

Impact of Pollination Modes on Size and Quality of Strawberry (*Fragaria ananassa* Duch.)

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ABSTRACT

Strawberry (*Fragaria* × *ananassa* Duch.) stands as one of the most popular and widely consumed berries globally, celebrated for its exceptional flavor and nutritional benefits. As a member of the Rosaceae family, strawberries are abundant in vitamins, antioxidants, and dietary fibers. The increasing global demand for strawberries has instigated comprehensive research regarding their cultivation practices. Pollination is a vital determinant that significantly influences both the size and quality of strawberry fruits. A thorough understanding of the various pollination modes is essential for optimizing strawberry production. The present study systematically investigates the impact of different pollination methods on the size and quality of strawberries. The field experiment was conducted at Horticulture farm of Sant Baba Bhag

Singh University and laboratory work was done in Horticulture lab of the University. We evaluated the impact of self, natural, wind, and artificial pollination techniques on fruit development, evaluating key parameters such as weight of fruit, size, and number of achenes, yield, TSS, Titrable acidity and pH. Our findings indicate significant variations in both size and quality attributes associated with the mode of pollination employed. Specifically, the natural pollination strategy—wherein insects play a pivotal role—demonstrated superior fruit weight and enhanced sensory characteristics when compared to self-pollination and wind pollination. Furthermore, the synergistic effect of cross-pollination combined with induced pollination emerged as the most advantageous approach for strawberry cultivators, yielding good results in terms of fruit quality and production. The results of the research work highlight the critical importance of pollination strategies in strawberry cultivation and suggest that optimizing these methods could facilitate improved fruit yields and heightened consumer satisfaction.

Keywords *Fragaria* × *ananassa* Duch., Aggregate fruit, Manual pollination, Synergistic effect, Achenes.

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INTRODUCTION

Fruits play a vital role in human nutrition, offering both sensory enjoyment and important dietary benefits (Sahana *et al.* 2020). Among these, strawberries (*Fragaria* × *ananassa*), a hybrid member of the

Rosaceae family, are particularly popular. The term “strawberry” comes from the agricultural practice of using straw to cover the plants during berry development. This cultivated species originated through hybridization between two North American species: *Fragaria chiloensis* and *Fragaria virginiana*. Fresh strawberries are known for their enticing aroma, bright red color, juicy texture, and sweet flavor (Sharma and Godara 2020). Nutritionally, strawberries are rich in vitamin C, fiber, potassium, and antioxidants, which are linked to various health benefits (Paikra *et al.* 2020). In India, the majority of strawberry production occurs in Himachal Pradesh, accounting for over 90% of the nation’s output. However, strawberry cultivation faces numerous challenges that can lead to significant losses in their health-promoting qualities. A key challenge is maintaining fruit quality and size.

Strawberries exhibit a unique reproductive biology; each flower is hermaphroditic, containing both male and female reproductive organs, making pollination critical for fruit development—even though the edible part does not originate from the ovary. Classified as aggregate fruits, strawberries consist of numerous small individual fruits called achenes, which are embedded within a fleshy receptacle. The brownish or whitish specks perceived as seeds are the true fruits, each containing a tiny seed. Their floral structure features a poly-carpellary and apocarpous arrangement, requiring that each pistil undergo pollination, as any un-pollinated pistil can adversely affect fruit development. Strawberries utilize a dual reproductive mechanism of self-pollination and cross-pollination, with the latter often facilitated by pollinators, prompting an exploration of how different pollination strategies influence fruit development. Although strawberries can set fruit via self-pollination, evidence suggests that cross-pollination, primarily supported by insect pollinators, significantly enhances fruit characteristics. Thus, pollination is a critical factor affecting fruit size and quality. Effective pollination is essential for achieving optimal fruit size, shape, and quality; additionally, insect-mediated pollination can improve overall fruit quality and extend shelf life (Klatt *et al.* 2014).

