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Triacontanol spray mediated plant growth and productivity in fruits crops: A review

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Abstract
Among various plant growth regulators studied in crop plants so far, the triacontanol (TRIA), a new class of plant growth regulators is gaining attention due to its beneficial role in enhancing plant growth and crop productivity. Current knowledge on triacontanol suggests that it has potential functions in regulating and modifying various physiological processes in plants. This review briefly articulates the key aspects of the current scientific efforts in the context of plant growth promotion and enhancing flowering, yield and quality of fruits.

Keywords: Plant growth regulators, triacontanol, plant growth, flowering, fruit yield, fruit quality

Introduction
Plant hormones also known as phytohormones, are signal molecules, produced within the plant, functioning in low concentrations and regulate various plant morphological, photosynthetic, biochemical, and developmental processes in plants. A large number of synthetic chemical compounds being used to regulate the growth and development of cultivated plants; these compounds are called plant growth regulators (PGRs). Triacontanol (TRIA) is an endogenous plant hormone first discovered in *Medicago sativa* (L.) by Ries *et al.* (1977) [1] that facilitates numerous plant metabolic activities. It is a natural component of plant epicuticular waxes that can enhance plant growth (Ries *et al.*, 1977; Uchiyama and Ogasawara, 198) [1, 2]. Distribution of triacontanol in the epicuticular waxes reported in diverse genera (Hufford and Oguntimein, 1978; Luzbetak *et al.*, 1978; Freeman *et al.*, 1979) [3, 4, 5]. Various studies indicate strong evidence that the application of triacontanol in low quantity either to the root medium or to the leaves enhanced the growth and yield of crops plants (Naeem *et al.*, 2012) [6]. Many studies revealed that the triacontanol also regulates the resistance to abiotic stress to the plants viz. water stress, salt stress, drought stress, and high-temperature stress (Lu and Zhu, 2005; Abbasi *et al.*, 2010; Perveen *et al.*, 2017; Zaid et al., 2020) [7, 8, 9, 10]. The use of triacontanol in different crops is increasing day by day, and several commercial formulations are being available in the market trade. The present review encompasses the responses of triacontanol on plant growth, flowering fruiting, and yield and fruit quality of fruit crops.

Vegetative growth of plant
Previous studies suggest that triacontanol induced improvement in the growth of plants might be attributed to the triggering of secondary messenger for the enzymes activities that involve in carbohydrate metabolism, physiological and biochemical processes (Ries and Houtz, 1983, Ries 1985; Ries and Stutte, 1985) [11, 12, 13]; modulation in antioxidant activities (Perveen *et al.*, 2010) [14]. and up-regulation of genes involved in the photosynthetic process (Chen *et al*. 2002, 2003) [15, 16]. Triacontanol play important role in signal transduction in plants resulting in the stimulation of plant growth, leading to cell enlargement and proliferation, amino acids, and protein accumulation (Naeem *et al.*, 2012) [17]. Various studies revealed that exogenously applied tricontanol regulates a broad spectrum of plant growth processes (Raies, 1985; Naeem *et al*., 2012 Sharma, 2018) [12, 17, 18]. Thakur *et al.* (1991) [19] observed the highest number of leaves and leaf area in strawberry cv. Tioga plants when the plants were treated with triacontanol (10, 25, or 50 ppm). Triacontanol application (5, 10, and 20 ppm) increased leaf area of the olive tree (Sharma *et al.*, 2009) [20].

Abubakar *et al*. (2013) [21] found that the low concentration of triacontanol enhanced shoot growth and leaf area in *Punica granatum* L. Kumar *et al*. (2012) [22] revealed that strawberry (cv. Sweet Charlie) plants treated with triacontanol (1.25, 2.50, and 5 ppm) exhibited the highest plant height, plant spread, number of leaves, and leaf area. Choudhary *et al.* (2013) [23] recorded increased plant spread in Nagpur mandarin *(Citrus reticulata* Blanco.) by Triacontanol (5, 10, 15, and 20 ppm). Baba *et al.* (2017) [24] reported that triacontanol @ 10 µM resulted in enhanced vegetative growth (plant height, number of leaves per plant, plant speeded) of strawberry cv. Camarosa.

