Mitigating Fruit Cracking and Premature Dropping in Bael (*Aegle marmelos* L.) cv. NB-9 under Subtropical Conditions: Evaluating the Effects of Bio-formulations and Boric Acid

ABSTRACT

The present investigation ~~entitled "**Mitigating Fruit Cracking and Premature Dropping in Bael (*Aegle marmelos*) cv. NB-9 under Subtropical Conditions: Evaluating the Effects of Bio-formulations and Boric Acid**"~~ was carried out during the year 2022-2023 at Main Experimental Station, Department of Fruit Science, College of Horticulture & Forestry, A.N.D.U.A.&T., Narendra Nagar (Kumarganj), Ayodhya, Uttar Pradesh, India. The treatments comprised the application of various Bio-formulations and Boric acid with eco-friendly materials to study the various vegetative properties, fruit cracking, fruit drop and effect ~~of the above treatments~~ on the vegetative growth of fruit. The experiment was laid down in randomized block design (RBD) with (12) treatments and (03) replications.The experiment consists of 12 treatments including control, T_1 (Control), T_2 (FYM 50 Kg), T_3 (FYM 100 Kg), T_4 (Boric acid 200g), T_5 (Boric acid 400g), T_6 (Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]), T_7 (FYM 50Kg + Boric acid 200g), T_8 (FYM 50Kg + Boric acid 400g), T_9 (FYM 50Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]), T_{10} (FYM 100Kg + Boric acid 200g), T_{11} (FYM 100Kg + Boric acid 400g) and T_{12} (FYM 100Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]) was used for this study. The results revealed that treatment T_7 outperformed the rest with minimum fruit cracking (1.53%), fruit drop (76.20%),the maximum number of flowers per plant (171.19), day-to-flowering (31.38) and yield (181.69q/ha)was most effective in a vegetative quality and yield point of view. Thus, the treatment combination T_7 is therefore recommended for application to Bael trees in subtropical conditions to obtain high yields with better quality fruits.

Comment [MK1]: Location coordinates

Keywords: Azotobacter, Bael, Biofertilizer, Biovita, Bio-formulations, Boric acid, Fruit cracking, Fruit drop, PSB, Subtropical conditions.

1. INTRODUCTION

Bael, or *Aegle marmelos* (L.) Correa, is a prominent figure in the world of botany, especially in the Rutaceae family. The Eastern Ghats and Central India are home to the fruit-bearing tree known as the Bengal quince, which has gained popularity due to its nutritional worth and therapeutic qualities. Bael is widely grown in tropical and subtropical areas, usually at an elevation of 1200 meters [Singh et. al., (2014)]. It may even survive in hot, dry climates with little upkeep. Numerous nations, including the Philippines, Cambodia, Malaysia, Java, Egypt, Surinam, Trinidad, and Florida, as well as India, Sri Lanka, Thailand, Pakistan, Bangladesh, Myanmar, and Vietnam, are home to these trees. As per past accounts [Nagar et. al., (2017)].

Comment [MK2]: rewrite

Respected for its hardiness and capacity to yield copious amounts of fruit even in difficult soil conditions, Bael has established itself as a mainstay in traditional medicine, especially in ayurvedic procedures. native to the Indian subcontinent and highly valued for its numerous health advantages as well as its religious importance. Bael fruit is a highly nutritious fruit with many health benefits that also include amino acids, fatty acids, different organic acids, minerals, carbs, vitamins, and fibre [Bhardwaj, (2014)]. WHO (2005) states that it is also an excellent source for extracting medicines and other economically significant herbal components. Particularly well-known for its exceptional fruit quality and subtropical climatic adaptation is the cultivar NB-9. But fruit cracking and early dropping are widespread problems that seriously reduce the quantity and quality of bael fruits, causing growers to suffer large financial losses and obstructing the flow of this precious crop. Numerous factors, including nutritional imbalances, physiological illnesses, and environmental pressures, can influence these events, making management of them a crucial and intricate task.