The aim of this study is to elucidate how different pollination methods—self, natural, insect, wind, and

artificial—alone and in combination affect strawberry size and fruit quality, with the goal of informing more sustainable and productive cultivation practices.

MATERIALS AND METHODS

Planting material

Strawberry saplings of Chandler cultivar were obtained from a certified nursery in Jammu for use as planting material.

Location of experiment and cultural operations

In 2022 -2023 growing season many treatments like effect of GA3, NAA, CCC, TRIA, removing early blooms, cutting of runners, mulching, self-pollination, wind-pollination, manual pollination were evaluated. The main experiment was conducted at the fields of the Department of Agriculture, Sant Baba Bhag Singh University, during the 2023–2024 growing season by selecting appropriate treatments from the treatments evaluated in previous season. Prior to the transplantation of strawberries, the experimental plot underwent all the needed agronomical practices such as field preparation, weeding, irrigation. A recommended dose of nitrogen fertilizer, in the form of urea, was applied in two instalments: 50% prior to transplantation and 50% subsequently.

Treatments

This study investigated several strategies, including the application of Gibberellic Acid (GA3), mulching, and various pollination methods, to assess their impact on improving fruit quality. The primary focus of the research was on the different modes of pollination. GA3, a plant growth regulator, was applied at a concentration of 75 ppm as a foliar spray on two occasions: Once during the early growth phase and again just prior to flower initiation. Treatments included: Mulching (Covering of beds with black plastic mulch), Self-pollination (ensured by covering flower buds with butter paper bags. Plate 1A), Wind pollination (by enclosing the flower buds in loosely woven mesh like cloth bags to prevent insect intrusion Plate 1B), Natural pollination (Self, wind, insect pollination Plate 1C). Additionally, manual (induced)



Plate 1. **1A.** Self-pollination ensured by covering flower buds with butter paper bag. **1B.** Wind pollination ensured by covering flower buds with net cloth. **1C.** Natural pollination; insect in action. **1D.** Pollination rate improvement by manual pollination.

pollination was performed using fine brushes during peak flowering periods to ensure pollination of all pistils (Plate 1D). Furthermore, the study evaluated the synergistic effects of combining GA3 application, natural pollination, mulching, and induced pollination methods to determine their collective impact on fruit quality enhancement. In few plants pollination was prevented by removing anthers in bud condition and then covering the buds with butter paper bag.

Table 1. Details of treatments.

Sl. No.	Treatment symbol	Treatment detail
1	T1	GA3 + Natural Pollination
2	T2	Mulching + Natural Pollination
3	T3	GA3 + Mulching + Natural Pollination
4	T4	GA3 + Mulching + Self Pollination
5	T5	GA3 + Mulching + Wind Pollination
6	T6	GA3 + Natural + Induced (Improved) Pollination
7	T7	GA3 + Mulching + Natural + Manual Pollination

Experimental design

A Randomized Block Design (RBD) was implemented for this study, with the treatments specified in Table 1. Each of the treatment was replicated thrice, yielding a total of 21 experimental units. The data collected were analyzed statistically using OPSTAT software.

RESULTS AND DISCUSSION

RESULTS

Floral and fruit production assessment

A comprehensive evaluation involving ten distinct plant specimens was conducted to quantify the production of flowers throughout each flowering cycle of the cropping season. The mean value of number of flowers produced per plant was subsequently



Plate. 2A. Polycarpellary apocarpous hermaphrodite flower. **2B.** Number of pistils 3-4 times more than number of stamens.

Table 2. Effect of treatments on pollination success rate.