Flowering

Triacontanol considerably enhance the flowering and fruiting in several fruit crops as reported by several researchers. Thakur *et al.* (1991) [19] reported that foliar-applied triacontanol (10, 25, and 50 ppm) significantly affects the number of secondary and tertiary flowers; however, the number of primary flowers were not affected. Kumar *et al.* (2012) [22] studied the effect of foliar-applied triacontanol (1.25, 2.25, and 5 ppm) on strawberry cv. Sweet Charlie and reported that the plants treated with 5 ppm triacontanol took the maximum number of days for flowering, bud formation, and delayed harvesting. Sharma *et al.* (2009) [20] studied the effect of triacontanol (5, 10, and 20 ppm) on fruit quality of olives (O*lea europaea* L.) and observed that the triacontanol on olives increased the number of flowers as compared to control.

Fruit set

The fruit set in litchi was reported to be improved due to triacontanol application (Zhuang *et al*., 1983) [25]. Chandel (1985) [26] obtained enhanced fruit set in Santa Rosa plum with triacontanol alone or in combination with paclobutrazol. Premature fruit drop in Bendizao mandarin *(Citrus succosa)* was prevented by triacontanol through inhibition of pre-abscission pectinase and cellulase activities (Hu *et al*., 1985) [27]. Increased fruit set in the ‘Santa Rosa’ plum with 20 ppm triacontanol application was observed by Jindal and Chandel (1996) [28]. Mandal *et al.* (1989) [29] observed that application of mixtalol @ 6 ml L^{-1} (triacontanol) three weeks before fruit set resulted in the highest fruit set percent in guava. Joolka and Sharma (2003) [30] recorded the maximum fruit set in 'New Castle' apricot with the application of 5 ppm triacontanol 15 days before flowering. Patil *et al*. (2005) [31] sprayed triacontanol (300, 500 and 700 ppm) mango cv. Parbhani Bhushan at flowering stage and pea and marble size of the fruit.

They observed that the spraying triacontanol resulted in the highest percentage of fruit retention. Sharma *et al.* (2009) [20] studied the effect of triacontanol (5, 10, and 20 ppm) on fruit quality of olives (O*lea europaea* L.) and observed that the application of triacontanol increased the fruit set and reduces fruit drop as compared to the control. Choudhary *et al* (2013) [23] studied an effect of triacontanol (5, 10, 15, and 20 ppm) on the growth and yield of Nagpur mandarin *(Citrus reticulata* Blanco.) and they found that the plants treated with triacontanol increased fruit retention and early harvest as compared. Baba *et al*. (2017) [32] reported that triacontanol @10 µM enhanced the number of flowers per plant and also impacted the earliness in flowering, and early fruit maturity in strawberry cv. Camarosa. Zubair *et al* (2018) [33] revealed that the combinations of solubor, biozyme, and triacontanol were best to improve the fruit set and yield of apple fruits.

Fruit yield

It has been advocated that triacontanol increases the net assimilation rate in plants thereby the photosynthesis has been implicated as an important response to increased growth and dry weight of plants as well as fruit weight due to accumulation of photosynthates (Eriksen *et al*. 1981) [34]. Barua (1998) [35] reported that foliar applied triacontanol (commercial formulations Miraculan and Paras) promotes the yield of ‘Santa Rosa’ plum with most effective treatment @ 2.5 ppm. Sharma *et al.* (2009) [20] studied the effect of triacontanol (5, 10, and 20 ppm) on fruit quality of olives (O*lea europaea* L.) and observed that application of triacontanol on olives increased yield and yield efficiency as compared to untreated control. Jain and Dashora (2010) [36] studied the effect of triacontanol to fruit quality and yield of Guava (*Psidium Guajava L.*) cv. Sardar. They revealed that the highest fruit yield was recorded in fruits sprayed with triacontanol compared to control. Kumar *et al.* (2012) [22] studied the influence of triacontanol (1.25, 2.50, and 5 ppm) on the quality of strawberry cv. Sweet Charlie and revealed that the plants treated with triacontanol recorded the highest yield as compared to control. Choudhary *et al.* (2013) [23] studied the effect of triacontanol (5, 10, 15, and 20 ppm) on the growth and yield of Nagpur mandarin *(Citrus reticulata* Blanco.). Baba *et al.* (2017) [32] noted enhancement in fruit yield of strawberry cv. Camarosa due to triacontanol application and suggested that two sprays of triacontanol @ 10 µM during flowering is most effective for realising highest fruit yield.

