



ORIGINAL ARTICLE

Potentiality of Anthropophily to Enhance Nut Production in Cashew (*Anacardium occidentale* L.)

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KEY WORDS

Benefit-cost ratio;
Hand-pollination;
Human pollinator;
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Nut yield;
Vitamin treatment

ABSTRACT

Cashew nuts are highly demandable due to their nutritional value and utility. However, yield is below the optimum level. Several strategies were deployed to overcome its low productivity, like artificial hybridization, hormone treatment and bee management. Here, for the first time, we assessed the impact of vitamin (e.g., folic acid) treatment and anthropophily pollination on cashew yield. We sprayed vitamins started before the blooming period and continued through the flowering period; recorded flowering patterns; performed hand-pollination; recorded fruit set and fruit quality parameters for different systems at the Vidyasagar University campus (in the Paschim Medinipur district, West Bengal, India), during 2021–2023. Vitamin treatment significantly increased the number of flowers (both hermaphrodite and male flowers) development. Anthropophily pollination enhanced fruit set and nut quality (e.g., weight, length and breadth). Combined with vitamin treatment and anthropophily, it increases nut yield approximately five times compared to a non-manipulated system. While an additional cost is needed for human pollinators, the benefit-to-cost ratio in anthropophily pollination was high (i.e., 1.84: 1). Therefore, non-traditional human pollinators (i.e. anthropophily pollination) in addition to growth promoters (e.g., vitamins) utilization will be an effective strategy to increase the nut yield of cashew trees.

Introduction

The cashew (*Anacardium occidentale* L.) tree is a drought-resistant tropical and subtropical tree native to Brazil and Peru. Cashew nut kernel is nutrient-rich and has a significant amount of fat, protein and carbohydrate contents (Olatidoye *et al.*, 2020). In cashews such as walnut unsaturated fatty acids content remains higher than saturated and trans fatty acids (Rico *et al.*, 2015; Sarikhani *et al.*, 2021). Kernel oil has a mixture of fatty acids and minerals, is non-drying in nature (Akinhanmi *et al.*, 2008; Pakrah *et al.*, 2021, Sarikhani *et al.*, 2021) and is useful in many industries for varnishes and paints. Therefore,

cashew nut remains a high-value export crop that provides a source of income for millions of rural households in Africa and Asia (Topper *et al.*, 2001). However, the global average yield of cashew nuts remains very low, at around 780 kg ha⁻¹ (FAO, 2018). Several factors are responsible for low nut yields like lower number of hermaphrodite flowers, pollination deficit (Layek *et al.*, 2021), low fruit set (Holanda-Neto *et al.*, 2002), genetically poor variety of planting material (Chacko *et al.*, 1990; Foltan and Ludders, 1995), adverse environmental conditions (Parameswaran *et al.*, 1984). To overcome the

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problem of low productivity, researchers addressed the issue in many ways. Some workers (e.g., Bigger, 1960; Northwood, 1966; Freitas and Paxton, 1998; Layek *et al.*, 2021) uncovered the floral biology and pollination ecology. A few researchers (e.g., Damodaran, 1975; Manoj and George, 1993; Cavalcanti *et al.*, 2000) used hybridization to achieve hybrid vigour regarding the nut yield. Some researchers (e.g., Aliyu *et al.*, 2011) used exogenous plant hormones to increase the number of hermaphrodite flower development, resulting in higher nut yield. Some researchers (e.g., Smith, 1958; Layek *et al.*, 2021) employed bee management (via the installation of managed bee colonies or habitat management) to overcome pollination deficit and increase fruit set.

Anthropophily (i.e., pollination carried out by human beings) is a technique farmers use to overcome the pollination deficit of some crops, especially for the members of Cucurbitaceae (bearing unisexual flowers). Most cases, anthropophily remains successful in increasing crop yield. Besides cucurbits, humans also acted as pollinators for other fruit crops (like apples by Maoxian farmers: Partap and Ya, 2012). However, the benefit-cost ratio varies with regions and fruit crop types.

In the case of cashews, anthropophily may be effective to overcome pollination deficit and to increase nut yield. But, there is no existing literature about anthropophilic activity on cashew trees. Here, we aimed to evaluate the impact of anthropophily (in addition to vitamin treatment) on nut yield.