Sl. No.	Treatment	No. of flowers/plant	No. of fruits/plant	Pollination success rate (%)
1	T1	22.26 ± 0.17	18.40 ± 0.11	82.63 ± 0.68
2	T2	18.00 ± 0.11	15.20 ± 0.11	84.44 ± 0.59
3	T3	24.33 ± 0.43	22.66 ± 0.35	93.20 ± 2.16
4	T4	21.13 ± 0.17	14.26 ± 0.06	67.50 ± 0.38
5	T5	23.53 ± 0.17	14.86 ± 0.06	63.17 ± 0.50
6	T6	27.20 ± 0.23	24.46 ± 0.24	89.97 ± 1.52
7	T7	28.46 ± 0.17	26.80 ± 0.12	94.16 ± 0.97
	SE(m)	0.23	0.18	1.22
	CD	0.74	0.57	3.80
	(p=0.05)			

calculated based on the collected data. Following the flowering phase, a systematic assessment of the same ten plants was undertaken to determine the total number of developing fruits. This evaluation was performed at 15-day intervals, and the cumulative counts were utilized to compute the overall yield per plant. To assess pollination success, the flower-to-fruit set ratio was calculated, providing insights into the effectiveness of the pollination process. Data related to floral and fruit development evaluations and pollination success rate has been summarized in Table 2.

The results presented in the table indicate that the highest fruit set was achieved in treatment T7, which examined the synergistic effects of GA3 application, mulching, natural pollination, and manual (improved) pollination. Treatment T3, which involved mulching, GA3, and natural pollination, closely followed in effectiveness. Additionally, treatment T6 exhibited

promising results. Conversely, the treatments relying on self and wind pollination demonstrated the poorest outcomes, as they did not enhance fruit setting. The results depicted that more flowers got converted into fruits where natural pollination was supplanted with artificial pollination. GA3 treatment also significantly increased high pollination success rate. These findings align with previous research of Saima *et al.* (2014) and Lata *et al.* (2018).

Fruit quality assessment

Fruit size: The dimensions of the fruit were assessed using vernier calipers on a sample of ten plants selected at random from each treatment group. These measurements were subsequently multiplied to calculate the fruit area, expressed in square centimeters (cm²).

Fruit weight: The average of 10 randomly selected fruits from 10 plants was calculated and expressed in grams.

Number of achenes: The number of achenes was counted from ten randomly selected plants of each treatment.

Fruit yield: The total yield from each of the randomly selected plant for each treatment was determined and expressed in grams. The results are summarized in Table 3.

The data indicate that treatments T7 and T6 were superior regarding fruit size, individual fruit weight, number of achenes, and overall yield per plant. These

Table 3. Effect of treatments on fruit quality parameters.

Sl. No.	Treatment	Fruit area (cm) (L × B)	No of achenes/ berry	Fruit (berry) weight (g)	Fruit yield/plant (g)
1	T1	22.26 ± 0.17	368.33 ± 4.40	17.82 ± 0.02	349.39 ± 2.29
2	T2	18.00 ± 0.11	302.00 ± 5.56	14.16 ± 0.03	215.33 ± 1.54
3	T3	24.33 ± 0.43	388.33 ± 6.00	19.68 ± 0.20	446.02 ± 3.09
4	T4	21.13 ± 0.17	276.00 ± 4.93	12.45 ± 0.27	178.07 ± 3.30
5	T5	23.53 ± 0.17	310.00 ± 2.64	12.12 ± 0.08	180.32 ± 2.02
6	T6	27.20 ± 0.23	413.33 ± 3.52	22.28 ± 0.06	545.12 ± 5.68
7	T7	28.46 ± 0.17	442.33 ± 4.33	25.60 ± 0.11	670.70 ± 2.99
	SE(m)	0.55	4.77	0.13	3.33
	CD (p=0.05)	1.71	14.86	0.40	10.37

treatments involved the synergistic effect of multiple interventions. Treatments T3 and T1 also demonstrated promising outcomes. In contrast, treatments that utilized self-pollination and wind-pollination yielded the least favorable results. The findings further illustrate that treatments incorporating GA3 resulted in improved outcomes. Natural open pollination, in conjunction with supplemental artificial pollination, showed best results. Negi *et al.* (2018) found that cross-pollination significantly enhanced fruit quality, evidenced by increased fruit length and breadth. In alignment with these findings, Klatt *et al.* (2014) reported a 54.3% decrease in the commercial value per fruit attributed to self-pollination compared to bee pollination. Webb *et al.* (1974) noted that the number of achenes per cm² of ripe berries serves as an indicator of berry development throughout the fruiting. Furthermore, Hortyński *et al.* (1991) reiterated that fruit size is determined by receptacle dimensions and the number of achenes.

