Influence of some plant growth regulators on quality attributes of pineapple (*Ananas comosus* L.)

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ABSTRACT

Aims: A trial was conducted to investigate the influence of plant growth regulators on the growth and quality attributes of pineapple fruits.
Study design: The experiment was arranged in a randomized completed block design (RBCD) with three replications using 25 plants per replication.
Place and Duration of Study: The experiment was carried out between 2020 and 2021 at the Central Horticultural Experiment Station, Aignia, Bhubaneswar, India.
Methodology: The application of PGRs i.e. naphthalene acetic acid (NAA), gibberellic acid (GA), and brassinosteroid (BR) was done at the flower initiation stage. Only water application is done in case of control. Fruits were harvested at the ripe stage and an analysis of different growth and quality parameters were done.

Results: The application of naphthalene acetic acid (NAA), and gibberellic acid (GA) significantly improved the yield and quality attributes of pineapple. Application of NAA 200 mgL^{-1} (T3) was found to be the most effective in enhancing absolute growth rate (2.65 g day-1), fruit weight (1.58 kg), and fruit/crown ratio (6.38). It was also evident that the application of NAA 200 mgL^{-1} improved fruit quality in terms of soluble solid contents (17.67 ^{o}Brix), soluble solid contents to acid ratio (19.49), reducing sugar (3.54%), and total sugar content (12.38%). Higher pulp content (73.89%), pulp-to-peel ratio (3.49), and juice content (54.50%) were also observed with NAA 200 mgL^{-1}.
Conclusion: NAA 200 mgL^{-1} significantly improved fruit growth i.e. fruit weight, fruit-to-crown ratio, and absolute growth rate. It also enhanced the quality attributes of pineapple fruits i.e. pulp content, pulp-to-peel ratio, juice content, pH, soluble solid contents, SSC to acid ratio, reducing sugar, and total sugar content.

Keywords: Pineapple, NAA (naphthalene acetic acid), GA (gibberellic acid), BR (brassinosteroid), MD2, growth, quality, plant growth regulators (PGRs).

1. INTRODUCTION

Pineapple (*Ananas comosus*) is a popular tropical fruit known for its unique taste and aroma. The fruit is known for its unique flavor due to the presence of several volatile compounds in small amounts and complex mixtures. Additionally, pineapples are a rich source of minerals and vitamins that have several health benefits. It belongs to the family Bromeliaceae and originated in South America [31, 26]. Pineapple is presently considered the third most important fruit crop in world production after banana and citrus [19]. Fresh pineapple fruit contains substantial amounts of vitamin A, vitamin B complex (thiamine, riboflavin, niacin, pyridoxine, folic acid), and vitamin C. Moreover, the pineapple fruit is rich in minerals i.e. potassium, calcium, magnesium, and phosphorus [4]. It contains a proteolytic enzyme called bromelain, which helps in the digestion process by breaking down proteins [2]. Uniform fruit size is a major limitation that affects pineapple farmers in the MD-2 variety. Therefore, to address this issue various PGRs i.e. naphthalene acetic acid (NAA), gibberellic acid (GA), and brassinosteroid (BR) with different concentrations were applied. Various metabolic processes, such as cell division, differentiation and expansion, organogenesis, and germination, are controlled by plant regulators, which are used to enhance fruit quality. The quality of the fruit also plays an important role in determining the shelf life as well as the choice of purchasing for customers. It determines the acceptance by the consumer and they are willing to pay a higher price for good quality fruits. It is now well established that the pineapple plant reacts to the application of PGRs such as naphthalene acetic acid (NAA), gibberellic acid (GA), and brassinosteroid (BR) in several ways and improves fruit growth along with its quality [30, 34, 40, 41, 42, 43]. In this context, the primary purpose of this research work was to investigate the influence of PGRs in enhancing the fruit growth and quality attributes of pineapple.

2. MATERIAL AND METHODS

The experiment was carried out between 2020 and 2021 at the Central Horticultural Experiment Station, Aignia, Bhubaneswar, India. The experimental site is located in the eastern coastal region of India (20˚ 27′ N latitude and 85˚ 40′ E longitude). Pineapple variety MD-2 was taken for the study. Different concentration of PGRs was sprayed on pineapple fruit at different stages by using a hand sprayer until the fruits were wet to runoff. Additional fruits were also sprayed with distilled water as the control.