Material and Methods

Plant species and study site

We experimented on cashew (*Anacardium occidentale* L.) trees belonging to the plant family Anacardiaceae. The plant produces many male flowers and a few hermaphrodite flowers. The fruit set is meagre in non-manipulated fields. Cashew nuts are in high demand worldwide.

The present work was conducted at the

Vidyasagar University campus in the Paschim Medinipur district of West Bengal, India, during 2021–2023. The study location is 23 meters above sea level at latitude 22.43033°N and longitude 87.301069°E. The climate is tropical, and the land surface is characterized by rugged rock. Besides cashew trees, other associated plants are *Acacia auriculiformis* A. Cunn.ex Benth and *Eucalyptus tereticornis* Sm.

Experimental design

We randomly selected five cashew trees for vitamin treatment. Before blooming (during the initiation of flower buds), we sprayed vitamin (i.e., folic acid in 0.2 ml L⁻¹) on twigs. Then, it was sprayed at regular intervals of 10 days until flowering ceased. We also select another three trees as non-manipulated, i.e. control set. We counted the number of opened hermaphrodite and male flowers produced per inflorescence (n = 20 for vitamin-treated, n = 20 for the control set).

We estimated fruit sets in four different systems—(i) non-manipulated, (ii) vitamin (folic acid) treatment, (iii) anthropophily, and (iv) a combination of vitamin treatment and anthropophily. Twenty sampling days were employed for each treatment, and on each sampling day, we selected 30–70 flowers for a system. We conducted anthropophily pollination on both vitamin-treated and non-treated plant inflorescence and with non-self cross-pollens. Anthropophily was done on 2nd day of the flower at 10.00–14.00 h when the stigma remains receptive (Layek *et al.*, 2021). For the marked inflorescences, hand-pollination was carried out at 2-day intervals to pollinate almost all the flowers.

We estimated fruit quality for these four systems. We assessed the weight of fleshy thalamus (i.e., apple) and nuts (sun-dried) (n = 20 for each system). We measure the length and breadth of nuts for these systems (n = 20 for each system).

We calculated the yield enhancement in vitamin-treated and combined vitamin and anthropophily

systems as follows:

$$\text{Yield enhancement (\%)} = \frac{(FS_i \times W_i - FSc \times Wc)}{FSc \times Wc} \times 100$$

Where FS_i is the fruit set in the i system, FSc is the fruit set in the control system, W_i is the weight of fruit (here, nut) in the i system, and Wc is the weight of fruit in the control system. Here, we considered the number of fruits formed per panicle.

Benefit-cost ratio in anthropophily pollination

We estimate the number of hermaphrodite flowers that can be pollinated by a worker per hour. Then, calculate the number of flowers that can be pollinated by a worker on a working day. By yield enhancement, how much money can be earned additionally and how much money needs to be given as wages of workers were determined.

Statistical analyses

Using descriptive data analysis, we derived the mean and standard deviation. We performed a t-test to compare the data of the number of opened flowers/inflorescence/day between vitamin-treated and non-manipulated systems. Data about fruit sets

and fruit quality parameters (e.g., weight, length, breadth) were analyzed using one-way ANOVA. If a significant difference was found, the DMRT post hoc test (with a significance threshold of 0.05) was used to identify differences between the means. The statistical software SPSS (ver. 25.0) were used for these analyses.

Results

Impact of vitamin treatment on flowering

The total number of flowers developed on an inflorescence differed significantly between vitamin-treated and control (i.e., non-manipulated) systems ($t = 5.08, p < 0.001, df = 38$). Vitamin treatment resulted in more flowers per inflorescence (1710.60 ± 206.53) than the control sets (1407.95 ± 168.69). Both the number of hermaphrodites and male flowers were significantly higher in the vitamin-treated systems (413.60 ± 93.28 hermaphrodite flowers and 1297 ± 113.98 male flowers per inflorescence) than in non-manipulated systems (Table 1). In contrast, the ratio of hermaphrodite to male flowers does not differ between these two systems ($t = 0.86, p = 0.40, df = 38$).

Table 1. Number of flowers developed in vitamin-treated and non-manipulated systems.