Bael's significance is varied and goes beyond its therapeutic benefits. Its fruit has a profusion of opportunities for functional food products and industrial applications due to its richness in phytochemicals and critical nutrients. They have a great deal of potential for being made into a variety of goods, such as syrup, wine, slabs, powder, jam, and preserves [Singh et. al., (2014)]. Babel fruits are used in India to make a wide range of goods, such as syrups, murabba, and sherbet. Ripe bael fruits are enjoyed in many places, such as Indonesia and Thailand, where they are sliced and used in various dishes. Cake ingredients can also include bael fruit syrups [Baliga et. al., (2011)]. However, difficulties with Bael cultivation still exist, ranging from fruit cracking to nutritional deficits in soils, despite its extensive cultivation and cultural significance. Innovative strategies are needed to address these issues, such as incorporating boron supplements and bio-formulations into growing techniques. The authors [Rangare et. al. (2022)] emphasize the significance of having a comprehensive understanding of nutrient management to maximize fruit quality and decrease physiological ~~diseases~~ disorders.

Comment [MK3]: English readers don't understand this nomenclature

Comment [MK4]: What are these diseases?

The methods used in cultivation, the crops' therapeutic value, their nutritional makeup, and the difficulties encountered in growing Bael crops. This review aims to further our awareness of the potential of Bael cultivation and its applications in a range of domains, from traditional medicine to agro-industrial sectors, by synthesizing existing research and emphasizing emerging developments. Using boric acid and bio-formulations has been a viable method to address these problems in recent years. Bio-formulations, which are composed of organic materials and beneficial bacteria, provide a sustainable method of boosting plant health and stress tolerance through increased nutrient uptake, improved soil fertility, and systemic stress resistance. On the other hand, boric acid is essential for controlling the synthesis of cell walls and stabilizing cell membranes, both of which are critical for avoiding fruit shattering and enabling the fruit to remain on the tree until it ripens properly. According to [Khan et. al. (2023)], this method may help with issues such as fruit cracking and early fruit drop in addition to enhancing growth and output. In recent years, there has been a lot of promotion for this alternative [Khan et. al., (2020); Pathak et. al., (2022); Ayilara et. al., (2023)]. Therefore, the term "bio-formulation" describes the process of producing material that contains beneficial and living microbial strains using suitable carrier materials for their efficient use in industry, agriculture, bioremediation, and other domains [Balla et. al., (2022)]. A bio-formulated product or bioformulation's key ingredients are potentially beneficial bacteria for plant growth, such as nutrient solubilizers, nitrogen fixers, biocontrol agents, and bioremediation [Pirttila et. al., (2021)].

The effectiveness of these treatments in subtropical climates, with a focus on assessing how well they mitigate fruit cracking and early dropping in the bael cultivar NB-9. The study aims to provide significant insights into sustainable agricultural practices that can improve the production quality and yield of bael, thereby supporting farmers' livelihoods and the availability of this nutrient-rich fruit. This will be accomplished through a thorough analysis of experimental data and observations. This research aims to pave the road for a more robust and productive bael production system by tackling these issues with creative and eco-friendly solutions.

2. MATERIALS AND METHODS

The present investigation was carried out at the Main Experiment Station, Horticulture, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during the years 2022-2023. The experiment was laid out in randomized block design with 12Treatment, namely: T_1 (Control), T_2 (FYM 50 Kg), T_3 (FYM 100 Kg), T_4 (Boric acid 200g), T_5 (Boric acid 400g), T_6 (Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]), T_7(FYM 50Kg + Boric acid 200g), T_8 (FYM 50Kg + Boric acid 400g), T_9 (FYM 50Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]), T_{10} (FYM 100Kg + Boric acid 200g), T_{11} (FYM 100Kg + Boric acid 400g) and T_{12} (FYM 100Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]). The experiment was replicated three times. The climate in the Ayodhya district is categorized as semi-arid, with three distinct seasons: summer, which is hot, winter, and rainy or wet. With an average of 1200 mm of rain, the rainy season starts the last week of June and lasts through September or possibly October. The soil was found to be sandy loam, with an average pH of 7.71 and average amounts of silt (22.76%), clay (14.95%), and fine sand (64.77%). The experiment used plants that were sixteen years old. For the regular cultural activities, plant protection measures, and basal application of manures and fertilizers, the Bael plantation's set timetable was adhered to.Data was collected on fruit cracking, fruit drop and flowering and yield parameters likefruit cracking (%),