2.1 Experimental details

The experiment consisted of 7 treatments, comprising NAA (100 and 200 mg L^{-1}), GA (50 and 100 mg L^{-1}), and Brassinosteroid (2 and 4 mg L^{-1}). Spraying of the treatments was done at the flower initiation stage. The control was a sample without any application of PGRs from the beginning of the research until the pineapple harvest. The experiment was arranged in a randomized completed block design (RBCD) with three replications using 25 plants per replication. The treatments were comprised of: **T1** – control (water application); **T2** – NAA (naphthalene acetic acid) 100 mg L^{-1}; **T3** – NAA (naphthalene acetic acid) 200 mg L^{-1}; **T4** – GA (gibberellic acid) 50 mg L^{-1}; **T5** – GA (gibberellic acid) 100 mg L^{-1}; **T6** – BR (brassinosteroid) 2 mg L^{-1}; **T7** – BR (brassinosteroid) 4 mg L^{-1}. The growth parameters and yields were recorded and analyzed as per Gomez and Gomez [44] using analysis of variance (ANOVA) at a 5% significance level.

2.2 Analysis of growth parameters

Fruits were harvested at the ripe stage. Fruits were weighed using a digital weighing machine. Pineapple fruits were peeled and the core was removed using a knife 100 grams of the pulp was weighed 100 grams from where the juice was extracted for estimating the juice content per 100 grams of pulp. Dry weights were taken by keeping pulp in Petri plates and drying was done inside an oven drier for 72 hours at 60ºC.

2.3 Analysis of quality parameters

The total soluble solids (TSS) content was recorded with the help of a digital refractometer. The pH of the juice was recorded with a pH meter. The titrable acidity, reducing sugar and total sugar was determined by following the methods of Ranganna (1986). The ascorbic acid or vitamin C of pineapple fruits was determined by following the standard technique as described by AOAC [3]. The 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay was also carried out according to Blois [8] method. Protein content was measured by the Bradford method [10] using BSA as standard.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

The duration of fruit maturity was significantly (5% level of significance) influenced by PGRs treatments. From table 1, it was observed that the least number of days (100 days) from flower initiation to fruit maturity was found in treatment T7 (BR 4 mg L^{-1}) followed by treatment T6 (BR 2 mg L^{-1}) i.e. 102 days and highest number of days from flower initiation to fruit maturity (107 days) was recorded in the treatment T1 (control). The shorter duration of flower initiation to fruit maturity is due to the early ripening induction of the pineapple fruits and it is a well-known fact that in non-climacteric fruits the respiratory burst and rise in ethylene production are not evident. Therefore, increased levels of brassinosteroids (BRs) hormone might have promoted ripening through complex interactions [12]. Brassinosteroid is involved in stimulating ethylene production which may, in turn, promote the biosynthesis of abscisic acid, which both directly prevent tissue growth and enhance the fruit ripening process [35, 15, 5]. Brassinosteroid application has been found to induce early maturation of sweet cherry cv. 'Tulare' and 'Bing' (Mandava and Wang 2016). The same results were supported Chai *et al*. [11] in strawberries and Wang *et al.* [38] in sweet orange.

