ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(8): 1088-1092
www.agriculturaljournals.com
Received: 02-07-2025
Accepted: 05-08-2025

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Effect of hand pollination on fruit set, and yield of custard apple

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DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i8j.677

Abstract
The present investigation entitled "Effect of hand pollination on fruit set, quality and yield of custard apple" was conducted during 2024-25 at Central Research Station, Dr. PDKV, Akola. The experiment was laid out in a Randomized Block Design (RBD) with eight treatments, including natural pollination and hand pollination with 40, 50, 60, 70, 80, 90, 100 flowers per plant, replicated thrice on 16-year-old trees of custard apple. Hand pollination significantly enhanced fruit set at pea stage (97.51%) and marble stages (95.89%), improved fruit yield (24.54 kg/plant) and (9.80 t/ha). Maximum fruit weight (373.83 g), pulp weight (190.93 g), were recorded in hand-pollinated treatments, especially with 40-90 flowers. Higher proportions of Grade I fruits, Grade II fruits were observed under moderate flower retention. The study concludes that hand pollination with 40 to 90 flowers per plant is optimal for achieving superior fruit yield in custard apple cv. Balanagar.

Keywords: Custard apple, hand pollination, fruit set, yield, fruit grades, balanagar, randomized block design (RBD), flower retention

Introduction
Custard apple (*Annona squamosa* L.), is a widely grown tropical fruit crop valued for its taste, adaptability, and nutritional content. Low productivity of annonaceous fruits is the main constraint in expanding their commercial cultivation (George and Nissen, 2002; Dag *et al.*, 2020) [8, 6]. Enough flowers are born on a custard apple plant to give a good crop but the poor fruit set causes low yield. Only one to eight percent fruit set has been reported under natural conditions (Gottsberger, 1989; Nagel *et al.*, 2020; Bhardwaj *et al.*, 2021; Gajbhiye *et al.*, 2019) [9, 13, 1, 7]. The low fruit set in custard apple is primarily attributed to poor pollination, which results from both external and internal factors, such as extreme humidity conditions during flowering, soil moisture stress, competition between vegetative and reproductive growth, hypogyny, protogynous dichogamy, poor pollen germination, and lack of effective insect pollinators Kishore *et al.* (2012) [10]. The protogynous dichogamy phenomenon, as described by George *et al.* (2002) [8], makes self-pollination nearly impossible because the stigma becomes receptive long before pollen is shed. Consequently, although a large number of hermaphrodite flowers are produced, only 1 to 2% of them set fruits naturally (Rajan *et al.*, 2011) [15]. Moreover, the flowers of custard apple are less attractive to pollinating insects, further reducing the likelihood of natural pollination (Singh *et al.*, 2010) [17]. Therefore, relying solely on natural pollination cannot ensure economic yields. Hand pollination has been recognized as an effective technique, improving fruit set and resulting in larger, well-shaped, and more uniform fruits without compromising their edible quality (Shivakumar *et al.*, 2018) [16].

Methodology
The present investigation entitled "Effect of hand pollination on fruit set, quality and yield of custard apple" was conducted during 2024-25 at the Central Research Station, Dr. PDKV, Akola, and the analytical work of the experiment was carried out at Analytical Laboratory, Department of Fruit Science, Dr. PDKV, Akola with the objectives to study the effect of hand pollination on fruit set, yield, and quality of custard apple and to standardize the number of flowers to be retained per plant for effective pollination and better fruit quality.

The experiment was laid out in Randomized Block Design (RBD) with eight treatments comprising of T_1-Natural pollination, T_2-Hand pollination with 40 flowers per plant, T_3-Hand pollination with 50 flowers per plant, T_4-Hand pollination with 60 flowers per plant, T_5-Hand pollination with 70 flowers per plant, T_6-Hand pollination with 80 flowers per plant, T_7-Hand pollination with 90 flowers per plant, and T_8-Hand pollination with 100 flowers per plant. All treatments were replicated three times on 16-year-old custard apple trees (cv. Balanagar) planted at a spacing of 5×5 meters. For hand pollination, pollen grains were collected from freshly opened male flowers during evening hours and kept overnight under a bulb for activation. The following morning, during the receptive hours (7:00 AM to 10:00 AM), pollination was carried out by using a syringe by depositing the activated pollen directly on the stigma of selected female flowers. The number of flowers pollinated per plant was maintained as per the treatment combination. Observations were recorded on fruit set at pea and marble stages, fruit weight, fruit yield per plant and per hactare, and fruit grade distribution as per commercial standards (Grade I: 350-500 g, Grade II: 200-349 g, and Grade III: <200 g).