Quality attributing parameters

Total soluble solids (TSS): It was determined with

Table 4. Effect of treatments on quality attributing parameters.

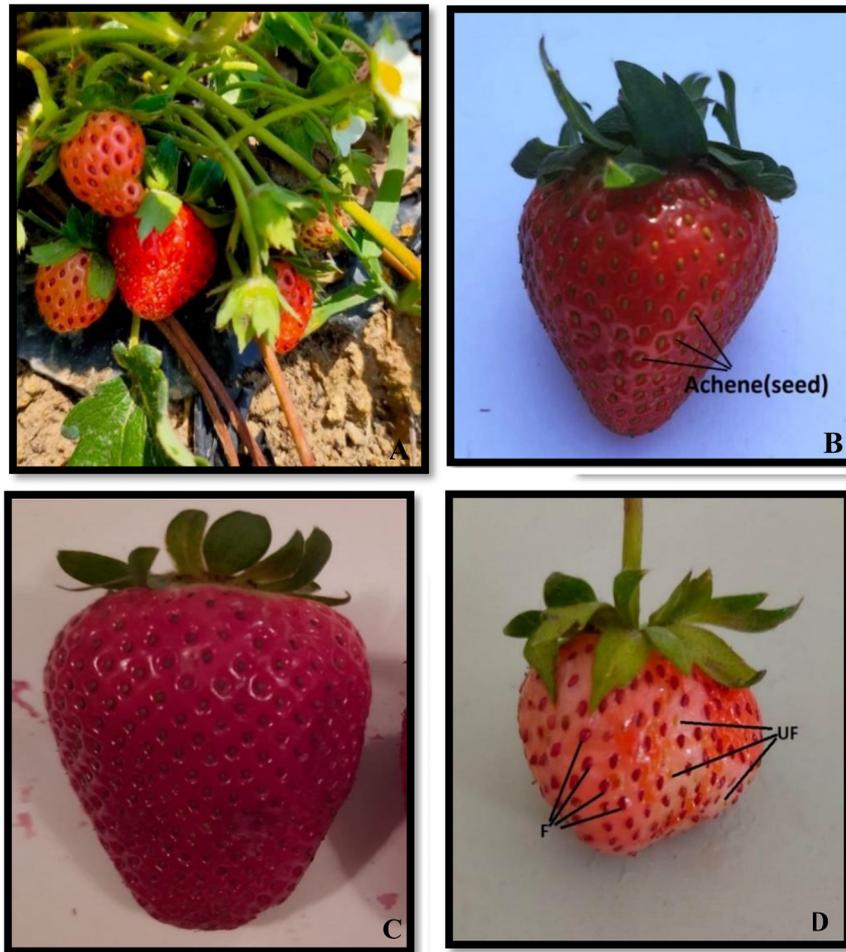
Sl. No.	Treatment	pH of Juice	TSS	Titration acidity
1	T1	3.80 ± 0.05	8.76 ± 0.12	0.87 ± 0.006
2	T2	3.43 ± 0.08	7.96 ± 0.08	0.75 ± 0.006
3	T3	4.00 ± 0.06	9.00 ± 0.11	0.89 ± 0.009
4	T4	2.70 ± 0.10	6.20 ± 0.05	0.57 ± 0.009
5	T5	3.03 ± 0.12	6.33 ± 0.03	0.58 ± 0.12
6	T6	4.13 ± 0.03	8.90 ± 0.05	0.94 ± 0.012
7	T7	4.26 ± 0.12	9.50 ± 0.25	0.98 ± 0.012
	SE(m)	0.11	0.13	0.009
	CD (p=0.05)	0.27	0.39	0.027

the help of brix refractometer.

pH of juice: The pH of extracted fruit juice was measured using a calibrated digital pH meter.