Fruit weight varied significantly (5% level of significance) with the application of PGRs (Table 1). The data indicated that the fruit weight was significantly increased when the pineapple fruits were treated with NAA and GA. Maximum fruit weight was observed in T3 i.e. NAA 200 mg L^{-1}. There was a substantial increase in fruit weight i.e. 1.58 kg when treated with NAA 200 mg L^{-1} (T4) followed by fruits treated with NAA 100 mg L^{-1} (T2) when compared to control i.e. T1 (1.30 kg). When compared to the control (T1), there is a 21.54% increase in fruit weight in T3 (NAA 200 mg L^{-1}). Both the concentration of Gibberellic acid (50 and 100 mg L^{-1}) also showed a significant increase in fruit weight when compared to the control shown in Table 1. Application of brassinosteroids doesn't show much variation with control and it was at par. Various treatment data showed that there is a significant variation in crown weight when fruits are treated with growth regulators. It is evident from the data that with the increase in fruit weight the crown weight decreases. Therefore, maximum crown weight was observed in control (T1 – 230.04 g) compared to other treatments which were at par with fruits treated with brassinosteroids (T6 – 226.72 g and T7 – 224.17 g). Data (Table 1) also revealed that the fruit-to-crown ratio was significantly higher under treatment T3 (NAA 200 mg L^{-1}) i.e. 6.38 followed by T2 (NAA 100 mg L^{-1}) i.e. 6.03 in comparison to T1 (control) i.e. 4.64. It is clearly observed that higher fruit weight implies a higher fruit-to-crown ratio. Data (Table 1) revealed that the absolute growth rate (g day^{-1}) ranged from 1.97 to 2.65 g per day when fruits are sprayed with different concentrations of PGRs. The highest absolute growth rate based on dry weight was observed in fruits treated with NAA 200 mg L^{-1} (T3 – 2.65 g day^{-1}), whereas, the lowest absolute growth rate was observed in fruits with no treatments i.e. control (T14 – 1.97 g day^{-1}). T5 (GA 100 mg L^{-1}), T2 (GA 50 mg L^{-1}), and T4 (NAA 200 mg L^{-1}) showed very little variation i.e. 2.51, 2.53, and 2.54 g day^{-1} respectively which is at par with each other. PGRs play an important role in increasing plant growth as well as quality, additionally, affecting vegetative and fruit production [37, 22, 18]. Findings indicated that fruit weight, fruit-to-crown ratio, as well as absolute growth rate of fruits, are enhanced by the application of NAA and GA. The highest fruit weight, fruit-to-crown ratio, and absolute growth rate of fruits were observed in fruits treated with NAA 200 mg L^{-1}. NAA can increase the fruit size as it is proven that there is an increase in cell division and cell elongation caused by NAA and spraying of NAA may have increased the cell wall elasticity, thereby resulting in enlargement due to increasing the rate of growth in fruits, which leads to the formation of larger fruits [16, 25]. These findings were supported by Maibangra and Ahmed [19], Suresh *et al*. [34] and Senapati *et al*. [30] in pineapple, Agrawal and Dikshit [1] in sapota, Stern *et al*. [33] in japanese plum, and Hanafy *et al*. [14] in orange.

Table 1: Influence of PGRs on growth attributes of pineapple fruits

Treatments	Fruit weight (kg)	Crown weight (g)	Fruit/crown ratio	Absolute growth rate (g day^{-1})	Days from flower initiation to maturation
T1 -Control	1.30	230.04	4.64	1.97	107
T2 - NAA 100 mg L^{-1}	1.52	215.26	6.03	2.53	104
T3 - NAA 200 mg L^{-1}	1.58	214.34	6.38	2.65	105
T4 - GA 50 mg L^{-1}	1.48	212.03	5.99	2.54	102
T5 - GA 100 mg L^{-1}	1.49	212.73	6.01	2.51	103
T6 - BR 2 mg L^{-1}	1.31	226.72	4.79	2.15	102
T7 - BR 4 mg L^{-1}	1.32	224.17	4.91	2.22	100
SEm (±)	0.015	3.043	0.044	0.029	0.991
CD (5%)	0.05	9.38	0.14	0.09	3.05

3.2 Quality Attributes

The quality attributes are significantly (5% level of significance) varies with the application of PGRs. The pulp content (%) is shown in Fig.1(a). Data revealed that fruits treated with NAA 200 mg L^{-1} (T3 – 73.89%) showed maximum pulp content percentage followed by fruits treated with NAA 100 mg L^{-1} (T2 – 73.72%), GA 100 mg L^{-1} (T5 – 73.59%), and GA 50 mg L^{-1} (T4 – 73.5%). The lowest pulp content percentage was observed in the control (T1 – 71.89%) with no treatments followed by fruits BR 2 mg L^{-1} (T6 – 72.03%) and BR 4 mg L^{-1} (T5 – 72.33%). Application of NAA 200 mg L^{-1} (T3), increases the pulp content by 2.8% when compared with the control (T1). The lowest percentage of peel content i.e. 21.20% was observed in T3 (NAA 200 mg L^{-1}) followed by T2 (NAA 100 mg L^{-1}), T5 (GA 100 mg L^{-1}), and T4 (GA 50 mg L^{-1}) i.e. 21.36, 21.44, and 21.50% respectively, whereas, the highest value was observed in T1 (control) with 22.45% as shown in Fig. 1(b). The maximum pulp-to-peel ratio (3.49) was observed with treatment NAA 200 mg L^{-1} while the minimum ratio (3.15) with T6 (BR 2 mg L^{-1}) and fruits treated with T7 (BR 4 mg L^{-1}) and T1 (control) i.e. 3.20 as shown in Fig. 1(c). The percentage of juice content was also significantly influenced by the application of PGRs Fig. 1(d). It is observed that the maximum percent of juice content i.e. 54.50% was observed in fruits treated with NAA 200 mg L^{-1} (T3) followed by 54.00% in fruits treated with NAA 100 mg L^{-1} (T2), whereas, minimum juice content was observed in T1 (control) and T6 (BR 2 mg L^{-1}) i.e. 52.50%. The pulp content, as well as pulp to peel ratio of pineapple fruits, had been observed to be the maximum when pineapple fruits are treated with NAA. This might be due to fruit development results in fruit enlargement as discussed earlier in this paper. Similar findings were reported by Pal *et al*. [23] and Senapati [31] in pineapple. According to Sandhu [28], the application of NAA raised the endogenous level of auxin in fruit which increases fruit size and juice content percentage due to cell expansion by auxin. These findings corroborate with Sarkar *et al*. [29] in pineapple and Kumar *et al*. [17] in guava.