Comment [MK5]: ?

fruit drop (%), the maximum number of flowers per plant, day-to-flowering (days) and yield (q/ha).The data obtained during experimentation were statistically analysed as per the method given by Panse and Sukhatme(1985).

Comment [MK6]: Needs full details related to materials and methods. Seems very vague and general

3. RESULT AND DISCUSSION

Comment [MK7]: Discussion part is missing throughout

3.1Effect of Bio-formulations and Boric acid on fruit cracking and fruit drop attributes offruits of Bael

3.1.1 Fruit cracking (%)

The data significantly presented in **Table 1 and Graph 1** revealed thatthe treatment T_7 [FYM 50Kg + Boric acid 200g] recorded the minimum fruit cracking (%) i.e., [1.53 (2022-23), 1.52 (2023-24) and 1.53 (Pooled)] % over all other treatments during both the years of study as well as pooled analysis. The 2nd best treatment combination was found to be treatment T_8 [FYM 50Kg + Boric acid 400g] with [1.91 (2022-23), 1.89 (2023-24) and 1.90 (Pooled)] % fruit cracking. However, during both the years of study as well as pooled data, the effect of treatment T_8 [FYM 50Kg + Boric acid 400g], T_{10} [FYM 100Kg + Boric acid 200g] and T_4 [Boric acid 200g] were found at par with the treatment T_7 [FYM 50Kg + Boric acid 200g]. The highest fruit cracking (%) i.e., [39.86 (2022-23), 39.42 (2023-24) and 39.64 (Pooled)] % was recorded in T_1 [Control] during both the years of study as well as pooled analysis.The application of treatment T_7 [FYM 50Kg + Boric acid 200g] resulted in minimum fruit cracking (%) of Bael.

3.1.2 Fruit drop (%)

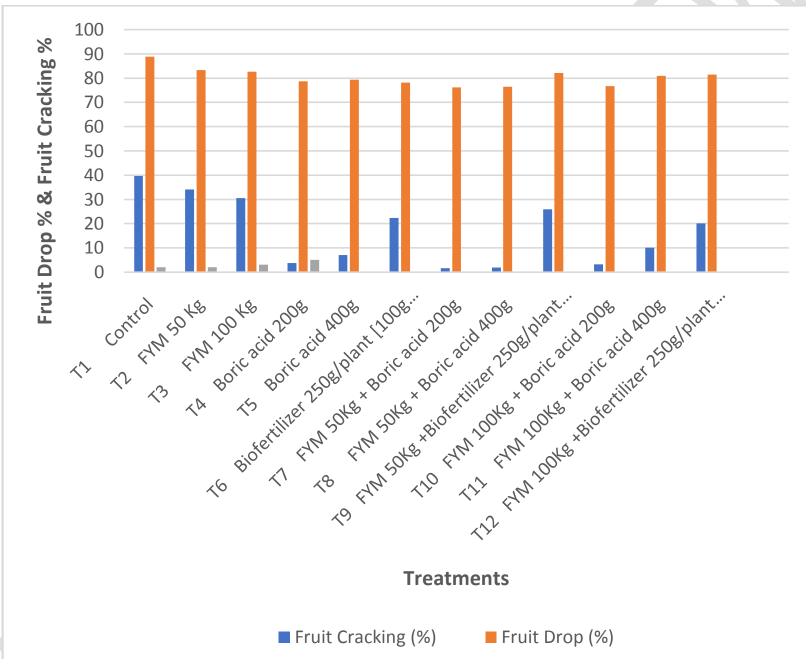
Data presented in**Table 1 and Graph 1**indicated thattreatment T_7 [FYM 50Kg + Boric acid 200g] recorded the minimum fruit drop (%) i.e., [77.12 (2022-23), 75.28 (2023-24) and 76.20 (Pooled)] % over all other treatments during both the years of study as well as pooled analysis. The 2nd best treatment combination was found to be treatment T_8 [FYM 50Kg + Boric acid 400g] with [77.46 (2022-23), 75.62 (2023-24) and 76.54 (Pooled)] % fruit drop. However, during both the years of study, the effect of treatment T_8 [FYM 50Kg + Boric acid 400g] and T_{10} [FYM 100Kg + Boric acid 200g] were found at par with the treatment T_7 [FYM 50Kg + Boric acid 200g] whereas according to pooled data only T_8 [FYM 50Kg + Boric acid 400g] was found at par with the treatment T_7. The highest fruit drop (%) i.e., [90 (2022-23), 87.86(2023-24) and 88.93 (Pooled)] % was recorded in T_1 [Control] during both the years of study as well as pooled analysis.

