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Design and Development of Rotary Tubular Drum Dryer for Quarantine of Pink Bollworm infested Cottonseeds in Indian Ginning Industry

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Abstract : Pink bollworm is a dreaded pest that causes significant yield loss and adversely affect cotton fibre and seed quality and farmers income. Ginning industries serves as site for reintroduction of pink bollworm, as the live larvae gets escaped through cottonseed during ginning and then spread into neighbourhood cotton fields. Currently, in India, there are no specific regulations and technologies for quarantining cottonseed infested with pink bollworm. To address this issue and breakdown the pest's life cycle, a prototype of a rotary tubular drum dryer (RTTD) was designed, developed, and assessed its performance for quarantine of pink bollworm infested cottonseed. The RTTD comprises of a central drum, flights and lifters, steam joint, piping assembly, transporting moisture, bucket elevator, and seed bagging system. The process protocol for quarantining pink bollworm infested cottonseed was formulated. The cottonseed is indirectly heated by circulating thermic fluid through the piping system. RTDD performed satisfactorily to quarantine pink bollworm infested cottonseeds having initial moisture contents between 12 to 15 per cent at the operating conditions of: incoming thermic fluid temperatures between 180 °C and 200 °C, retention time of 5 to 6 minutes and corresponding dryer capacity of 500 and 600 kg/h. At these conditions the indirect heating of cottonseed by circulating thermic fluid through piping system resulted in attainment of desired temperature range (65-68°C) and moisture content (≤6%) of cottonseed after drying process. The RTTD holds significant promise in reducing the potential for pink bollworm spread from ginneries.

Keywords: Cotton, cottonseed, dryer, ginning, pink bollworm, quarantine

The pink bollworm, hereafter referred as PBW, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), is a highly destructive insect pest of cotton crop across the global cotton producing areas. Pink bollworm causes significant yield losses and adversely affects cotton fibre and seed quality and income of cotton farmers and ginners. The life cycle of PBW (Fig.1) is normally completed in about 35-37 days after passing through four distinct developmental stages *viz*., egg, larva, pupa and adult (Fig. 1). The larvae of PBW feed on developing flower buds and seeds of green bolls of cotton plant, which causes rosetted flowers, premature opening and heavy shedding of infested bolls, reduction in fibre length and poor quality of lint due to staining (Fand *et al*., 2019, 2021).

Recently, PBW has re-emerged as a major pest problem in Indian cotton production, mainly due to development of resistance against transgenic cotton carrying Cry1AC and Cry2Ab2 genes from entomopathogenic bacterium *Bacillus thuringiensis* Kurstaki (Dhurua and Gujar, 2011; Naik *et al*., 2017; Fand *et al*., 2019). This has posed a serious threat to the continued success of genetically modified cotton in combating serious bollworm pests. The widespread infestation of PBW causing yield

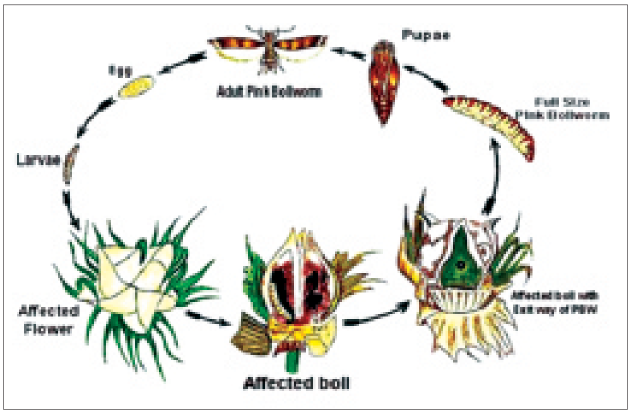

Fig. 1. Fig.1. Pink bollworm life cycle

losses between 10-30 per cent was reported in central and southern cotton growing belts of India during 2017-2018 (Fand *et al.*, 2019). Heavy outbreak of PBW causing huge losses to the *Bt* cotton crop has been reported in northern cotton belts of India during cropping season of 2021-2022. Currently, the PBW management in cotton in India is highly reliant on use of chemical insecticides. About 50 per cent of total pesticide use in India is accounted for managing various pest problems in cotton, and a major portion of it is shared by PBW alone.

Timely termination of *Bt* cotton crop is a must to break down the life cycle of PBW resulting in very low carryover of PBW population and low PBW damage in the subsequent season. PBW larva can survive in uprooted cotton stalks stored by farmers (Vennila *et al.*, 2007). PBW larvae feed and multiply on the seed cotton, cottonseeds and gin trashes stored in cotton gins. The pupae enter into diapause phase of life cycle of the pest in the absence of cotton crop through stored cotton, cottonseed, crop residues and gin trash. Longer the storage, higher the propensity to multiply. Appropriate treatment need to be given to cottonseed for quarantine of PBW and to break down its life cycle.