Titration acidity of juice: It was measured from the juice extracted from selected fruits. The results of the research related to quality parameters have been incorporated in Table 4.

It is very much evident from the results that the treatments T7 and T6, T3 and T1, which involved natural pollination supplemented with GA3 are much better than other treatments. Further the treatment T7 proved to be best as in this case natural pollination was supplemented with manual pollination. In the above mentioned treatments pH was optimum, TSS was quite high and titration acidity was high. All these features add to the better quality. The results are similar to the findings of Abrol *et al.* (2019). The data from Tables 2–4 indicate that treatment T7, which combines GA3 application, mulching, natural pollination, and induced (manual) pollination, achieved the best overall results across all evaluated parameters. Treatment T6 followed closely, while treatments T1 (GA3 application + natural pollination) and T3 (GA3 + mulching + natural pollination) also yielded favorable outcomes. In contrast, self-pollination and wind pollination performed significantly worse. Prasad *et al.* (2012) previously reported beneficial effects of GA3 treatment combined with black mulch. Our findings further suggest that individual applications of GA3, mulching, and natural pollination came close to the efficacy of treatment T7 in enhancing strawberry quality and yield. Among the chemical treatments,



Plates. 3A. Fruiting stage. **3B.** Each pistil develops into achene. **3C.** Large fruit when all achenes fertilized. **3D.** F= Fertilized, U.F= Unfertilized achenes.

the most effective was GA3 applied at 75 ppm, administered twice, corroborating previous research by Rajbhar *et al.* (2015), Kumar *et al.* (2012), Kumar *et al.* (2022). Furthermore, Gudowska *et al.* (2024) established that pollinators significantly enhance the production of superior strawberries, while Menzel (2023) highlighted that fruit set in strawberries is moderately reliant on insect pollinators.

DISCUSSION

The floral architecture (Polycarpellary apocarpous) of *Fragaria spp.* comprises several key components essential for reproductive success and fruit develop-

ment. Notably, the number of free carpels significantly exceeds the number of stamens (Plate. 2A–B). As a result, when the anthers release pollen, it lands on many, but not on all of the pistils. Strawberry fruit is categorized as an aggregate accessory fruit in which fleshy edible part is derived not only from the ovary (the achenes) but also from the receptacle, which enlarges as the achenes develop. The small, seed-like achenes located on the surface of the strawberry are the actual fruits of the flower, containing the seeds. (Plate. 3A–B) Our results demonstrate a significant relationship between fruit weight and the number of achenes produced, indicating that an increase in achenes corresponds to greater fruit size and weight

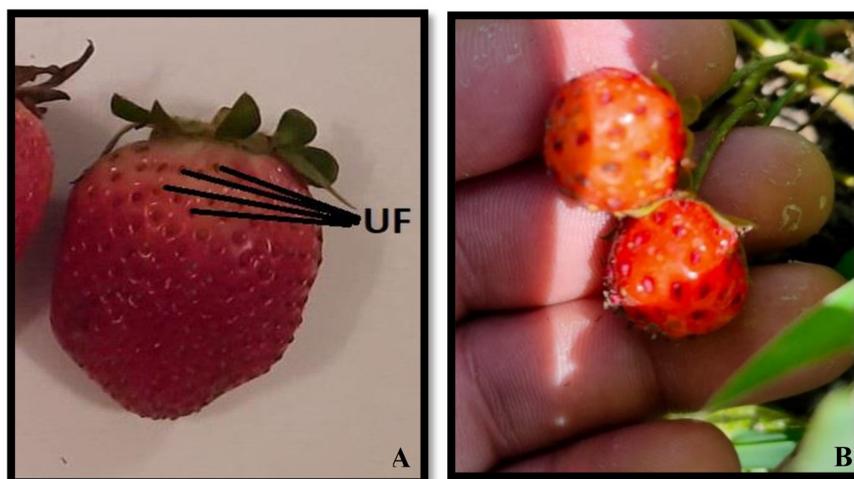


Plate 4A. Mis-shapen fruit with many unfertilized achenes in self-pollination. **4B.** Extremely small distorted fruit when pollination was not allowed.

