Journal of Nuts

Journal homepage: sanad.iau.ir/journal/ijnrs

ORIGINAL ARTICLE

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

Kartik Kandar[1], Ujjwal Layek[2], Prakash Karmakar*[1]

[1]*Department of Botany & Forestry, Vidyasagar University, Midnapore-721102, W.B., India*

[2]*Department of Botany, Rampurhat College, Rampurhat-731224, W.B., India*

K E Y W O R D S

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

A B S T R A C T

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

***Corresponding author**: Email address: prakashbot1973@gmail.com
Received: 10 October 2023; Received in revised form: 15 November 2023; Accepted: 9 December 2023
DOI: 10.22034/jon.2023.2001026.1255

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 Cucubitaceae (bearing unisexual flowers). Most cases, anthopophily 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, anthopophily 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:

$$\text{Yield enhancement (\%)} = (FSi \times Wi - FSc \times Wc / FSc \times Wc) \times 100$$

Where *FSi* is the fruit set in the *i* system, *FSc* is the fruit set in the control system, *Wi* 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).

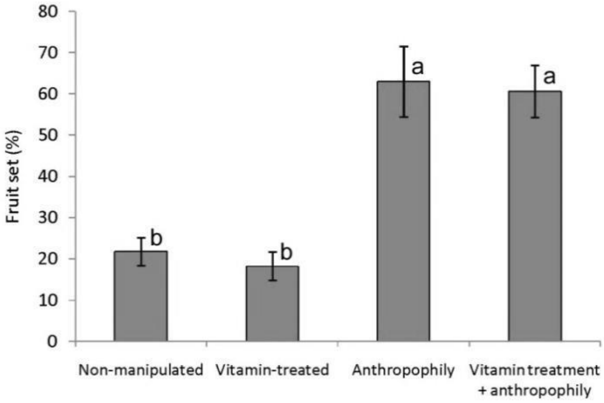

Fig. 1. Percentages of fruit set of cashew in different systems. Different letters indicate significant differences (DMRT at 5% level).

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).

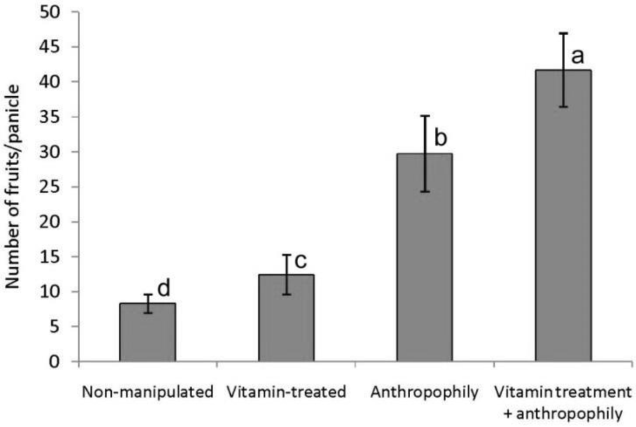

Fig. 2. Number of fruit set per panicle in different systems. Different letters indicate significant differences (DMRT at 5% level).

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 considered an effective approach for overcoming low cashew productivity and increasing nut output quality and quantity.

Acknowledgements

We are thankful to the authority of Vidyasagar University for providing with thenecessary laboratory facilities. Financial assistance provided by WBDSTDBT as a research project [Memo No. 1840(Sanc.)/STBT-11012(11)/8/2021-ST SEC] is gratefully acknowledged.

Conflict of interests

The authors declare no competing interest.

References

African Cashew Initiative, 2013. The study of the effects of integrating beekeeping into cashew farms in Ghana and Benin, ACi. http:www. African cashewinitiative .org/ imglib/downloads/ 140218_ beekeeping %20study.pdf

Akinhanmi TF, Atasie VN, Akintokun PO (2008) Chemical composition and physicochemical properties of cashew nut (*Anacardium occidentale*) oil and cashew nut shell liquid. Journal of Agricultural, Food and Environmental Sciences. 2(1), 1–10.

Aliyu OM, Adeigbe OO, Awopetu JA (2011) Foliar Application of the Exogenous Plant Hormones at Pre-Blooming Stage Improves Flowering and Fruiting in Cashew (*Anacardium occidentale* L.). Journal of Crop Science and Biotechnology. 14(2), 143–150.

Bigger M (1960) Selenothrips rubrocinctus (Giard) and the floral biology of cashew in Tanganyika. The East Africa Agricultural Journal. 25(4), 229–234.

