

Does Sodium in Floral Nectar Enhance Pollination & Plant Reproduction?

Max Hunt & Paul CaraDonna

RMBL 2025

Abstract.

This research focused on how increased sodium concentrations in nectar can lead to changes in plant and pollinator interactions. It is widely known that sodium is a limiting nutrient in much of nature; however, how this affects plant and pollinator interactions remains poorly understudied. The main study species is *Delphinium barbeyi*, with the main study sites being beside the Gothic Research Center. Using one control solution and 5 varying sodium concentration solutions on different stalks of a single plant. The goal of the research was to see how different concentrations of sodium in floral nectar influence pollinator visitation and subsequent reproductive output. To date, no study has made the link between sodium in floral nectar and plant reproductive output.

Introduction.

It is widely known that sodium is a limiting nutrient in much of nature, exemplified by cows and other large herbivores that take advantage of salt licks (Duvall et al., 2023), but also for many insects, such as butterflies, mud puddling, or ants... (Lamie et al., 2025; Kaspari et al., 2008). For plants, sodium is not an overly important nutrient—but, for primary consumers, it is vital (Welti et al., 2019). Despite the fact that widespread sodium limitation among animals is well known, we still lack the knowledge of how it affects many interactions (Welti et al., 2019; Kaspari et al., 2008), including those between plants and pollinators which was the focus of this research. To date, the role of sodium in plant-pollinator interactions is understudied. What we do know is that sodium in floral nectar consistently increases pollinator visitation and richness (Finkelstein et al., 2022; VanValkenburg et al., 2024; Kaspari et al., 2008), but it is not clear whether this translates into increased plant reproduction. Therefore, this research investigated how sodium mediates plant-pollinator interactions, and in particular, whether different sodium concentrations in floral nectar enhance pollinator visitation and plant reproductive output. Our hypothesis is based upon previous research, suggesting that increased sodium concentrations in nectar will result in increased plant reproduction.

The lack of research into how sodium affects plant-pollinator interactions was recognized by some researchers who conducted studies on what happens when the amount of sodium in nectar is artificially increased. The results showed that increasing the concentration of sodium in plant nectar via an artificial nectar solution significantly increases the number of visits and the richness of visits that targeted plants receive in

comparison to their controls (Finkelstein et al., 2022; VanValkenburg et al., 2024). But this research collected data pertaining to whether or not these changes cause a difference in visitation, but did not explore how the effect changes over a gradient of sodium concentrations. The tipping point at which sodium concentrations become favorable to pollinators has not yet been precisely quantified. In addition, sodium-influenced changes in plant pollinator interactions may lead to changes in plant fitness (Finkelstein et al., 2022), but this link has not yet been made.

Therefore, the main goal of this research was to test if different concentrations of sodium in nectar would result in changes to pollinator visitation and changes to plant reproduction.

Methods.

I have built upon the general methods of Finkelstein et al. (2020) and VanValkenburg et al. (2024). My study sites were the North side of the Gothic Research Center and by the Gates Cabin. The species that I studied was *Delphinium barbeyi* (Ranunculaceae). In the general study area, I selected 25 similarly sized *D. barbeyi* plants, each with at least 6 flower stalks. I applied at random one of the 6 artificial nectar solutions on each plant and to each of the 6 flower stalks. All nectar solutions mimicked the naturally observed floral nectar sugar content of *D. barbeyi* with ~50% sucrose solution. The six treatments were as follows: (i) control (50% sucrose only), 0.1% sodium, 0.2% sodium, 0.3% sodium, 0.4% sodium, and 0.5% sodium. Note that the naturally observed sodium concentration of *D. barbeyi* is approximately $0.006\% \pm 0.001$; the greatest sodium concentration represents approximately 8x that of naturally occurring sodium in floral nectar (VanValkenburg et al., 2024). To differentiate the 6 stems from one another, twist ties were used with different colored beads to tell the stalks apart, along with corresponding Sharpie marks as a level of redundancy. The colors used were as follows Yellow - Treatment 1(Control 0% Sodium), Blue Treatment 2(0.1% Sodium), Green Treatment 3(0.2% Sodium), Orange Treatment 4(0.3% Sodium), Pink Treatment 5(0.4% Sodium), and Purple Treatment 6(0.5% Sodium). These identification tags were placed at least a foot below the lowest flower to avoid any potential issues with pollinators being attracted to the different bead colors.