Concerns for reintroduction of pink bollworm from cotton ginneries

Since last few years, concerns are being raised in India that cotton ginning industries serves as site for reintroduction of pink bollworm, as the live larvae gets escaped through cottonseed in the process of ginning and eventually the moths emerging from them spread into neighbourhood cotton growing areas causing damage. Recent re emergence of pink bollworm as a major threat to transgenic *Bt* cotton on account of development of resistance to *Bt* toxins placed the Indian cotton industry at its risk with increasing concerns for all the stakeholders. The pink bollworm infestation in cotton is higher generally towards the end of the

Table 1. Performance evaluation of Rotary Tubular Drum Dryer at incoming thermic fluid temperature of 180°C

Rotational speed of Tubes (rpm)	Feed Rate/ Capacity (kg/h)	Retention time (min)	Initial moisture content of cottonseed (%)	Temperature after drying (°C)	Final moisture content of cottonseed after drying (%)
6	400	8	12	72	6.1
8	500	6		68	7.1
10	600	4		56	9.4
6	400	8	15	62	7.6
8	500	6		56	9.1
10	600	4		51	11.6
6	400	8	18	58	14.9
8	500	6		50	16.1
10	600	4		46	17.0

Table 2. Performance evaluation of Rotary Tubular Drum Dryer at incoming thermic fluid temperature of 200 °C

Rotational speed of Tubes (rpm)	Feed Rate/ Capacity (kg/h)	Retention time (min)	Initial moisture content of cottonseed (%)	Temperature after drying (°C)	Final cottonseed moisture content after drying (%)
6	400	8	12	78	5.5
8	500	6		70	6.2
10	600	4		68	8.9
6	400	8	15	72	6.5
8	500	6		68	8.3
10	600	4		60	10.6
6	400	8	18	59	13.2
8	500	6		54	14.6
10	600	4		49	16.0

season (Kranthi, 2015; Fand *et al*., 2019). The larvae of pink bollworm at flag end stage of crop season normally enters overwintering stage for the want of appropriate host stage to perpetuate, and can hibernate either in infested bolls on cotton stalks and or damaged seeds in the harvested seed cotton ((Mallah *et al*., 2000, Vennila *et al*., 2009; Kranthi *et al*., 2015). The larvae in hibernating stage remain live for longer period on the seed cotton, cottonseeds and gin trashes stored in cotton gins till the favourable conditions come. Once the signals received by the larvae about seasonal changes, mainly due receipt of light showers at the begging of monsoon season, they resume active growth, enters the pupation and emerge as moths to colonise the next season's crop in the adjoining areas of ginneries. Longer the storage of raw infested cotton, higher the inoculum load of the pest. Therefore, it becomes imperative to give a suitable treatment to the cottonseed to effectively quarantine the pink bollworm and disrupt its life cycle.

In the countries like US and Egypt, there are specific regulations in place especially to prevent the build up and spread of the pink bollworm from ginneries. These regulations pertain to the treatment and movement of seed cotton, cotton lint, cottonseed, and related products within and from regulated areas. Cotton producers, ginners, and seed processors have to abide by these regulations. Hence, the impact of pink bollworm is minimal in these countries. The US has been declared recently as free from pink bollworm due to collective efforts through community approach involving IPM along with sterile insect release techniques (Tabashnik *et al*., 2020). However till recently, such regulations and treatment systems are seriously lacking from India.

In recent years, there have been growing concerns in India regarding the role of cotton ginning industries in the potential resurgence of the pink bollworm. This concern stems from the observation that pink bollworm infestations have occurred in areas surrounding cotton ginning mills (Kranthi, 2015; ICAR-CICR, 2023). The movement of seed cotton and cottonseed from infested regions or gins to non infested ones has facilitated the rapid spread of the pest (Kumar *et al*., 2020). Notably, during the ginning process, there exists the possibility for pink bollworm to survive and bypass pre cleaning and ginning machinery. The larvae of pink bollworm become embedded within cottonseed, lint, and gin residues (Huges *et al*., 1994), only to become active when favourable conditions arise (Kranthi, 2015; Fand, 2021, 2021). It is highly probable that both gin residues and cottonseeds harbour active or dormant stages of pink bollworm larvae and pupae. This raises concerns that ginning facilities might contribute to the build-up and lead to the expansion of the pink bollworm into unaffected regions. Incidents have been documented in various parts of the country, especially in the North zone where ginning cum oil extraction mills have been identified as a channel for the pink bollworm spread through gin residues and infested cottonseed (Kumar *et al*., 2020). In this context, it is therefore of paramount importance to curtail the dissemination of pink bollworm through the ginning process.