Bisui S, Layek U, Karmakar P (2020) Utilization of Indian dammar bee (*Tetragonula iridipennis* Smith) as a pollinator of bitter gourd. Acta Agrobotanica. 73(1), 7316.

Brittain C, Kremen C, Garber A, Klein AM (2014) Pollination and plant resources change the nutritional quality of almonds for human health. PloS one. 9(2), e90082.

Cavalcanti JJV, Pinto CABP, Crisostomo JR, Ferreira DF (2000) Análise dialélica para avaliação de híbridosinterpopulacionais de cajueiro. Pesquisa Agropecuária Brasileira. 35, 1567–1575.

Damodaran VK (1975) Hybrid vigour in cashew (*Anacardium occidentale* L.). Agricultural Research Journal of Kerala.13, 195–196.

FAO (2018) Food and Agriculture Organization of the United Nations, Crop Production Statistics Division.

Foltan H, Ludders P (1995) Flowering, fruit set and genotype compatibility in cashew. Angewandte Botanik. 69, 215–220.

Freitas BM, Paxton RJ (1998) A comparison of two pollinators: the introduced honey bee (*Apis mellifera*) and an indigenous bee (*Centris tarsata*) on cashew (*Anacardium occidentale*) in its native range of NE Brazil. Journal of Applied Ecology. 35, 109–121.

Holanda-Neto JPD, Freitas BM, Bueno DM, Araujo ZBD (2002) Low seed/nut productivity in cashew (*Anacardium occidentale*): Effect of self-incompatibility and honey bee (*Apis mellifera*) foraging behavior. The Journal of Horticultural Science and Biotechnology. 77, 226–231.

Layek U, Bera K, Bera B, Bisui S, Pattanayek SK, Karmakar P (2021) Assessment of yield enhancement in cashew (*Anacardium occidentale* L.) by the pollinator sharing effect of magnetic bee-friendly plants in India. Acta Ecologica Sinica. 41(3), 243-252.

Layek U, Das A, Karmakar P (2022) Supplemental stingless bee pollination in fennel (*Foeniculum vulgare* Mill.): An assessment of impacts on native pollinators and crop yield. Frontiers in Sustainable Food Systems. 6, 820264.

Manoj PS, George TE (1993) Heterosis in cashew (*Anacardium occidentale* L.). The Cashew. 7, 7–9.

Northwood PJ (1966) Some observations on flowering and fruit-setting in the cashew, *Anacardium occidentale*. Tropical Agriculture. 43, 35–42.

Olatidoye OP, Akinyemi Shittu T, Olusegun Awonorin S, Akin Ajisegiri ES (2020) Nutritional profile, protein quality, and biological value of raw and roasted cashew kernels (*Anacardium occidentale*) grown in southwest Nigeria. Croatian Journal of Food Science and Technology. 12(1), 11–19.

Pakrah S, Rahemi M, Nabipour A, Zahedzadeh F, Kakavand F, Vahdati K (2021) Sensory and nutritional attributes of Persian walnut kernel influenced by maturity stage, drying method, and cultivar. Journal of Food Processing and Preservation, e15513.

Parameswaran NK, Daramodaran VK, Prabhakaran PV (1984) Factors influencing yield in cashew (*Anacardium occidentale* L.). Indian Cashew Journal. 16, 15–19.

Partap U, Ya T (2012) The human pollinators of fruit crops in Maoxian country, Sichuan, China. Mountain Research and Development. 32(2), 176–186.

Rico R, Bulló M., Salas-Salvadó J (2016) Nutritional composition of raw fresh cashew (*Anacardium occidentale* L.) kernels from different origin. Food science & nutrition. 4(2), 329–338.

Sarikhani S, Vahdati K, Ligterink W (2021) Biochemical properties of superior persian walnut genotypes originated from southwest of Iran. International Journal of Horticultural Science and Technology. 8(1), 13 - 24.

Silva CA, Godoy WA, Jacob CR, Thomas G, Câmara GM, Alves DA (2018) Bee pollination highly improves oil quality in sunflower. Sociobiology. 65(4), 583 - 590.

Smith FG (1958) Beekeeping observations in Tanganyika 1949-1957. Bee World. 39, 29 – 36.

Topper CP, Caligari PDS, Camara M, Diaora S, Djaha A, Coulobay F, Asante AK, Boamah A, Ayodele EA, Adebola PO (2001) Report of the West Africa regional cashew survey covering Guinea, Guinea Bissau, Cote d'Ivore, Ghana and Nigeria. Sustainable Tree Crop Programme Report No.BHA-01109.BiohybridsAgrisystem Ltd. P. O. Box 2411, Earley, Reading RG65FY, UK.