(Plate. 3C–D). These findings align with observations made by Hulewicz and Hortyński (1972). It is crucial for optimal seed and berry development that each individual pistil undergoes pollination. The fertilization of ovules, which develop into achenes, triggers the release of auxins that promote the growth of the receptacle (Nitsch 1950). Achenes that arise from fertilized ovules are encased in robust, fleshy tissue, while receptacles with non-fertilized ovules fail to develop appropriately, resulting in smaller and misshapen berries (Vincent *et al.* 1990). In the present study also it was found that the flowers in which pollination was prevented by removing pre-mature anthers and covering the flowers with butter paper bag, extremely small sized poorly developed misshapen fruits were formed (Plate. 4A–B).

Our research indicates that self-pollination and anemophily often fail to effectively pollinate all pistils, resulting in smaller, lighter, and malformed fruits with reduced commercial viability. Notably, Gudowska *et al.* (2024) found that strawberry plants relying only on self-pollination produced fewer fertilized achenes when compared to those exposed to natural pollination methods. Our findings suggest that even after natural pollination many pistils may still remain un-pollinated thus, a combination of natural pollination supplemented by artificial methods significantly improves fruit size, weight, and overall quality. Gib-

berellic acid (GA3) is recognized as a potent growth regulator that enhances growth in strawberry plants by promoting increased photosynthetic activity and food production, ultimately elevating fruit quality. Nor *et al.* (2014) also reported that GA3 spray at 75 ppm, in conjunction with black mulch, showed significantly improved growth, fruit weight, and quality characteristics.

CONCLUSION

The findings of our research strongly indicate that although the fruit of strawberry is not a true fruit as it is not derived from ovary, yet ensuring cent percent pollination is crucial for improving fruit quality. Additionally, the application of 75 ppm gibberellic acid (GA3) during the growth stage and immediately prior to flower initiation further enhances the quality attributes of the fruit. We recommend that strawberry growers apply GA3 at 75 ppm alongside natural and manual pollination techniques to achieve higher yields and increased income. While manual pollination may not be feasible at a large scale, diversifying pollination sources remains the most effective option. Installation of beehives at different sites is most suitable strategy to ensure 100% pollination of strawberry flowers. However, installation of beehives should conform to specific recommendations to design to enhance their effectiveness in strawberry cultivation

over the long term.

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DECLARATION

The authors affirm and declare that they do not possess any conflicts of interest either directly or indirectly related to the research being reported in the publication.

AUTHORS' CONTRIBUTION

First author is credited with conceptualization of research topic, designing of the experiments, interpretation of results and preparation of manuscript. Second author helped in execution of field and laboratory experiments and collection of data with the help of third author. The fourth author is credited with performing statistical analysis of the data.

