of seed cotton per hectare, which is a little higher yield than the average. JKCH 1050, which yielded yields of 2,955 kg/ ha, became the next strain to closely follow it. When compared to the group that served as the control, there was also a discernible increase in the total number of bolls produced by each individual plant. Alba Plus QM 301 and JKC 724, both of which are non-Bt, had lower yields of 2066 and 821 kg/ ha, respectively, when treated to the same circumstances with less bolls produced by each plant. This was the case even though both of these varieties had the same number of plants. For the second year, observations were recorded that were quite comparable to the observations made on the first year; for instance, both JKCH1947 and JKCH 1050 reported 1765 kg/ ha, whereas JKCH 1050 recorded 1865 kg/ ha.

Bakhsh et al. (2017) analyze the influence of Bt cotton on farms' input, yield, and profitability. This experiment evaluates the benefits of adopting Bt cotton seed in Punjab over the 2008 and 2009 growing seasons. The results reveal that Bt cotton adopting farmers receive a 9% rise in yield per hectare, a 21.7% decrease in pesticide usage per hectare, and a 6% increase in irrigation water consumption per hectare. In comparison to other studies conducted in Pakistan and India that did not employ the panel approach, our projections for the increase in cotton output are significantly lower. Ali et al. (2010) used cross-sectional data that was collected from farmer surveys in the Punjab province of Pakistan to analyze the direct impact of adoption of *Bacillus thuringiensis* cotton on yield, average income, poverty and pesticide mandate. Results showed that acceptance or implementation of new technologies reduce the poverty and pesticide use, while increase the average earning and yield of crop.

Bryant et al. (2003) carried out a field experiment to analyze and evaluate the differences in yield between non-Bt and Bt cultivars. The findings showed that there was no discernible variation in yield across the board for any of the cultivars that were put through their paces over three of the five site years. For the other two years at this site, the varieties with the highest yields and those that were not significantly different from the varieties with the highest yields included those with Bt, stacked gene, conventional, and glyphosate tolerant traits. The findings made it quite clear that no single cultivar had a superior return on investment year after year. After a short period, differences emerged between the cultivars.

Qaim et al. (2003) conducted an experiment to investigate the agronomics and sustainability of genetically modified cotton. The objective of this study was to determine whether Bt cotton increases crop yield. Compared to other nations, a significant difference in yield was detected, which may be attributable to the current low use of insecticides. Argentina's average yield impacts have been 32% for the past two growing seasons, although in the United States and China they are often less than 10% (Carpenter et al., 2002; Pray et al., 2002). Bt is not only effective for increasing the output potential of plants, but also for reducing agricultural losses caused by pests. Huang et al. (2002) carried out many surveys in villages to evaluate the effect of Bt on yield in China that depicts that highest yield was obtained by Bt cotton than its counterparts. In 2001, when yield comparison was conducted for all surveyed farms, Bt cotton farmers were around 10 percent higher yield as compared to other traditional cultivars. Non-Bt cotton, however, was lower than Bt cultivars in term of net sales due to numbers of chemical sprays.

G. Socio-economic effects

Available evidence suggests that Bt cotton has had a sizable positive influence on the livelihoods of subsistence farmers in underdeveloped nations. The focus is on India, South Africa, and China, yet India and China are among the world's greatest cotton producers. In general, the studies demonstrate an increase in yield and a decrease in insecticide use, as well as reduced expenses (due to the use of less pesticide) and a larger gross margin for Bt cotton varieties vs non-Bt cotton varieties. The expenses incurred for pesticides, as well as those for labor, fertilizer, planting materials, the upkeep of machinery, and so on, are all included in the ‘all costs’ category. If the yield and price that the farmer was able to obtain are known, predicting revenue should be a reasonably straightforward process. Yet, calculating the cost of production remains a challenge, despite the fact that this step makes estimate revenue quite easy. The costs of the inputs that are utilized during crop growth, such as seeds, fertilizer, pesticides, water, and so on, are fairly clear. But, the expenses of labor are also significant and should not be overlooked. They are referred to as variable costs because they change depending on the choices that the farmer makes, and the farmer has the ability to make those choices if he or she desires to bring any of these expenses down to zero. As a consequence of this, yield increases as variable costs grow; nevertheless, the law of diminishing returns complicates the relationship between the two variables.