Treatment application.

A total of 25 plants were chosen to be part of the research. The flowers on each plant were bagged before they opened. Once every selected stalk on a plant had approximately 10 flowers, the bags were removed for one day. During this exposed day, the artificial nectar solution was applied to the flowers twice, once in the morning and again just before/after midday. Artificial nectar solutions were added on top of existing

nectar crops. Each plant was observed for three 10-minute periods on its exposed day at appropriate times for proper pollinator activity. After one day of available pollination, all selected stems on each exposed plant were bagged again. These bags were only removed after the flowers of every selected stem of the plant went to seed. The stalks for each treatment on every plant will be picked randomly to avoid bias. With the control and different treatments all happening on the same plant, it helped eliminate potential variables you would run into with having them on separate plants. Visitation is recorded in both the number of pollinator visits a stalk receives and the duration of each visit. When it was possible, observation occurred immediately after a plant's application was completed. This observation period was feasible for the midday application; however, it was not reasonable for the early morning applications, as the majority of pollinators are not active at this point in time. As such, morning visitation observation was done later on in the morning when the majority of pollinators are active. To achieve 3 observations, a second round was done after the completion of the first set of afternoon observations. The stalks on each plant were rebagged in the evening, generally 5-7 pm or later, depending on whether the second application happened before or after noon.

Plant reproduction.

The collection of fruits and counting of seeds is an ongoing process. However, fruits were first counted by stalk on each plant, and a fruit was recorded if it was healthy-looking and seemed like it would have matured fine if it had been allowed to continue growing. The fruits were then harvested from each stalk of every plant to be stored in plant/stem labeled zip-lock bags until they can be processed. To count the seeds, the fruits were carefully broken open, and the number of seeds inside was counted and recorded. Splitting the seed category into large or small seeds.



Study area, with outline in blue with individual plants represented as green dots. Top down view of the area just outside of the Gothic Research Center and Gates Cabin.

Results.

Overall, we observed 21 plants over the course of 3 weeks. With 60 total observation sessions and over 130 pollinator exclusion bags used. We observed several different pollinators foraging from our experimental *Delphinium barbeyi* plants, including bumblebees, hummingbirds, and flies of multiple species. The most common pollinators were bumble bees.

Pollinator visitation.

Across our six experimental nectar treatments, mean visitation was relatively similar and we did not observe statistically significant differences (Fig. 1; Negative Binomial GLM: chi-square = 1.956; d.f. = 5; $P = 0.855$).

Fruit and seed set.

Seed set results are pending. (Fig. 2 it is likely that unintentionally collected fruits from flowers that were not treated. However, because this was done consistently, we still conducted a preliminary examination of the fruit set in response to treatment.) Based on figure 2, we did not observe any significant patterns within the fruit set among the varying floral nectar treatments.