Pineapple fruit treated with PGRs significantly increased the pH of the juice (Table 2). The pH was observed maximum in fruits treated with NAA 200 mg L^{-1} (T3) i.e. 3.81 followed by

T2 - NAA 100 mg L^{-1} (3.78), T4 - GA 50 mg L^{-1} (3.74), and T5 - GA 100 mg L^{-1} (3.72). The minimum pH of juice i.e. 3.62 was observed in T1 (control) followed by T6 (BR 2 mg L^{-1}) i.e. 3.64. Similar results were observed in the soluble solid contents (SSC) of fruits when the fruits were treated with growth regulators (Table 2). Various treatment data showed that there is a significant increase in SSC when fruits are treated with growth regulators such as NAA. Maximum SSC of fruits was observed when fruits are sprayed with NAA 200 mg L^{-1} (T3) i.e. 17.67 ^{o}B followed by NAA 100 mg L^{-1} (T2) i.e. 17.40 ^{o}B. The lowest SSC was observed in fruits with no treatments (T1) i.e. 16.80 ^{o}B followed by fruits treated with BR 2 mg L^{-1} (T6) i.e. 16.83 ^{o}B. When compared to the untreated fruits i.e. T1 there is an increase of 5.18% in SSC when treated with NAA 200 mg L^{-1}. The titrable acidity (Table 2) of the pineapple juice among different treatments increased ranging from 1.02-1.24% citric acid. Data about acidity showed that fruits treated with NAA 200 mg L^{-1} (T3) and GA 50 mg L^{-1} (T4) showed the lowest citric acid content i.e. 1.02% whereas the highest acidity was observed in control (T1) i.e. 1.24%. Thus, fruits sprayed with NAA 200 mg L^{-1} (T3 – 19.49) showed maximum SSC to acid ratio followed by NAA 100 mg L^{-1} (T2 – 18.01), whereas, the lowest was observed in fruits with no treatment control (T1 – 14.25). The reducing sugar ranged from 3.02 to 3.54%. The maximum percentage of reducing sugar was observed in fruits treated with NAA 200 mg L^{-1} (T3 – 3.54%) followed by NAA 100 mg L^{-1} (T2 – 3.14%), meanwhile, the minimum percentage of reducing sugar was observed in fruits with no treatment i.e. control (T1 – 3.02%). Similarly (Table 2), total sugar was found highest in NAA 200 mg L^{-1} (T3 – 12.38%) followed by NAA 100 mg L^{-1} (T2 – 12.18%), whereas, the lowest was observed fruits with no treatment i.e. control (T1 – 11.10%). Data (Table 2) pertaining to the percentage of non-reducing sugar was shown. Non-reducing sugar ranges from 8.36 to 9.03% when fruits are sprayed with different concentrations of PGRs. Across treatments highest non-reducing sugar percent was observed in T2 (NAA 100 mg L^{-1}) i.e. 9.03% followed by T4 (GA 50 mg L^{-1}) i.e. 8.86% and T3 (NAA 200 mg L^{-1}) i.e. 8.84%. Whereas, T1 (control or only water application) showed the lowest percentage of non-reducing sugar i.e. 8.36%. The vitamin C content ranged from 42.22 to 53.33 mg per 100 ml (Table 2). Vitamin C content showed a similar trend as the acidity of the fruit juice (Table 2). The maximum vitamin C content was estimated in fruits with no treatment T1 (53.33 mg per 100ml), meanwhile, the minimum vitamin C was observed in fruits treated with NAA 200 mg L^{-1} (T3 – 42.22 mg per 100ml)) followed by fruits treated with GA 50 mg L^{-1} (T4 – 44.44 mg per 100ml). Protein content was significantly influenced by different treatments of PGRs. Fruits treated with Gibberellic acid 50 mg L^{-1} (T4 – 0.69%) and Gibberellic acid 100 mg L^{-1} (T5 – 0.68%) were higher across treatments. In contrast, the protein content of the fruits treated with no treatment (T1) i.e. 0.51% was the lowest across the treatments (Table 2). Concerning total sugar (%), reducing sugar (%), soluble solid content (SSC), acidity, and SSC/acid ratio the results indicated that spraying fruits with NAA recorded the maximum total sugar, reducing sugar, SSC, and SSC/acid ratio and minimum acidity. This might be due to the action of auxin in the quick metabolic transformation of starch and protein in the soluble compound and the rapid translocation of sugar from leaves to the developing fruit [30]. These findings were in agreement with earlier findings of Pal *et al*. [23] and Bhowmick *et al*. [7] in pineapple. And this influence the SSC/acid ratio where the increase in SSC increase the SSC/acid ratio. Citric acid, as well as ascorbic acid, was higher in fruits with no treatment i.e. control with lowest in fruits treated with NAA. The decrease in the acidity of NAA treated fruits might be due to the effectiveness of NAA in increasing sugar content as discussed earlier. And percent acidity and pH are inversely related to each other, where lower acidity results in higher pH [13]. Several studies reported that high ascorbic acid results in higher antioxidant activity. Therefore, the control i.e. with no treatments showed maximum antioxidant activity compared to other treatments [26, 6,]. The best treatment in terms of higher protein content is obtained from fruits treated with GA. According to Huizen *et al*. [39], there is a change observed in the polypeptide in pea fruit when treated with gibberellin treatment. It might be due to the regulation of gibberellin on some inhibitory genes, which may lead to the accumulation of more protein content [9].