Parameters	Vitamin treated system	Non-manipulated system	Statistics
Total number of flowers/inflorescence	1710.60 ± 206.53	1407.95 ± 168.69	$t = 5.08, p < 0.001, df = 38$
Number of hermaphrodite flowers/inflorescence	413.60 ± 93.28	330.80 ± 73.02	$t = 3.13, p < 0.01, df = 38$
Number of male flowers/inflorescence	1297 ± 113.98	1177.15 ± 96.07	$t = 6.60, p < 0.001, df = 38$
Hermaphrodite to male flower ratio	0.32 ± 0.05	0.30 ± 0.04	$t = 0.86, p = 0.40, df = 38$

Values are given in mean ± standard deviation.

Fruit set in different systems

The percentage of fruit set significantly differed among the non-manipulated, vitamin-treated, anthropophily, and combined vitamin and anthropophilic systems ($F_{3,76} = 344.68, p < 0.001$).

The percentage of fruit sets was higher in the anthropophilic (62.99 ± 8.56) and combined vitamin and anthropophilic systems (60.66 ± 6.29) than in the other two systems (Fig. 1).

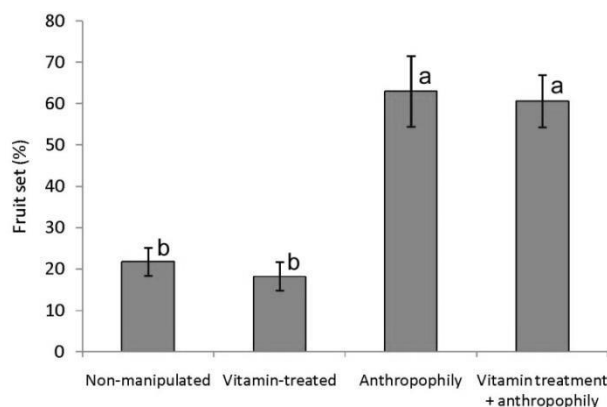


Fig. 1. Percentages of fruit set of cashew in different systems. Different letters indicate significant differences (DMRT at 5% level).

The number of fruit sets per panicle also differed among these four systems ($F_{3,76} = 287.59, p < 0.001$). The highest number of fruits per panicle were obtained in the combined vitamin and anthropophilic

system (41.70 ± 5.27), followed by anthropophilic (29.75 ± 5.44), vitamin-treated (12.45 ± 2.82) and non-manipulated systems (8.30 ± 1.30) (Fig.2).

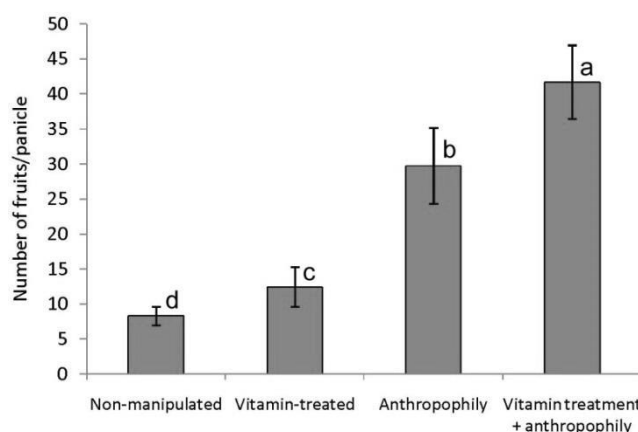


Fig. 2. Number of fruit set per panicle in different systems. Different letters indicate significant differences (DMRT at 5% level).

Fruit quality in different systems

The weight of the fleshy thalamus does not differ among the four systems ($F_{3,76} = 1.14, p = 0.34$). In comparison, nut weight differed among the systems ($F_{3,76} = 4.07, p < 0.01$). Nut weight remained higher in anthropophily (4.70 ± 0.81 gm) and in combination with vitamin treatment and anthropophily (4.93 ± 1.10 gm) than the non-manipulated (4.10 ± 0.76 gm) and

vitamin-treated (4.17 ± 0.88 gm) systems. The length and breadth of nuts also differed among these four systems (length: $F_{3,76} = 3.51, p < 0.05$; breadth: $F_{3,76} = 3.19, p < 0.05$). Comparatively, the nut’s length and breadth remained higher in anthropophily and combination with vitamin treatment and anthropophily than the other two systems (Table 2).

Table 2. Fruit quality of cashew in different systems.

