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Mansha Gul
Division of Plant Physiology, Faculty of Basic Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

BK Sinha
Division of Plant Physiology, Faculty of Basic Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

Gurdev Chand
Division of Plant Physiology, Faculty of Basic Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

Moni Gupta
Division of Biochemistry, Faculty of Basic Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

Amit Khokher
Division of Fruit Science, Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India

Amit Jasrotia
Division of Fruit Science, Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

AK Singh
Institute of Biotechnology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

M Iqbal Jeelani
Division of Social and Basic sciences, Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benhama, Ganderbal, Jammu and Kashmir, India

Corresponding Author:
Mansha Gul
Division of Plant Physiology, Faculty of Basic Sciences, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu and Kashmir, India

Enhancing productivity and quality of red delicious apples through paclobutrazol application

Mansha Gul, BK Sinha, Gurdev Chand, Moni Gupta, Amit Khokher, Amit Jasrotia, AK Singh and M Iqbal Jeelani

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Abstract
Paclobutrazol can restrict vegetative growth and boost productivity and fruit quality in apples. This study, conducted over two seasons on the Red Delicious variety ((*Malus domestica* Borkh), used a Randomized Complete Block Design (RCBD) with six treatments and three replications on a 15-year-old orchard. Treatments included a control and paclobutrazol at 0.50 ppm, 0.75 ppm, 1.00 ppm, 1.25 ppm, and 1.50 ppm. Results showed that higher paclobutrazol concentrations significantly increased the number of spurs, spur length, clusters per branch, and flowers per cluster. Return bloom percentage also rose with higher paclobutrazol levels, indicating enhanced flowering potential in following seasons. These findings highlight paclobutrazol's effectiveness in improving growth and reproductive traits in Red Delicious apples, offering practical benefits for apple growers.

Keywords: Paclobutrazol, return bloom, RCBD, red delicious

Introduction
Apple cultivation is a vital sector in agriculture, with varieties like Red Delicious holding significant economic importance. However, managing vegetative growth while optimizing fruit yield and quality poses a challenge for apple growers. Paclobutrazol, a growth-regulating chemical, has emerged as a potential solution to this challenge by curbing excessive vegetative growth and redirecting resources towards fruit development. Paclobutrazol has been extensively studied for its effectiveness in cultivation of various fruit crops. Numerous studies have demonstrated its efficacy in reducing canopy volume and increasing flower intensity in various fruit crops, including peach (Allan *et al.*, 1993) [2], plum (Olivier *et al*., 1990) [20], almond (Koukourikou-Petridou, 1996) [11], grapes (Christov *et al*., 1995) [7], and mango (Kulkarni, 1988; Nartvaranant *et al*., 2000) [12, 15]. Furthermore, paclobutrazol has shown effectiveness not only in flower induction but also in early and off-season flower induction in mango (Protacio *et al*., 2000; Blaikie *et al*., 2004; Yeshitela *et al*., 2004; Nafees *et al*., 2010; Burondkar *et al*., 2013) [16, 4, 19, 14, 5]. However, the action of plant growth regulators (PGRs) is highly specific to plant species, cultivar, and stage of development, and is strongly dependent on its rate of application and environmental conditions (Hoffmann, 1992) [9]. Thus, paclobutrazol holds considerable promise in the manipulation of flowering, yield, and vigor in fruit crops. Studies have also shown that paclobutrazol, as a synthetic plant growth retardant, effectively controls vegetative growth and induces flowering (Nartvaranant *et al*., 2000) [15]. Abdollahi *et al*. (2012) [1] reported that paclobutrazol reduced vegetative growth by decreasing both the fresh and dry weights of shoots, while also significantly reducing leaf area in strawberry cv. Selva. George and Nissen (1992) [8] observed an increase in return bloom in peach trees in the subsequent season following paclobutrazol application, potentially resulting in a large number of small fruit if a large percentage of flowers set. Similarly, Asin *et al*. (2007) [3] found that foliar application of paclobutrazol resulted in the highest return bloom in 'Blanquilla' pear trees. Additionally, Wani *et al*. (2007) [18] noted a significant increase in return bloom in Red Delicious apple trees following soil application of paclobutrazol. Paclobutrazol (PBZ) is a widely studied plant growth regulator that inhibits gibberellin synthesis, promoting flower induction and fruit development in fruit crops. Kumar *et al*. (2023) [13] provide contemporary insights into

its agronomic management and potential risks to the environment These collective findings provide strong evidence supporting the efficacy of paclobutrazol in improving various aspects of apple cultivation, from growth and yield to fruit quality.