REFERENCES

- Abrol, D. P., Gorka, A. K., Ansari, M. J., Ghamdi, A., & Khatani, S. A. (2019). Impact of insect pollinators on yield and fruit quality of strawberry. *Saudi Journal of Biological Sciences*, 26, 524-530.
- Gudowska, A., Emilia, C., Emilia, M., & Dawid, M. (2024). Pollinators enhance the production of a superior strawberry – A global review and meta-analysis. *Agriculture, Ecosystems and Environment*, 362, <https://doi.org/10.1016/j.agee.2023.108815>
- Hortyński, J. A., Zebrowska, J., Gawronski, J., & Hulewicz, T. (1991). Factors affecting fruit size in Strawberry (*Fragaria ananassa* Duch.). *Euphytica*, 56, 67-74.
- Hulewicz, T., & Hortyński, J. (1972). Self-compatibility and fruit development in some cultivars of strawberry (*Fragaria ananassa* Duch.). *Genetica Polonica*, 13(1), 1–12.
- Klatt, B. K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., & Tschardtke, T. (2014). Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of The Royal Society*, 281, 1-8. <http://dx.doi.org/10.1098/rspb.2013.2440>
- Kumar, L., Kumar, S., Verma, R. S., Yadav, S., & Singh, V. (2022). Effect of plant growth regulators and mulches on growth and yield of strawberry (*Fragaria × ananassa* Duch.) cv Chandler. *Journal of Pharmacognosy and Phytochemistry*, 11(1), 189-191.
- Kumar, R., Bakshi, P., Srivastava, J. N., & Sravanan, S. (2012). Influence of plant growth regulators on growth, yield and quality of strawberry (*Fragaria × ananassa* Duch.) cv Sweet Charlie. *The Asian Journal of Horticulture*, 7(1), 40-43.
- Lata, S., Shrama, G., Garg, S., & Mishra, G. (2018). Effect of different modes of pollination on fruit set and malformation of strawberry cultivars. *Research on Crops*, 19(3), 430–435.
- Menzel, C. M. (2023). Fruit set is moderately dependent on insect pollinators in strawberry and is limited by the availability of pollen under natural open conditions. *The Journal of Horticultural Science and Biotechnology*, DOI: 10.1080/14620316.2023.2212670
- Negi, D., Sharma, G., Thakur, K., Singh, D., & Sajwan, P. (2018). Pollination studies in strawberry (*Fragaria × ananassa* Duch.). *International Journal of Agriculture Science*, 10(5), 5227-5230.
- Nitsch, J. P. (1950). Growth and Morphogenesis of the Strawberry as Related to Auxin. *American Journal of Botany*, 37 (3), 211-215.
- Nor, S. S., Razifah, M. R., Mamat, A. S., & Adzemi, M. A. (2014). Application of gibberellic acid (GA₃) in stem cutting of dragon fruit (*Hylocereus Polyrhizus*): Effects on fruit quality and yield at harvest. *Journal of Biology, Agriculture and Healthcare*, 4(21), 51- 55.
- Paikra, S., Panigrahi, H. K., & Chandrakar, S. (2020). Influence of NAA and GA₃ on Yield and Yield Attributing Parameters of Strawberry *Fragaria × ananassa* Duch.) cv. Sabrina under Net Tunnel. *International Journal of Current Microbiology and Applied Science*, 9(10), 2473-2478.
- Prasad, M., Minz, M., Kumar, R., & Das, B. (2012). Effect of Mulching and PGRs on growth, yield and quality of strawberry cv. Douglas. *International Journal of Agriculture Science*, 16 (1), 4415.
- Rajbhar, Y. P., Singh, B., Singh, G., Singh, D. K., & Kumar, M. (2015). Studies on the effect of growth regulator and vermicompost on growth and yield of different cultivars of strawberry (*Fragaria × ananassa* Duch). *The Asian Journal of Horticulture*, 10(2), 222-231.
- Sahana, B. J., Madaiah, D., Shivakumar, B. S., Sridhara, S., & Pradeep, S. (2020). Influence of organic manures on growth, yield and quality of strawberry (*Fragaria × ananassa* Duch.) under naturally ventilated polyhouse. *Journal of Pharmacognosy and Phytochemistry*, 9 (5), 3284-3287.
- Saima, Z., Sharma, A., Umar, I., & Wali, V. K. (2014). Effect of plant bio- regulator on vegetative growth, yield and quality of strawberry cv Chandler. *Academic Journals*, 9 (22), 1694-1699.
- Sharma, A., & Godara, A. (2020). Effect of Gibberellic Acid Application on the Growth, Vigor, Flowering, Fruiting and Quality of Strawberry: A Review. *International Journal of Current Microbiology and Applied Science*, 9(10), 3426-3431.
- Vincent, C., De Oliveira, D., Bélanger, A. (1990). The management of insect pollinators and pests in Québec strawberry plantations, pp 177–192.
- Webb, R. A., Purves, J. V., & White, B. A. (1974). The components of fruit size in strawberry. *Scientia Horticulture*, 2 (2), 165-174.