Parameter	Different systems				Statistics
	Non-manipulated	Vitamin	Anthropophily	Vitamin + anthropophily	
Weight of fleshy thalamus (gm)	40.30 ± 16.49	44.20 ± 17.06	46.79 ± 13.75	49.61 ± 18.72	$F_{3,76} = 1.14, p = 0.34$
Weight of dry nut (gm)	4.10 ± 0.76	4.17 ± 0.88	4.70 ± 0.81	4.93 ± 1.10	$F_{3,76} = 4.07, p < 0.01$
Length of nut (cm)	2.87 ± 0.22	2.95 ± 0.22	2.99 ± 0.16	3.11 ± 0.33	$F_{3,76} = 3.51, p < 0.05$
Breadth of nut (cm)	1.80 ± 0.21	1.84 ± 0.20	1.98 ± 0.20	2.01 ± 0.38	$F_{3,76} = 3.19, p < 0.05$

Nut yield enhancement

Vitamin treatment enhances nut yield by about 52.57% compared to a non-manipulated system. Anthropophily alone increased nut yield by about 310.89%. Vitamin treatment and anthropophily in combination increased nut yield by approximately 504.12% compared to the control system.

Benefit-cost ratio in anthropophily pollination

A worker can pollinate 249.70 ± 28.46 flowers in an hour. If a working day constitutes 5 hours, then a total of 1248.50 flowers can be pollinated. For that, nut yield will be increased by about 2.58 kg (compared to a non-manipulated system), with an Indian market value of about Rs. 1290. The average wage of a worker is approx. Rs. 700 per day. Then, the benefit-to-cost ratio in anthropophily pollination was 1.84:1 (calculation based on the same market price of the nuts for control and treated systems). However, good quality nuts (resulting in treated systems) may sold in the market at a higher price than the nuts of control sets; therefore, the benefit-to-cost ratio will be more than the estimated value.

Discussion

To our knowledge, this is the first assessment of anthropophily in combination with vitamin treatment on cashew trees. Folic acid treatment increased the number of hermaphrodite flowers and also male flowers. The increase in hermaphrodite flower production by phyto-hormone treatment was reported by some researchers (e.g., Aliyu *et al.*, 2011). However, the percentage of fruit set is not enhanced by vitamin treatment. This is due to inadequate pollination services in open conditions. Through anthropophily pollination, the percentage of fruit set significantly increased. It may overcome the pollination limitation of cashew flowers. Supplementary pollination services by the management of bees increase nut yield, which was also documented for cashews (Smith, 1958; African

Cashew Initiative, 2013). The number of fruits per panicle increases by both vitamin treatment and anthropophily systems. The highest fruits/panicle was obtained in the combination of vitamin treatment and anthropophily. This system resulted in a higher number of fruits in two ways— (i) vitamin increased the number of hermaphrodite flower development, and (ii) anthropophily pollination overcame pollination deficit. Nut quality (weight, length, breadth) also improved through vitamin treatment and anthropophily pollination. Adequate pollination can enhance fruit quality is known for many crops (Bisui *et al.*, 2020; Layek *et al.*, 2022). Further, nutritional composition may also depend on the level of pollination achieved (Brittain *et al.*, 2014; Silva *et al.*, 2018). In comparison to the non-manipulated system, anthropophily enhanced nut yield about three times and vitamin treatment with anthropophily pollination increased yield five times. In addition to yield, nut quality remained better for the treated systems than for the control systems. Good quality nuts (resulting in treated systems) may fetch a greater price on the market than control set nuts. So, considering the labour cost of anthropophily, the gain was much higher. Anthropophily pollination can be regarded as an effective strategy to overcome low productivity and enhance the quality and quantity of nut yield. However, the availability of trained workers for anthropophily pollination may be a limitation of the procedure. We need to train the farmers as they successfully and effectively pollinate the flowers.

Conclusions

Vitamin (folic acid) treatment increased the number of hermaphrodite and male flowers. But not the percentage of fruit set. Anthropophily pollination with vitamin treatment increased the percentage of fruit set (60.66 ± 6.29) and obtained a higher number of fruits per panicle (41.70 ± 5.27). Nut quality (weight, length and breadth) also improved in anthropophily pollination with vitamin treatment. By

using vitamins and anthropophily pollination, nut yield was enhanced about fivefold compared to a non-manipulated system. Hence, anthropophily pollination can be considered an effective approach for overcoming low cashew productivity and increasing nut output quality and quantity.

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Conflict of interests

The authors declare no competing interest.

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