This study investigates the effects of paclobutrazol on morphological parameters of Red Delicious apple trees. Higher concentrations of paclobutrazol significantly increased spurs, spur length, clusters per branch, and flowers per cluster. The return bloom percentage also rose with higher paclobutrazol levels, indicating improved flowering potential for future seasons. These findings highlight the practical benefits of paclobutrazol in enhancing apple productivity, offering growers a valuable tool to optimize growth and fruit quality in Red Delicious apples.

Materials and Methods

The experiment was conducted following a Randomized Complete Block Design (RCBD) with six treatments and three replications at the experimental orchard in Shalimar area of Kashmir division, UT of J&K, India during the years 2022 and 2023. Red Delicious apple trees, aged over 15 years, were selected for the study. Paclobutrazol treatments were applied at concentrations of 0.50 ppm, 0.75 ppm, 1.00 ppm, 1.25 ppm, and 1.50 ppm, alongside a control group receiving no paclobutrazol application. Data collection included recording morphological parameters such as the number of leaves, number of spurs per branch, spur length, number of clusters per branch, number of flowers per cluster, and return bloom percentage. Statistical analysis and data visualization were performed using R Studio version (4.2.2, 2022) with the AgroR library. Analysis of Variance (ANOVA) was conducted to assess the significance of treatment effects on the recorded morphological parameters. Mean separation was performed using the Least Significant Difference (LSD) test at a significance level of $p \leq 0.05$.

Results

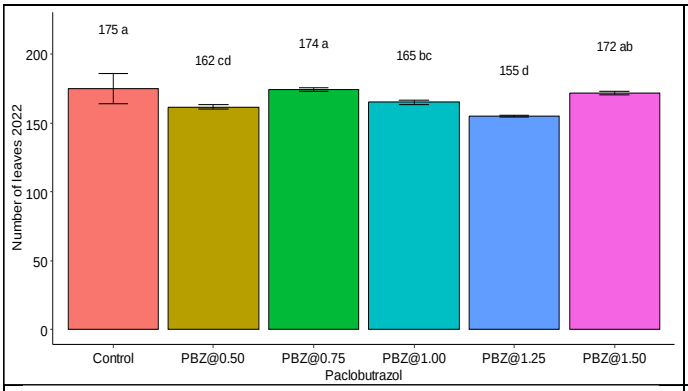
In the analysis of the morphological parameters of Red Delicious apple trees, the highest number of leaves was observed in the control group, with a value of 181.18. However, as the concentration of paclobutrazol increased, the number of leaves decreased progressively. Among the paclobutrazol treatments, the highest number of leaves was recorded in the treatment with 0.50 ppm paclobutrazol, with a value of 162.08. Conversely, the lowest number of leaves was observed in the treatment with 1.25 ppm paclobutrazol, with a value of 155.53 (Table1).

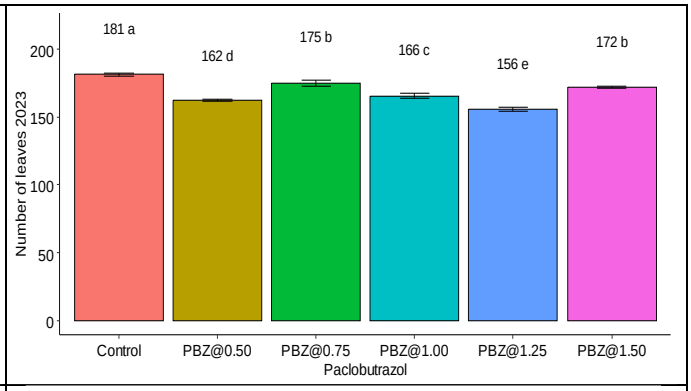
Table 1: Effect of paclobutrazol on Morphological Parameters of apple cv. Red Delicious