ICAR-Central Institute for Research on Cotton Technology (CIRCOT), Mumbai, India has recently developed gin trash treatment system to destroy pink bollworm larvae and pupae and prevent its dissemination from cotton ginneries (Arude *et al*., 2022). Besides, immediate post-ginning treatment of cottonseeds is crucial to effectively quarantine the pest as the pink bollworm larvae primarily remain concealed within the infested seeds,. Therefore, it is imperative to establish measures ensuring that all pink bollworm larvae entering the ginning process undergoes quarantine. To address this issue and disrupt the pest's life cycle and in the absence of suitable devices and technologies in India for treating pink bollworm infested cottonseed, a prototype of a rotary tubular drum dryer has been conceptualized, developed, and assessed. This innovation aims to isolate and contain pink bollworm infested cottonseed, thus mitigating the risk of its spread from ginneries.

MATERIALS AND METHODS

Development of rotary tubular drum dryer (RTTD)

A continuous processing type Rotary Tubular Drum Dryer (RTDD) having a capacity of 1 tonne/hour was designed and developed at Ginning Training Centre (GTC) of ICAR-Central Institute for Research on Cotton Technology (HQ. Mumbai) located at Nagpur in the state of Maharashtra. The RTTD comprises several components, including a central drum, flights and lifters for movement, a steam joint, and a piping assembly, a system for transporting moisture, a bucket elevator, and a seed bagging system. The cottonseed is indirectly heated by circulating thermic fluid through the piping system, maintaining the desired temperature range of 65-68°C for approximately 5-6 minutes. The process protocol for quarantining pink bollworm infested cottonseed was also formulated.

The major sub-assemblies of the developed RTDD (Fig. 2) are described briefly as follows:

Bucket elevator

It is developed for lifting of about 2 tonnes/h cottonseed vertically to about 2500 mm height and feeding same to the dryer inlet using a 2 HP electric motor. There are specially designed metallic cups attached over a vertical belt conveyor for lifting and feeding of cottonseed. A variable frequency drive (VFD) is provided to control the feeding rate. The length, width and height of the developed bucket elevator are 210 mm, 510 mm and 2800 mm, respectively.

Rotary joint

It is one of the most critical components of indirect heating dryers. It is meant for supply of hot and cold thermic fluid to the dryer. In the developed system, a rotary joints having 75 mm and 90 mm diameter are selected for supply of hot and cold fluids, respectively into and out of the dryer.

Elliptical shell

It is used for housing of metal tubes, which are installed longitudinally within its interior. The outer portion of the shell is insulated using glass wool. The height, diameter and length of the shell are 1042 mm, 600 mm and 2500 mm, respectively. Two heat resistant bearings are mounted on either side of the shell to support the tubing system.

Tubing system

A bunch of well-designed metal tubes are used for transportation of hot and cold thermic fluids into the dryer. It consists of a main annulus central tube of 127 mm internal diameter and 7.6 mm thickness. It is mounted inside and at the centre of the elliptical shell over bearings. The hot fluid flows through the outer portion while the cold fluid flows through the inner portion of the central annulus tube. The central tube distributes the hot fluid to a bunch of 20 pipes (five tubes each are fitted longitudinally in four rows over the main pipe) having 50.8 mm internal diameter and 5 mm thickness through the four manifold pipes. The hot fluid circulated in these pipes supplies heat to cottonseeds and leaves the dryer through rotary joint via annulus space of the main central pipe. The whole tubing system is rotated using a VFD controlled 5 HP motor.

Flights and lifters

The wet cottonseeds fed into the dryer and subsequently elevated and guided into the drum by the combined action of flights and shovels, respectively. The pitch and shape of the flights and shovels influence the amount of material present in the rotary dryer. Flights and

Fig. 2. Rotary Tubular Drum Dryer (RTDD)

lifters are designed considering that the volume occupied by the load of solids in the rotary dryer shall be between 10 and 15 per cent of the total dryer volume. Two-segment type flights have been used in the rotary drum dryer of present system.

Moisture transportation system

It is designed and developed for removal of moisture evaporated during heating process from the dryer. It consists of a centrifugal fan and a 2D2D cyclone having 600 mm barrel diameter. An air damper has been provided at the fan inlet to control the rate of air flow of the moisture transportation system.

Cottonseed conveying and bagging system

A belt conveyor system has been designed and developed for transportation and bagging of the dried cottonseed.