Results and Discussions

Effect of hand pollination on fruit set (%)

The data presented in Table 1. Shows that the differences in fruit set at pea stage and marble stage influenced by different numbers of hand pollinated flowers was found to be significant. The maximum fruit set was recorded in T_2 (Hand pollination-40 flowers; 97.51%), which was statistically at par with T_3 (50 flowers; 96.02%) and T_4 (60 flowers; 96.11%), but significantly superior to natural pollination (T_1; 87.53%). The minimum fruit set occurred in T_8 (100 flowers; 89.05%), which was comparable to T_6 (80 flowers; 90.45%) and T_7 (90 flowers; 91.85%). this may be due to Higher early-stage fruit set in the moderately and well hand-pollinated treatments can be explained by improved pollen delivery, better stigma contact and subsequent pollen-tube growth leading to successful fertilization. Efficient fertilization at anthesis reduces early embryo abortion and strengthens ovary attachment, which increases retention through the pea stage. These results are closely associated with the findings of Sanghani & Varu (2022) reported that hand pollination significantly increased pea-stage fruit set in custard apple cv. Sindhan, with hand-pollinated treatments reaching 95-97% set, compared to 85% under open pollination. This closely aligns with the results where T_2 showed 97.51% and T_3 and T_4 were at par highlighting the effectiveness of manual pollination in enhancing early fruit retention.

Similarly, fruit set at marble stage has maximum fruit set was recorded in T_2-Hand pollination at 40 flowers (95.89%), and it is at par with T_4-60 flowers (94.49%) and T_3-50 flowers (94.07%), reflecting the benefit of moderate levels of assisted pollination. On the other hand, T_1-natural pollination resulted in the minimum fruit set (78.58%), followed closely by T_8-100 flowers (85.37%). This may be due to optimal pollination reduces early abscission by ensuring more ovules are fertilized and by stabilizing pedicel/fruit attachment during the critical early growth phases. These findings are closely associate with the findings of Choudhary *et al*. (2017) [5] reported that hand pollination in custard apple significantly increased fruit set compared to natural conditions. Similar findings were observed by Singh *et al*. (2010) [17] in guava, where improved pollination enhanced fruit retention at multiple growth stages. Furthermore, Bollard (1980) [2] documented that in feijoa, hand pollination improved fruit set and reduced early fruit drop. These studies highlight that moderate flower hand pollination optimizes fruit set by balancing fertilization success and resource availability.

Table 1: Effect of hand pollination methods on fruit set at pea stage in custard apple

Sr. No.	Treatment details	Fruit set at pea stage (%)	Fruit set at marble stage (%)
T_1	Natural pollination	87.53	78.58
T_2	Hand pollination-40 flowers	97.51	95.89
T_3	Hand pollination-50 flowers	96.02	94.07
T_4	Hand pollination-60 flowers	96.11	94.49
T_5	Hand pollination-70 flowers	94.76	91.42
T_6	Hand pollination-80 flowers	90.45	88.80
T_7	Hand pollination-90 flowers	91.85	90.01
T_8	Hand pollination-100 flowers	89.05	85.37
F-test		Sig	Sig
SE(m)±		0.88	1.51
C.D. at 5%		2.65	4.59

Effect of hand pollination on fruit, pulp, rind, and seed weight (g)

The data presented in Table 2. Shows that the differences in fruit weight, pulp weight, rind weight, seed weight in (g) influenced by different numbers of hand pollinated flowers was found to be significant. The fruit weight and related physical parameters of custard apple were significantly influenced by the number of flowers hand-pollinated per plant. The maximum fruit weight (373.83 g) was recorded in T_2-40 flowers (hand pollination with 40 flowers), statistically at par with T_3 (50 flowers; 352.11 g). The minimum fruit weight was observed under natural pollination (T_1; 257.25 g), which was at par with T_8 (100 flowers; 261.64 g). Pulp weight followed a similar trend, with the maximum$_1$ values in T_2-40 flowers (190.90 g) and T_3-50 flowers (189.01 g), both at par, while the minimum pulp weight was observed in T_8-100 flowers (124.34 g), at par with T_1-natural pollination (129.66 g). Rind weight peaked in T_2-40 flowers (149.24 g), followed by T_3-50 flowers (131.18 g), with the minimum rind weight in T_8-100 flowers (97.94 g), at par with T_1-natural flowers (103.52 g). Seed weight was maximum in T_2-40 flowers (33.65 g), statistically at par with T_3-50 flowers (31.92 g) and T_6 (80 flowers; 31.20 g), and minimum in T_1-natural pollination (24.07 g), at par with T_8-100 flowers (24.36 g). The superior fruit physical parameters observed in T_2-40 flowers and T_3-50 flowers are attributed to an optimal flower load ensuring efficient assimilate distribution and balanced source-sink relationships. Hand pollination facilitates complete fertilization, promoting seed development that acts as a strong sink to stimulate pulp and rind growth through enhanced hormonal signalling, particularly auxins and gibberellins (Chadha & Gopal, 2013) [4]. Excessive flower retention, as seen in treatments above 80 flowers, likely caused increased competition for carbohydrates, resulting in reduced individual fruit size. Natural pollination resulted in incomplete fertilization and fewer developed seeds, leading to lower fruit weight and size (Singh *et al*., 2010) [17]. These results are closely associate with the findings of Chadha and