4. CONCLUSION

The findings of the present study clearly reveal that significant variation was found in fruits treated with different concentrations of PGRs when compared to fruits with no treatment. NAA 200 mgL^{-1} significantly improved fruit growth i.e. fruit weight, fruit-to-crown ratio, and absolute growth rate. It also enhanced the quality attributes of pineapple fruits i.e. pulp content, pulp-to-peel ratio, juice content, pH, soluble solid contents, SSC to acid ratio, reducing sugar, and total sugar content. Hence, the application of NAA 200 mgL^{-1} is recommended for getting uniform fruits with better fruit weight as well as to obtain better quality fruits which is economically profitable to the farmers.

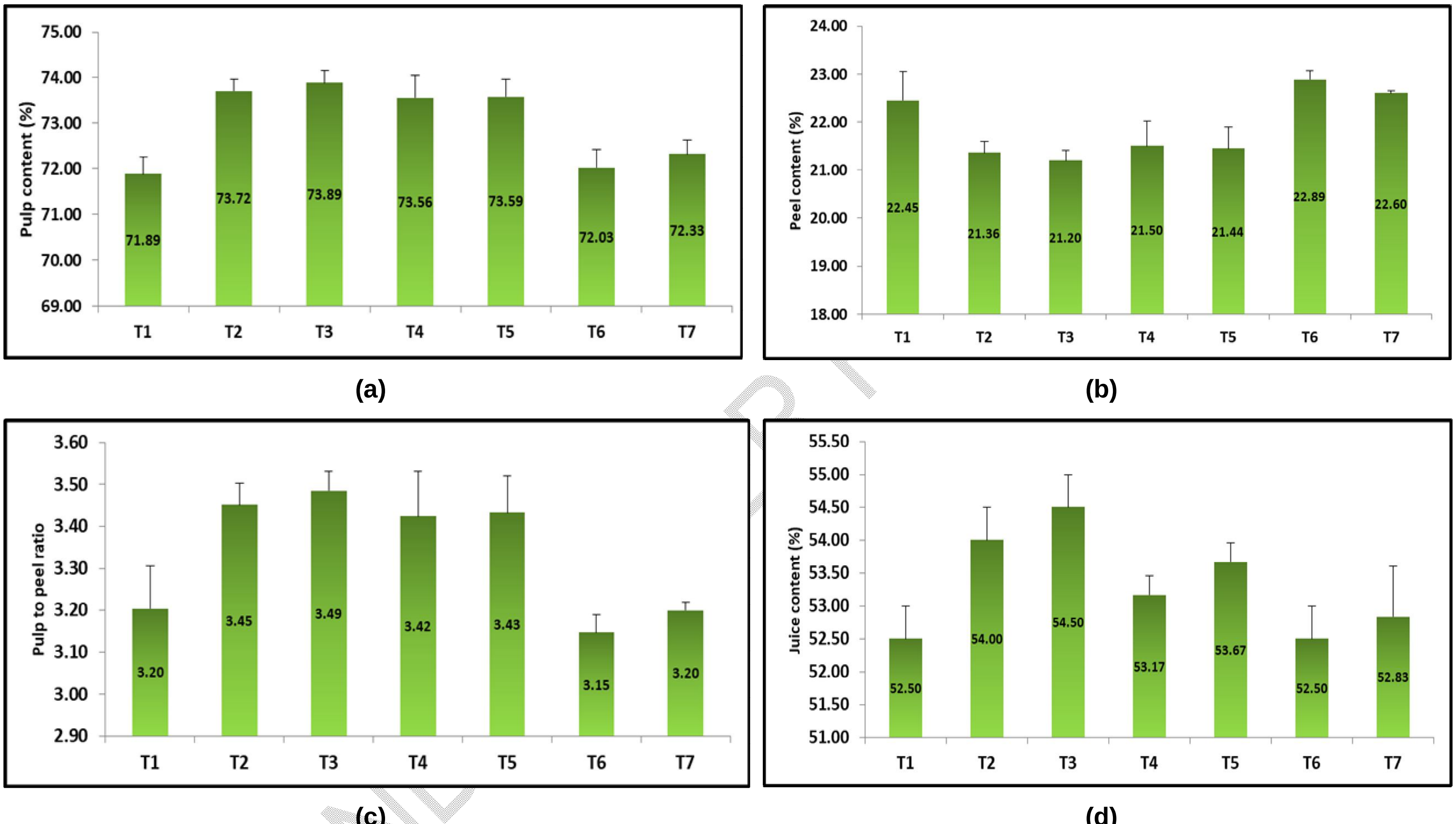

Fig. 1: Influence of PGRs on (a) pulp content, (b) peel content, (c) pulp to peel ratio, and (d) juice content of pineapple fruits. The bar shows standard errors (+) at a 5% significance level.

***T1** – control; **T2** - NAA 100 mg L^{-1}; **T3** - NAA 200 mg L^{-1}; **T4** – GA 50 mg L^{-1}; **T5** - GA 100 mg L^{-1}; **T6** – BR 2 mg L^{-1}; **T7** - BR 4 mg L^{-1}

Table 2: Influence of PGRs on quality attributes of pineapple fruits