RESULTS AND DISCUSSION

Performance evaluation of RTTD system

In this system, cottonseed is quarantined by indirectly heating it to about 65-70 °C for 5-6 minutes using thermic fluid HYTHERM 500 as a heating medium. The inlet temperature of thermic fluid can be safely increased to 200 °C by controlling the boiler fuel feeding. In the developed dryer, wet cottonseed is introduced into the upper end of the dryer shell and the fed cottonseed progresses through it by virtue of rotation of tubing system and dried cottonseed is withdrawn at the lower end of the dryer.

The developed RTTD was installed and evaluated for its performance at GTC (ICAR-CIRCOT), Nagpur. The variables studied were: incoming thermic fluid temperature range (180-200 °C), initial cottonseed moisture content of cottonseeds (12-18%) and tube rotational speeds (6-10 rpm) (Tables 1 and 2). The recorded room temperature and relative humidity were in the range of 25-28 °C and 35-40 per cent, respectively. For quarantine of pink bollworm from cottonseeds, the desired temperature of cottonseed after 5-6 minutes of drying using indirect heating by steam or thermic fluid is 65-68 °C.

Initially, it was observed that cottonseed conveying rate was very high at 8-10 rpm leading to fast withdrawal of cottonseeds from the dryer in less than a minute resulting into minimal rising of cottonseed temperature by 10-20 °C with a removal of cottonseed moisture content merely by 0.5-1 per cent. Hence the rotational speed of tubes was reduced to 2 rpm. At this speed it was observed that cottonseed was moving in lumps. Cottonseed was neither mixing properly nor coming into contacts of all peripheral tubes leading into insufficient heating of seeds resulting in poor moisture removal. It was learnt that optimum rotational speed of tubes is required for proper mixing of seeds for increasing its temperature and reducing moisture content. In order to address this issue, the shovels and lifters were modified to reduce the cottonseed transportation rate. The pitch of the lifters and flights was reduced to 100 mm from initial pitch of 500 mm. It resulted into proper mixing of cottonseeds at tubes rotational speed in the range of 6 to 10 rpm.

Full scale performance trials were conducted on the modified dryer by keeping incoming thermic fluid temperature at 180 °C and 200 °C, rotational speed in the range of 6 to 10 rpm, and cottonseed feed rate in the range of 400 to 600 kg/h. The initial cottonseed moisture content was kept in the range of 12 to 18 per cent. The cottonseed temperature and moisture content after drying were recorded for different trials. The initial cottonseed temperature was around 26 °C. The gauge pressures of incoming and outgoing thermic fluid were measured as 1 bar and 0.5 bar, respectively indicating a pressure drop of about 0.5 bar in the dryer.

The results of performance evaluation of the dryer at incoming thermic fluid temperature of 180 °C are presented in Table 1. For cottonseed with 12 per cent initial moisture content, the desired cottonseed temperature (65-68°C) for quarantine of pink bollworm after drying was achieved at rotational speed of 8 rpm and feed rate of 500 kg/h. The final moisture content found to reduce by around 5 per cent. However, the effectiveness of the dryer was not up to the mark for quarantine of cottonseed having 15 per cent and 18% moisture content as the maximum final cottonseed temperature achieved was lesser than required for quarantine purpose.

The Table 2 presents the results of performance evaluation of the dryer at incoming thermic fluid temperature of 200°C. For cottonseed with 12 per cent initial moisture content, the desired cottonseed temperature (65-68 °C) for quarantine of pink bollworm after drying was achieved at rotational speed of 10 rpm and feed rate of 600 kg/h. For cottonseed with 15 per cent initial moisture content, the desired cottonseed temperature (65-68°C) for quarantine of pink bollworm after drying was achieved at rotational speed of 8 rpm and feed rate of 500 kg/h. However, the effectiveness of the dryer was not up to the mark for quarantine of cottonseed having 18 per cent moisture content as the maximum final cottonseed temperature achieved was lesser than required for quarantine purpose.

CONCLUSIONS

A rotary tubular drum dryer (RTDD) designed and developed in present study was able to perform satisfactorily to quarantine the pink bollworm infested cottonseeds having initial moisture contents between 12 to 15 per cent at the operating conditions of: incoming thermic fluid temperatures between 180 and 200 ºC, retention time of 5 to 6 minutes and corresponding dryer capacity of 500 and 600 kg/h. At these conditions the indirect heating of cottonseed by circulating thermic fluid through piping system resulted in attainment of desired temperature range (65-68 °C) and moisture content (≤6%) of cottonseed after drying process. The RTTD holds significant promise in reducing the potential for pink bollworm spread from ginneries. Thus, it could prove valuable in both domestic and international quarantine initiatives aimed at containing the threat posed by this pest.

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