Gopal (2013) [4] demonstrated that hand pollination significantly improves fruit weight and quality in custard apple compared to natural pollination. Singh *et al*. (2010) [17] reported in guava that controlled fruit load and effective pollination enhance fruit weight and pulp development. Similarly, Nagaraju *et al*. (2013) [12] observed in mango that optimal flower thinning and hand pollination increased fruit size and weight. Bollard (1980) [2] also showed that hand pollination in feijoa increased fruit size by improving fertilization and assimilate partitioning.

Table 2: Effect of hand pollination on fruit, pulp, rind, and seed weight (g) in custard apple

Sr. No.	Treatment details	Fruit weight (g)	Pulp weight (g)	Rind weight (g)	Seed weight (g)
T_1	Natural pollination	257.25	129.66	103.52	24.07
T_2	Hand pollination-40 flowers	373.83	190.93	149.24	33.65
T_3	Hand pollination-50 flowers	352.11	189.01	131.18	31.92
T_4	Hand pollination-60 flowers	320.83	180.08	111.01	29.74
T_5	Hand pollination-70 flowers	305.72	158.50	117.67	29.55
T_6	Hand pollination-80 flowers	310.63	164.04	115.39	31.20
T_7	Hand pollination-90 flowers	273.30	140.55	104.16	28.59
T_8	Hand pollination-100 flowers	261.64	124.34	97.94	24.36
F-test		Sig	Sig	Sig	Sig
SE(m)±		4.72	5.79	21.04	1.86
C.D. at 5%		14.33	17.57	6.94	5.63

Effect of hand pollination on yield (kg/plant) and yield (ton/ha)

The data presented in Table 3. Shows that the differences in yield (kg/plant) and yield (ton/ha) influenced by different numbers of hand pollinated flowers was found to be significant. The maximum yield (24.54 kg/plant and 9.80 t/ha) was recorded in T_7, where 90 flowers per plant were hand-pollinated, followed closely by T_8 (100 flowers; 23.13 kg/plant and 9.20 t/ha). The minimum yield was observed in T_1 (natural pollination; 13.54 kg/plant and 5.40 t/ha), which was statistically at par with T_2 (40 flowers; 13.78 kg/plant and 5.47 t/ha). Intermediate yields were obtained in T_3 (50 flowers; 15.86 kg/plant and 6.30 t/ha), T_4 (60 flowers; 17.36 kg/plant and 6.90 t/ha), T_5 (70 flowers; 19.94 kg/plant and 7.90 t/ha), and T_6 (80 flowers; 22.31 kg/plant and 8.87 t/ha). The higher yields in treatments with 70-100 flowers pollinated per plant can be attributed to increased fruit set, as hand pollination ensures complete fertilization of more flowers, overcoming the low natural pollination efficiency of custard apple due to its protogynous flowering and limited pollinator activity. As the number of pollinated flowers increases, the total number of fruits harvested rises, directly boosting yield. However, a marginal decline in yield per plant from 90 to 100 flowers suggests the onset of resource competition, where excessive fruit load may reduce average fruit size and quality, even if total yield remains high. Optimal yield performance at 90 flowers likely represents a balance between maximizing fruit number and maintaining adequate assimilate supply for development. Significant yield improvements through hand pollination in custard apple have been reported by Patel *et al*. (2022, *The Pharma Innovation Journal*) [14], where manual pollination increased fruit set from 4-5% in natural conditions to over 80%, leading to higher yields. Choudhary *et al*. (2017, *ResearchGate*) [5] documented that controlled hand pollination in *Annona squamosa* effectively overcomes pollination constraints, substantially improving yield. Similar trends have been observed in soursop (*Annona muricata*), where pollinating 75-100 flowers per plant resulted in the maximum yields due to greater fruit set (Morton, 1987, *Fruits of Warm Climates*).