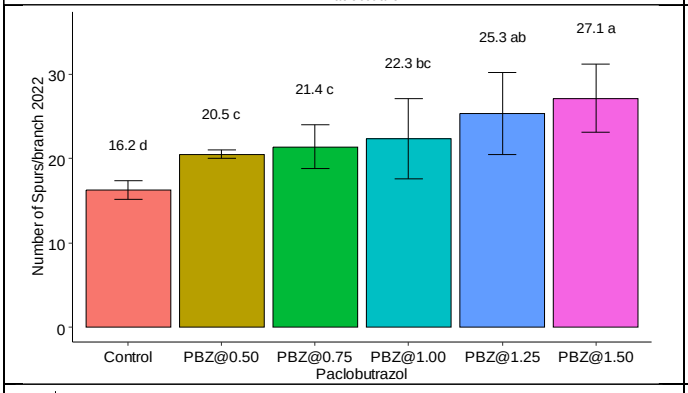
Treatments	No. of Leaves		No. of Spurs/ branch		Spur Length()		No. of clusters/branch		No. of Flowers per Cluster		Return bloom (%)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2023	2024
Control	174.86	181.18	16.21	17.90	4.67	5.09	1.39	1.26	3.21	3.53	30.83 (5.55)	33.15 (5.76)
PBZ @ 0.50	161.62	162.08	20.48	21.06	5.00	6.46	2.76	2.76	3.62	4.89	48.39 (6.96)	50.53 (7.11)
PBZ @ 0.75	174.23	174.69	21.39	23.51	5.42	6.73	3.14	3.33	4.44	5.95	54.39 (7.37)	56.04 (7.49)
PBZ @ 1.00	165.12	165.59	22.31	25.46	5.33	6.64	3.46	3.65	4.92	6.44	59.57 (7.72)	62.65 (7.91)
PBZ @ 1.25	155.06	155.53	25.34	27.74	5.78	6.88	3.61	3.82	5.63	6.69	67.07 (8.19)	69.81 (8.36)
PBZ @ 1.50	171.61	172.08	27.12	29.07	6.22	7.40	3.88	3.97	6.62	6.95	74.57 (8.64)	77.49 (8.80)
CD ($p \leq 0.05$)	2.43	2.05	0.68	0.55	0.53	0.42	0.14	0.11	0.20	0.37	0.11	0.13

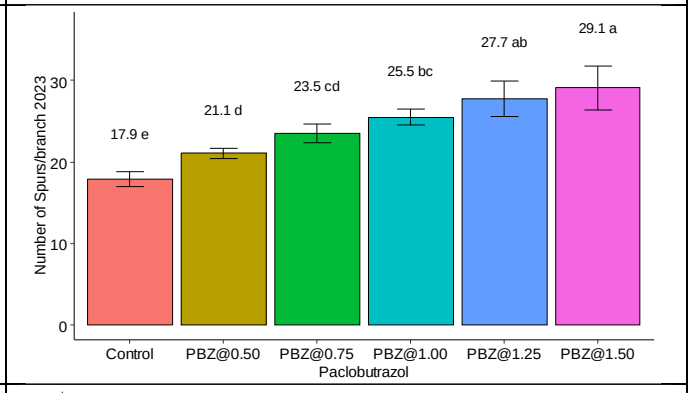
Note: Figures in parenthesis are transformed values

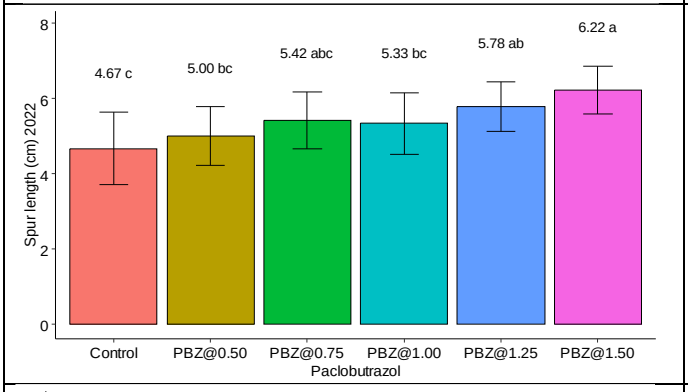
For the number of spurs per branch, the highest value was recorded in the treatment with 1.50 ppm paclobutrazol, with a value of 29.07, while the lowest value was observed in the control group, with a value of 17.90.. Regarding spur length, the highest value was recorded in the treatment with 1.50 ppm paclobutrazol, with a value of 3.97, while the lowest value was observed in the control group, with a value of 1.26. For the number of clusters per branch, the highest value was recorded in the treatment with 1.50 ppm paclobutrazol, with a value of 7.40, while the lowest value was observed in the control group, with a value of 5.09. Regarding the number of flowers per cluster, the highest value was recorded in the treatment with 1.50 ppm paclobutrazol, with a value of 6.95, while the lowest value was observed in the control group, with a value of 3.53. Lastly, for the return bloom percentage, the highest value was observed in the treatment with 1.50 ppm paclobutrazol, with a value of 77.49, while the lowest value was observed in the control group, with a value of 30.83 (Table1 & Figure 1).