Kathage and Qaim (2012) conducted an analysis of the economic effects of Bt cotton and the dynamics of those effects in India. Based on particular panel data gathered between 2002 and 2008 and adjusting for non-random selection bias in the adoption of technology, we show that Bt has generated a 24% improvement in cotton yield per acre as a result of reduced insect damage as well as a 50% rise in cotton profit among smallholders. These benefits are not just consistent, but there is evidence to suggest that they have also increased over time. Additionally, we demonstrate that the implementation of Bt cotton resulted in an 18% rise in consumer expenditures throughout the period of 2006-2008, which is a common measurement of the living standards of households. We can draw the conclusion that Bt cotton has contributed significantly to India's positive economic and social growth by providing benefits that are both considerable and sustainable.

Bt cotton's socio-economic impact in Karnataka was examined by Kiresur and Ichangi (2011). There was an average of 2.21 ha of Bt cotton planted per farm area, which accounted for 66% of the total landholding. In comparison to non-Bt cotton, Bt cotton had a yield that was 31% greater, coming in at 24 q/ hectare, and net returns that were 151% higher. Farmers that grow cotton without the Bt trait typically use excessive amounts of chemical fertilizer and organic waste, which leads to lower net returns. It has been discovered that factors such as the yield of Bt cotton, the cost of seed, and the cost of plant protection all have a substantial influence on the viability of adopting Bt cotton. Earnings for Bt producers in South Africa were found to be greater than those of non-Bt growers, according to research by Ismael et al. (2002). This was mostly attributable to the increased yields and lower costs of pesticides used by Bt producers. Pray et al. (2001) and Traxler et al. (2001) both elaborated on the benefits of Bt cotton to small farmers in their respective studies.

CONCLUSION

One of the world's most important natural crops, *Gossypium hirsutum* is widely used in the textile industry, which generates at least $600 billion in annual revenue around the world (Ashraf et al., 2018). Pakistan is the 4th largest cotton producing country. The average cotton production of Pakistan is 2031.83 million tons and its contribution is 2 percent to the GDP of Pakistan. Pesticides are often misused or overused by farmers in developing countries, including Pakistan. Farmers use pesticides more often, although pesticide use reduces with farm size. Cotton is considered as an earliest genetically modified crop commercially released in 1996 while Pakistan adopted Bt cotton as a first genetically modified crop in 2004 (Raman, 2017). Bt cotton, which resists bollworm, could solve cotton's insect problems. Pakistan yields 685 kg/ ha, more than the world average of 581 kg/ha, but 34% less than its needs.

In order to combat lepidopteran insect pests, Bt cotton is mostly grown today. A total of 2.56 million hectares, or 62.59% of the kharif (summer) crop area, was planted with Bt cotton in Punjab in 2012-13. Bahawalnagar, Bahawalpur, Rahim Yar Khan, and Vehari, which together make up 42% of Punjab's total cotton acreage, are the core cotton districts, where crop field intensity reaches 80%. Agroclimatic conditions, genotype of the variety, and cropping methods all have a role in Bt cotton output. A Bt variety that does well in one climate zone may not fare as well in another. Thus, it is advised that only certified Bt types suitable for the local agro-climatic conditions be used. Adopting bio-safety criteria is necessary for a government to grant approval for commercial usage of a Bt variety.

The effects of Bt cotton in developing world nations like Pakistan were studied by Orphal et al., 2005 and Traxler et al., 2003. With adopting Bt cotton, these countries have seen a decrease in insect infestation, an increase in sustainable yields and revenues. Bacillus thuringiensis (Bt) cotton farming benefited countries through higher yields and lower production costs due to reduced pesticide use (Subramanian and Qaim, 2009; Frisvold et al., 2006). A 2011 study by Kiresur and Ichangi found that Bt cotton had a 31% higher yield than Non-Bt varieties, with fewer negative effects on the environment. The adoption of Bt cotton has led to a decrease in pest infestations and an increase in both sustainable and total yields, as well as income, in numerous countries. Bt cotton demonstrated a 31% increase in yield compared to Non-Bt cotton, while simultaneously minimizing detrimental effects on the environment.

CONFLICT OF INTEREST

No conflict of interest.

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