Table 1: Fruit Cracking and Fruit Drop Attributes of Fruits of Bael

Treatments	**Fruit Cracking (%)**			**Fruit Drop (%)**		
	1st Year	**2nd Year**	**Pooled**	**1st Year**	**2nd Year**	**Pooled**
T_1Control	39.86	39.42	39.64	90.00	87.86	88.93
T_2FYM 50 Kg	34.26	33.88	34.07	84.37	82.36	83.37
T_3 FYM 100 Kg	30.73	30.39	30.56	83.75	81.76	82.75
T_4Boric acid 200g	3.66	3.62	3.64	79.74	77.84	78.79
T_5Boric acid 400g	7.06	6.98	7.02	80.36	78.45	79.40
T_6Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	22.46	22.21	22.33	79.12	77.24	78.18
T_7FYM 50Kg + Boric acid 200g	1.53	1.52	1.53	77.12	75.28	76.20
T_8 FYM 50Kg + Boric acid 400g	1.91	1.89	1.90	77.46	75.62	76.54
T_9FYM 50Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	26.00	25.71	25.85	83.13	81.15	82.14
T_{10}FYM 100Kg + Boric acid 200g	3.25	3.22	3.23	77.74	75.89	76.81
T_{11}FYM 100Kg + Boric acid 400g	10.13	10.02	10.08	81.89	79.94	80.92

T_{12}FYM 100Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	20.24	20.02	20.13	82.51	80.55	81.53
SEm ±	**1.08**	**1.07**	**0.76**	**0.24**	**0.21**	**0.16**
CD at 5%	**3.16**	**3.13**	**2.16**	**0.71**	**0.62**	**0.46**

Graph 1: Fruit Cracking and Fruit Drop Attributes of Fruits of Bael



Comment [MK8]: What is third bar?

3.2Effect of Bio-formulations and Boric acid on flowering behaviour and Yieldof Bael

3.2.1 Number of flowers per plant

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Number of flowers per plant, as presented in Table 2 and Graph 2that the treatment T_7 [FYM 50Kg + Boric acid 200g] recorded the maximum number of flowers per plant [168.22 (2022-23), 174.17 (2023-24) and 171.19 (Pooled)] over all other treatments during both the years of study as well as pooled

Comment [MK9]: How did you count flowers? No explanation in methods?

analysis. The 2nd best treatment combination was found to be treatment T_8 [FYM 50Kg + Boric acid 400g] with [166.35(2022-23), 172.22 (2023-24) and 169.29 (Pooled)] number of flowers per plant. However, the effect of treatment T_8 [FYM 50Kg + Boric acid 400g] was found at par with treatment T_7 [FYM 50Kg + Boric acid 200g]. The lowest number offlowers per plant i.e., [144.59 (2022-23), 149.56 (2023-24) and 147.08 (Pooled)] was recorded in T_1 [Control] during both the years of study as well as pooled analysis.