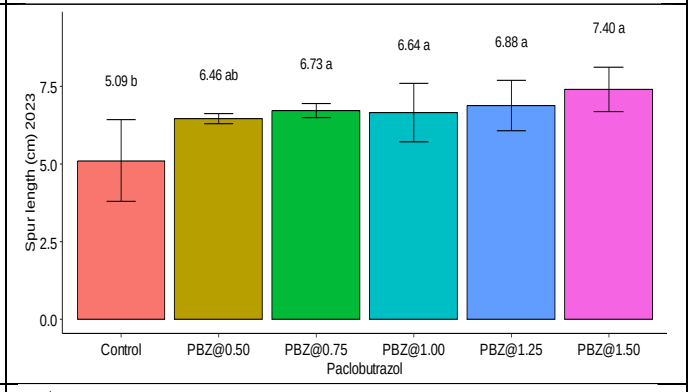

175 a
162 cd
174 a
165 bc
155 d
172 ab
Number of leaves 2022
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol

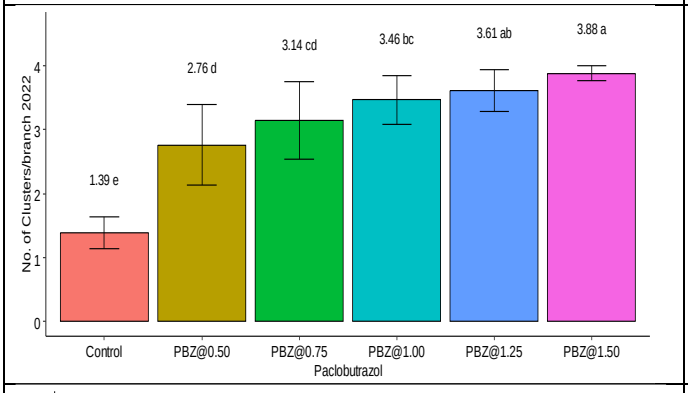

181 a
162 d
175 b
166 c
156 e
172 b
Number of leaves 2023
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol

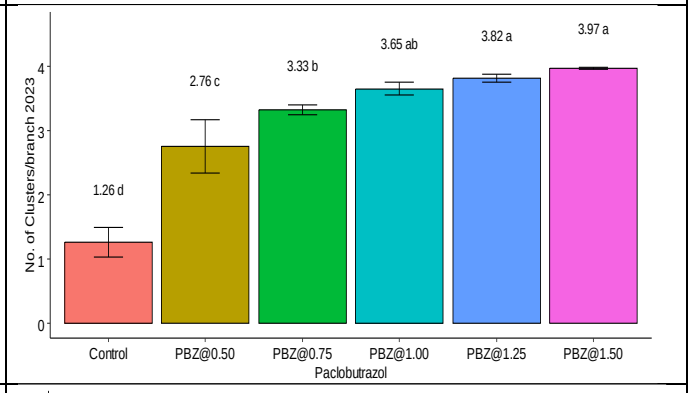

16.2 d
20.5 c
21.4 c
22.3 bc
25.3 ab
27.1 a
Number of Spurs/branch 2022
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol

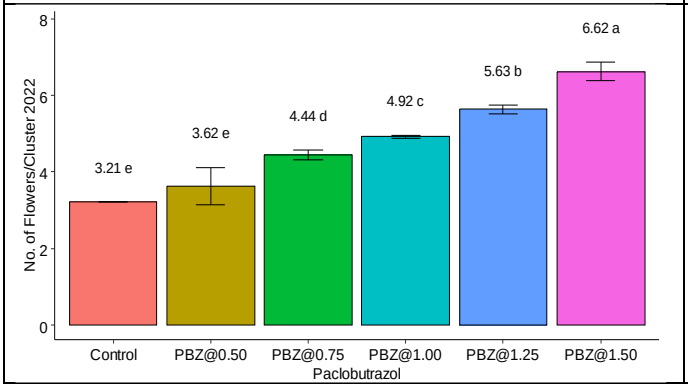

17.9 e
21.1 d
23.5 cd
25.5 bc
27.7 ab
29.1 a
Number of Spurs/branch 2023
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol

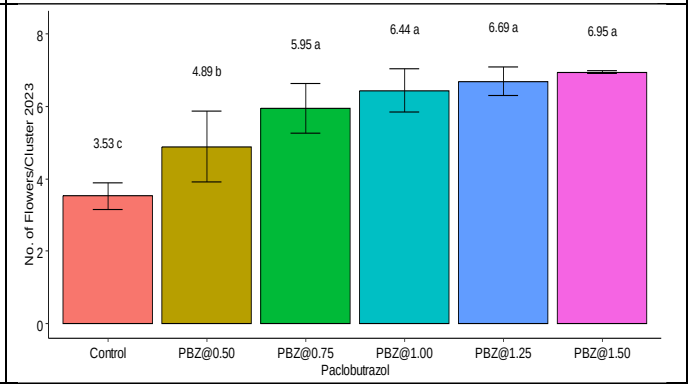

4.67 c
5.00 bc
5.42 abc
5.33 bc
5.78 ab
6.22 a
Spur length (cm) 2022
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol


5.09 b
6.46 ab
6.73 a
6.64 a
6.88 a
7.40 a
Spur length (cm) 2023
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol


1.39 e
2.76 d
3.14 cd
3.46 bc
3.61 ab
3.88 a
No. of Clusters/branch 2022
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol


1.26 d
2.76 c
3.33 b
3.65 ab
3.82 a
3.97 a
No. of Clusters/branch 2023
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol


3.21 e
3.62 e
4.44 d
4.92 c
5.63 b
6.62 a
No. of Flowers/Cluster 2022
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol


3.53 c
4.89 b
5.95 a
6.44 a
6.69 a
6.95 a
No. of Flowers/Cluster 2023
Control
PBZ@0.50
PBZ@0.75
PBZ@1.00
PBZ@1.25
PBZ@1.50
Paclobutrazol

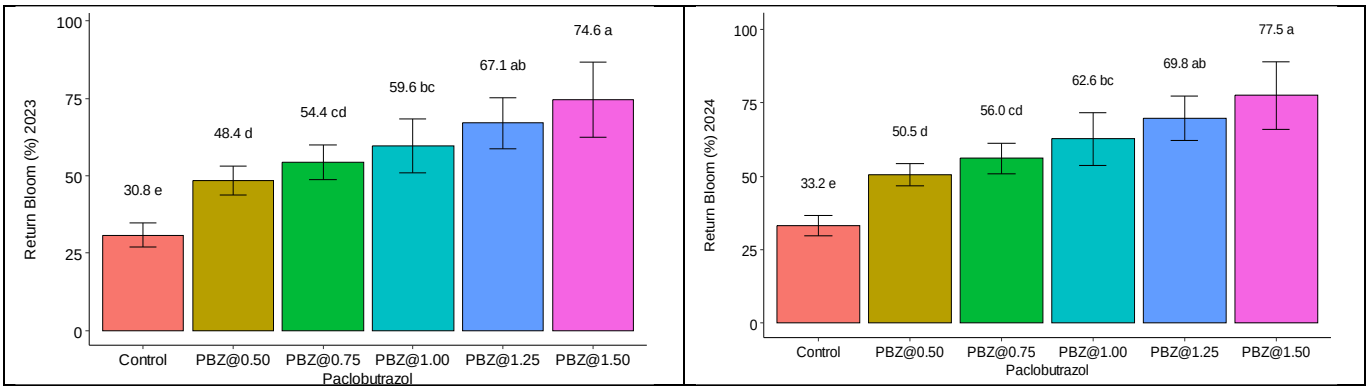


Fig 1: GGbar plots of Morphological Parameters of apple cv. Red Delicious

Discussion

Consistent with our findings, previous studies have reported a reduction in leaf number with paclobutrazol application in various fruit tree species. For example, Steffens *et al*., (1985) [17] observed a significant decrease in leaf number in apple trees treated with paclobutrazol, attributing this effect to the growth-inhibiting properties of the chemical. The significant increase in the number of clusters per branch following paclobutrazol treatment aligns with findings by Kumar *et al.*, (2023) [13], who reported a higher incidence of flowering and cluster formation in fruit trees treated with paclobutrazol under various studies. This effect is attributed to the growth-regulating properties of paclobutrazol, which redirect resources towards reproductive growth. Paclobutrazol's role in increasing the return bloom percentage, indicative of enhanced flowering potential in subsequent seasons, is supported by studies such as Kishore *et al*., (2015) [10], who reported a higher proportion of buds capable of flowering in apple trees treated with paclobutrazol. This long-term benefit underscores the value of paclobutrazol in orchard management strategies aimed at improving fruit yield and quality.

Conclusion

In conclusion, the findings of this study underscore the efficacy of paclobutrazol in enhancing the productivity and quality of Red Delicious apples. Through its ability to restrict vegetative growth and promote reproductive traits, paclobutrazol offers apple growers a valuable tool for optimizing orchard management practices. The significant increases in spurs, spur length, clusters per branch, flowers per cluster, and return bloom percentage observed with higher paclobutrazol concentrations highlight its practical benefits in improving fruit yield and quality. By elucidating the positive impact of paclobutrazol on apple cultivation, this study contributes valuable insights to orchard management strategies, providing growers with a strategic approach to enhance productivity and fruit quality in Red Delicious apples.

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