Treatments	pH (juice)	SSC (ºB)	Acidity (%)	SSC/ Acid ratio	RS (%)	NRS (%)	TS (%)	AA (mg 100ml^{-1})	Antioxidant activity (%)	Protein content (%)
T1 –Control	3.62	16.80	1.24	14.25	3.02	8.36	11.38	53.33	80.14	0.51
T2 - NAA 100 mg L^{-1}	3.78	17.40	1.07	18.01	3.14	9.03	12.18	47.77	74.29	0.61
T3 - NAA 200 mg L^{-1}	3.81	17.67	1.02	19.49	3.54	8.84	12.38	42.22	71.05	0.63
T4 - GA 50 mg L^{-1}	3.74	16.97	1.02	16.73	3.11	8.86	11.97	44.44	72.76	0.69
T5 - GA 100 mg L^{-1}	3.72	16.93	1.07	15.87	3.10	8.83	11.93	47.77	74.29	0.68
T6 - BR 2 mg L^{-1}	3.64	16.83	1.18	14.34	3.05	8.37	11.41	51.11	79.05	0.52
T7 - BR 4 mg L^{-1}	3.67	16.87	1.13	14.97	3.08	8.45	11.53	50.00	76.19	0.53
SEm (±)	0.012	0.271	0.059	0.616	0.036	0.146	0.143	1.248	1.635	0.014
CD (5%)	0.04	0.84	0.18	1.90	0.11	0.45	0.44	3.85	5.04	0.04

***SSC : Soluble solid content, RS : Reducing Sugar, NRS : Non-Reducing Sugar, TS : Total sugar, AA : Ascorbic acid (vitamin C)**

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