Table: 3: Effect of hand pollination on yield (kg/plant) and yield (ton/ha) in custard apple

Sr. No.	Treatment details	Yield (kg/plant)	Yield (ton/ha)
T_1	Natural pollination	13.54	5.40
T_2	Hand pollination-40 flowers	13.78	5.47
T_3	Hand pollination-50 flowers	15.86	6.30
T_4	Hand pollination-60 flowers	17.36	6.90
T_5	Hand pollination-70 flowers	19.94	7.90
T_6	Hand pollination-80 flowers	22.31	8.87
T_7	Hand pollination-90 flowers	24.54	9.80
T_8	Hand pollination-100 flowers	23.13	9.20
F-test		Sig	Sig
SE(m)±		1.00	1.22
C.D. at 5%		3.03	0.40

Similar finding also studies in feijoa (*Acca sellowiana*) also confirm that increasing the number of hand-pollinated flowers per tree significantly enhances total yield (Bollard, 1980 [2], *Acta Horticulturae* 240: 275-278). These findings align with the present results, indicating that increasing the number of flowers pollinated per plant in custard apple can maximize yield potential up to an optimal threshold.

Effect of hand pollination on grades of custard apple

The data presented in Table 4. Shows that the differences in effects of hand pollination on Grade I (350-500g) in (%), Grade II (200-349g) in (%), Grade III (Below 200g) in (%) in custard apple influenced by different numbers of hand pollinated flowers was found to be significant.

The proportion of fruits in different grades was significantly influenced by the number of flowers hand-pollinated per plant. The maximum percentage of Grade I fruits (350-500 g) was recorded in T_2 (40 flowers) at 66.82%, followed by T_3 (50 flowers) at 46.88%, both statistically higher than all other treatments. The minimum Grade I share was in T_1 (natural pollination; 16.05%) at par with T_8 (100 flowers; 21.85%). For Grade II fruits (200-349 g), the maximum proportion was noted in T_8 (49.61%), at par with T_6 (48.82%) and T_7 (47.74%), while the minimum was in T_2 (26.98%). In Grade III fruits (< 200 g), T_1 recorded the maximum share (54.41%), followed by T_8 (28.52%), whereas T_2 had the minimum proportion (6.09%), at par with T_3 (6.37%). The predominance of Grade I fruits in the 40-50 flower treatments is likely due to optimal fruit load, which ensures that each developing fruit receives an adequate supply of carbohydrates, minerals, and water, resulting in larger fruit size and better cell expansion. Hand pollination ensures complete seed set, which promotes hormonal signaling (auxins, gibberellins) that drive pulp growth and fruit enlargement. In contrast, natural pollination (T_1) results in poor fruit set and smaller fruits due to incomplete fertilization and low sink strength. Very high flower retention (≥ 90 flowers) increases the total fruit number but causes strong competition for assimilates, leading to more medium-and small-sized fruits (Grades II and III).

Table 4: Effect of hand pollination on Grade I (350-500g) in (%), Grade II (200-349g) in (%), Grade III (Below 200g) in (%) in custard apple

Sr. No.	Treatment details	Grade I (350-500g) in (%)	Grade II (200-349g) in (%)	Grade III (Below 200g) in (%)
T_1	Natural pollination	16.05	29.53	54.41
T_2	Hand pollination-40 flowers	66.82	26.98	6.09
T_3	Hand pollination-50 flowers	46.88	46.78	6.37
T_4	Hand pollination-60 flowers	29.32	45.96	24.70
T_5	Hand pollination-70 flowers	29.23	46.84	24.92
T_6	Hand pollination-80 flowers	32.38	48.82	18.79
T_7	Hand pollination-90 flowers	29.70	47.74	22.55
T_8	Hand pollination-100 flowers	21.85	49.61	28.52
F-Test		Sig	Sig	Sig
SE(m)±		2.37	2.08	1.86
C.D. at 5%		7.18	6.32	5.65

Similar findings are observed by Chadha and Gopal (2013) [4] reported that hand pollination in custard apple significantly increased fruit size and proportion of marketable grades compared to open pollination. In guava, Singh *et al*. (2010) [17] found that regulated fruit load through thinning and effective pollination enhanced fruit size distribution, increasing premium grade fruits. Similar observations were made in mango by Nagaraju *et al*. (2013) [12], where effective pollination coupled with flower thinning improved fruit weight and grade distribution. Additionally, studies on feijoa (Bollard, 1980) [2] have demonstrated that hand pollination increases the proportion of larger fruits by improving fertilization and assimilate partitioning.

Conclusion

Based on the results, it can be concluded that hand pollination with 40 to 90 flowers per plant significantly improved fruit set at both pea and marble stages, in custard apple. This practice also enhanced fruit weight and yield per plant (kg) and per hectare, along with a higher proportion of Grade I fruits and a reduction in Grade III fruits. Thereby enhancing overall fruits setting and their market value.

Acknowledgement

I am thankful to the Department of Fruit Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola and Central Research Station, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra for providing the necessary facilities to carry out the experimental work.

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