3.2.2 Days to flowering (days)

Comment [MK10]: Days to flowering? To what? Could not understand

As presented in **Table 2 and Graph 2**the treatment T_7 [FYM 50Kg + Boric acid 200g] recorded the minimum days to flowering (days) [32 (2022-23), 30.76 (2023-24) and 31.38 (Pooled)] days over all other treatments during both the years of study as well as pooled analysis. The 2nd best treatment combination was found to be treatment T_8 [FYM 50Kg + Boric acid 400g] with [32.36 (2022-23), 31.11 (2023-24) and 31.74 (Pooled)] days to flowering. However, during both the years of study, the effect of treatment T_8 [FYM 50Kg + Boric acid 400g] and T_{10} [FYM 100Kg + Boric acid 200g] were found at par with the treatment T_7 [FYM 50Kg + Boric acid 200g] whereas according to pooled data only T_8 [FYM 50Kg + Boric acid 400g] was found at par with the treatment T_7. The highest days to flowering (days) i.e., [42.53(2022-23), 40.88 (2023-24) and 41.71 (Pooled)] days were recorded in T_1 [Control] during both the years of study as well as pooled analysis.

Comment [MK11]: Better to present one table or graph, there is no errors with the data/values etc.

3.2.3 Fruit yield (q/ha)

Comment [MK12]: Use standard international units through MS

It is evident from the data presented in **Table 2 and Graph 2** that the treatment T_7 [FYM 50Kg + Boric acid 200g] recorded the maximum yield (q/ha) i.e., [176.28 (2022-23), 187.10 (2023-24) and 181.69 (Pooled)] q/ha over all other treatments during both the years of study as well as pooled analysis. The 2nd best treatment combination was found to be treatment T_8 [FYM 50Kg + Boric acid 400g] with [173.10 (2022-23), 183.72 (2023-24) and 178.41 (Pooled)] q/ha yield. However, during both the years of study, the effect of treatment T_8 [FYM 50Kg + Boric acid 400g] was found at par with the treatment T_7 [FYM 50Kg + Boric acid 200g]. The lowest yield (q/ha) i.e., [121.79 (2022-23), 129.23 (2023-24) and 125.51 (Pooled)] q/ha was recorded in T_1 [Control] during both the years of study as well as pooled analysis.

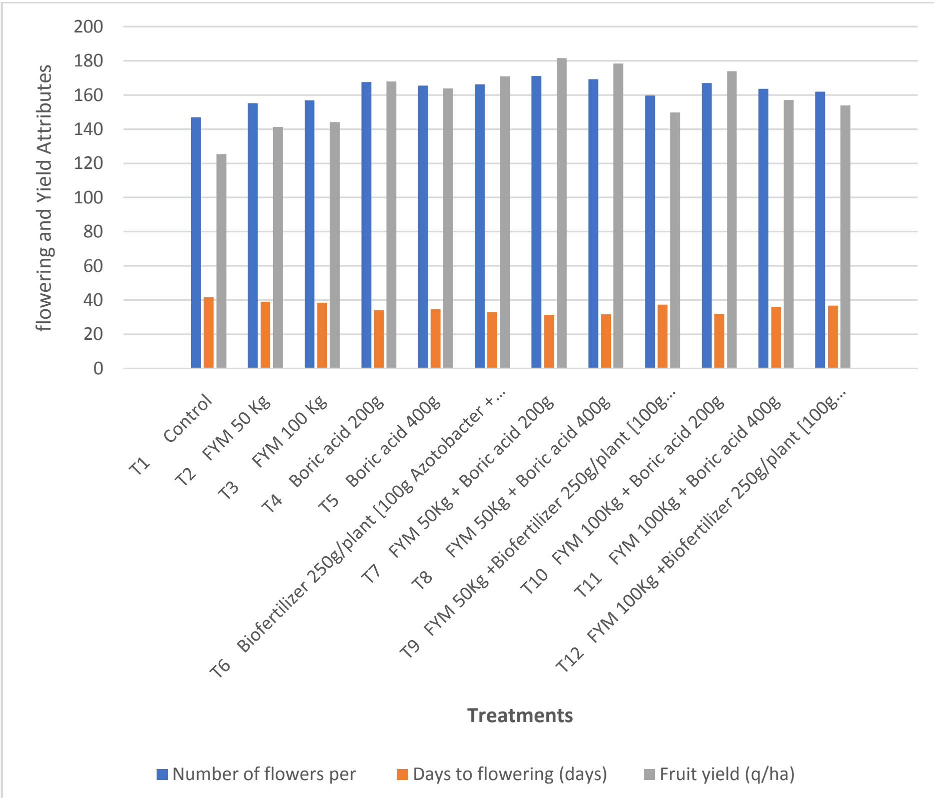
Table 2:Flowering and YieldAttributes of Fruits of Bael