Physical quality of fruit

In Santa Rosa plum, triacontanol (4 and 8 ppm) sprayed 10 days before harvest to increased size of fruits (Jindal and Dwivedi, 1986) [37] and fruit weight (Barua, 1998) [35]. Jindal and Chandel (1996) [28] also observed that the fruit weight of plum (*Prunus salicina* Lindl) was significantly increased due to triacontanol (20 ppm). According to Chander (1987) [38], triacontanol sprays had beneficial effects on fruit weight and enhancement of fruit quality in ‘New Castle’ apricot. Mehta *et al.* (1990) [39] studied the effect of triacontanol (5, 10, and 20 mg L^{-1}) on fruit quality of apricot cv. New Castle wherein treatments were applied at full bloom and pit hardening stage. They observed that the triacontanol application significantly increased fruit size and fruit weight as compared to control. Sud and Parmar (1990) [40] also reported that the application of triacontanol increased the size of fruits and the weight of apricots. In peach, Sud and Thakur (1998) [41] recorded an increase in fruit weight and volume of peach fruits cv. ‘July Elberta’ by the application of 7.5 ppm triacontanol. Beneficial effect on fruit weight, fruit size (length and breadth) reported in Olive (Sharma *et al.*, 2009) [20], guava (Jain and Dashora, 2010) [36], and mandarin (Choudhary *et al.*, 2013) [23]. Abubakar *et al*. (2013) [21] studied the effect of triacontanol on fruit cracking and quality attributes of pomegranate cv. Kandhari Kabuli and observed that the highest fruit length, as well as the diameter of fruit, was recorded in plants treated with triacontanol as compared to control. Khunte *et al*. (2014) [42] studied the effect of foliar spray triacontanol (100, 150, and 200 ppm) on strawberry cv. Chandler and reported that the application of 100 ppm triacontanol showed the maximum fruit size and fruit weight. According to Pang *et al*. (2020) [43] triacontanol treatment (50 µM) could promote fruit development by up-regulating factors related to fruit ripening-related growth and development strawberry. Baba *et al.* (2017) [32] reported that triacontanol @ 10 µM most effective in enhancing berry size, berry weight, and total fruit yield per plant in strawberry cv. Camarosa.

Biochemical quality of fruit

Mehta *et al.* (1990) [39] studied the effect of triacontanol (5, 10, and 20 mg L^{-1}) on fruit quality of apricot cv. New Castle (*Prunus armeniaca* L.) applied at full bloom and again at the pit hardening stage observed that the triacontanol application is significantly shown low acidity as compared to control. Triacontanol application also fount effective in enhancing total soluble solids in Santa Rosa' plum (Jindal and Chandel, 1996; Barua, 1998) [28, 35] and apricot (Sud and Parmar, 1990) [40]. Jain and Dashora (2010) [36] studied the effect of triacontanol on fruit quality and yield of Guava (*Psidium Guajava L.*) cv. Sardar and revealed that the total soluble solids content highest in fruits harvested from the plants those sprayed with triacontanol. Kumar *et al*. (2012) [22] studied the influence of triacontanol (1.25, 2.50, and 5ppm) on the quality of strawberry cv. Sweet Charlie and revealed that the plants treated with triacontanol recorded the high total soluble solids and low acidity in fruits as compared to control. Sud and Parmar (1990) [40] studied the effect of triacontanol application at 3 ppm at pea stage and just after pit hardening of the fruits in apricot. They found that the total sugars content was not affected by the application of triacontanol. Jindal and Chandel (1996) [28] experiment on an effect of triacontanol in 'Santa Rosa' plum and observed that application of triacontanol increased reducing sugars and total sugars content of fruit as compared to control. Jain and Dashora (2010) [36] reported that the reducing sugars, total sugars, and ascorbic acid content of fruit were highest in guava cv. Sardar fruits were highest with triacontanol treatment sprayed compared to control. According to Kumar *et al*. (2012) [22] triacontanol application (1.25, 2.50, and 5 ppm) exhibited the highest total sugars content in strawberry fruits as compared to control. In an experiment conducted by Sood *et al.* (2018) [44], the strawberry plants treated with PSB (6 kg ha^{-1}) + triacontanol (5 ppm) confirmed the highest fruit ascorbic acid, total sugar, reducing sugar and anthocyanin content. Pang *et al.* (2020)[43] also observed that triacontanol treatment (50 µM) increased the fruit sugar content of strawberry fruits.

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