Comment [MK13]: How about yield per tree and how many trees per hectare?

Treatments	Number of flowers per plant			Days to flowering (days)			Fruit yield (q/ha)		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
T_1Control	144.59	149.56	147.08	42.53	40.88	41.71	121.79	129.23	125.51
T_2FYM 50 Kg	152.66	157.97	155.31	39.78	38.24	39.01	137.22	145.61	141.41
T_3FYM 100 Kg	154.23	159.61	156.92	39.28	37.76	38.52	139.90	148.46	144.18
T_4Boric acid 200g	164.66	170.45	167.55	34.90	33.55	34.23	163.10	173.09	168.10
T_5Boric acid 400g	162.76	168.47	165.61	35.57	34.19	34.88	158.95	168.69	163.82
T_6Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	163.50	169.25	166.38	33.80	32.49	33.15	165.97	176.15	171.06
T_7FYM 50Kg + Boric acid 200g	168.22	174.17	171.19	32.00	30.76	31.38	176.28	187.10	181.69

T_8 FYM 50Kg + Boric acid 400g	166.35	172.22	169.29	32.36	31.11	31.74	173.10	183.72	178.41
T_9FYM 50Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	157.10	162.58	159.84	38.22	36.74	37.48	145.41	154.32	149.87
T_{10}FYM 100Kg + Boric acid 200g	164.20	170.00	167.10	32.69	31.42	32.06	168.85	179.21	174.03
T_{11}FYM 100Kg + Boric acid 400g	160.90	166.53	163.71	36.81	35.38	36.10	152.46	161.80	157.13
T_{12}FYM 100Kg +Biofertilizer 250g/plant [100g Azotobacter + 100g Biovita + 50g PSB]	159.16	164.72	161.94	37.52	36.07	36.80	149.47	158.63	154.05
SEm ±	**1.13**	**1.18**	**0.82**	**0.26**	**0.24**	**0.18**	**1.76**	**1.76**	**1.12**
CD at 5%	**3.32**	**3.45**	**2.33**	**0.76**	**0.71**	**0.50**	**4.08**	**5.16**	**3.20**

Graph 2:Flowering and Yield Attributes of Fruits of Bael



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4. CONCLUSION

From the ongoing summary of the present investigation, it can be inferred that vegetative parameters viz. fruit cracking, fruit drop and flowering and yield parameters like fruit cracking (%), fruit drop (%), the maximum number of flowers per plant, day-to-flowering (days) and yield (q/ha)were recorded maximum in flowering and yield attributes likemaximum number of flowers per plant, day-to-flowering and yieldbesides fruit drop and fruit cracking in the fruit was drastically reduced. It can be concluded that all the treatments show good effects on increasing fruit quality and minimizing fruit drop and fruit cracking as compared to the control but T_7 (FYM 50Kg + Boric acid 200g)was found to be more pronounced among all the treatments and can be used in increasing the quality and reducing fruit drop and fruit cracking of Bael.

5. FUTURE SCOPE

Bio-formulation is a system that helps to restore and sustain crop productivity and also assists in checking emerging micronutrient deficiencies. With this view, there is a dire need to minimize the use of chemical fertilizers with the use of integratednutrient management and organic waysfor better growth and yield of fruits.

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Comment [MK14]: Use the standard house style of the journal

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