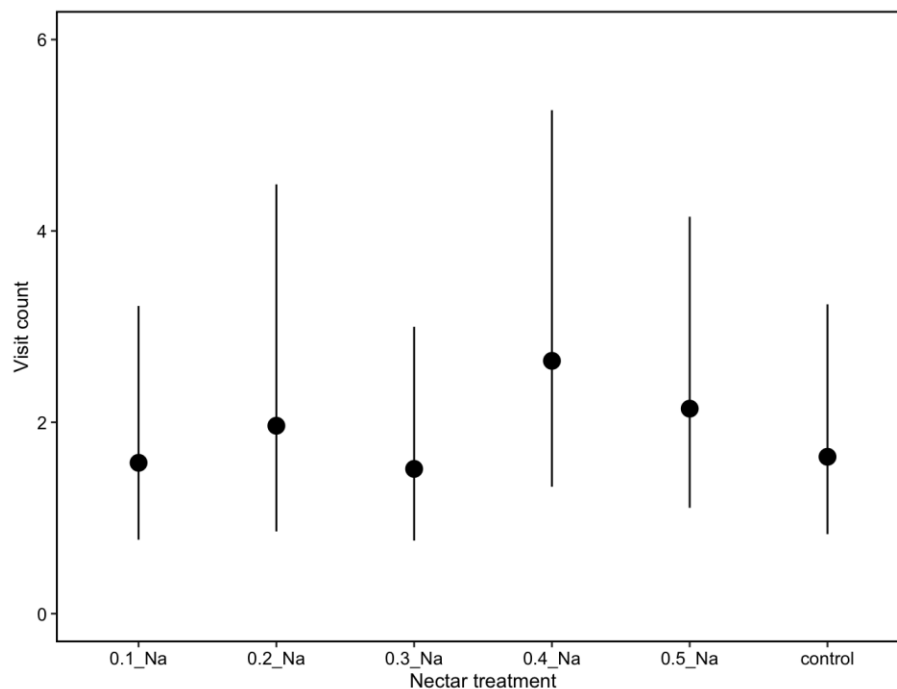


Figure 1. Variation in pollinator visitation across the six experimental sodium nectar treatments. Control on the far right and the 5 varying solutions of sodium concentration going from 0.1% to 0.5% Sodium concentration on the left.

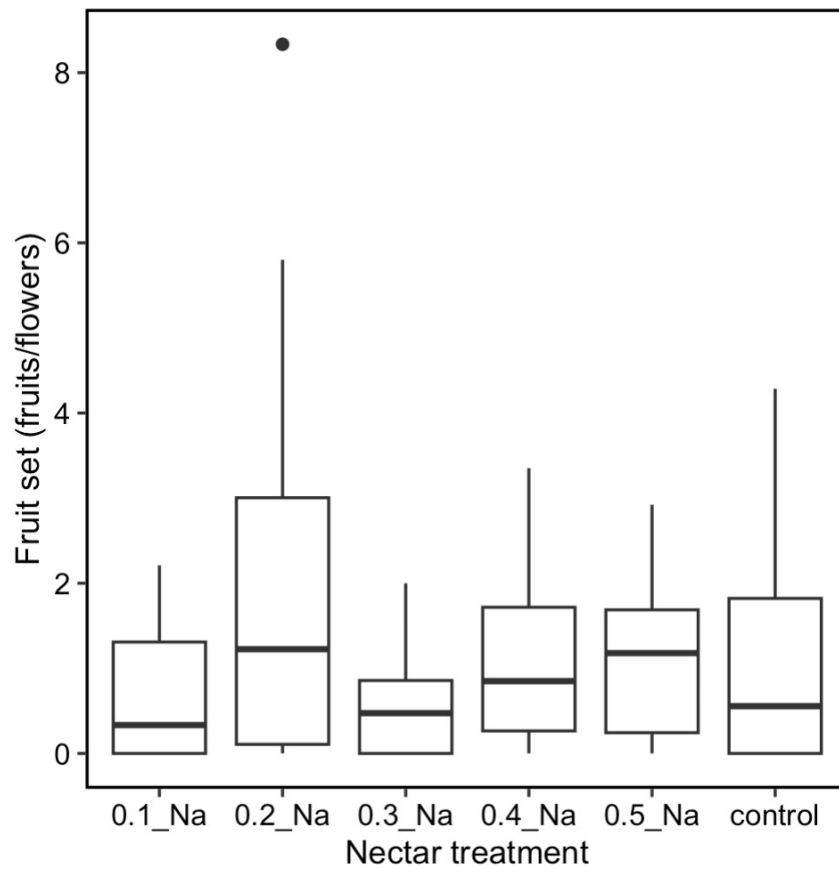


Figure 2. Variation in fruit count across the six experimental sodium nectar treatments. Control on the far right and the 5 varying solutions of sodium concentration going from 0.1% to 0.5% Sodium concentration on the left.

Discussion.

The importance of sodium as it relates to plant-pollinator interactions is still developing. There is compelling evidence to suggest that variation in the sodium concentrations in floral nectar influences aspects of pollinator visitation (Finkelstein et al. 2021; VanValkenburg et al. 2024), but it has remained unclear whether this translates into an effect on plant reproduction, which this study set out to investigate.

First, we did not find evidence consistent with either of our hypotheses: we did not observe variation in pollinator visitation across any of our sodium nectar treatments (Figure 1; plant reproduction data pending). The lack of significant trends, however, is suspected to be due to not having enough visitation data. More specifically, by focusing on individual stalks nested within plants—instead of entire plants—we ended up with limited visitation. As a result, too many zeros flooded the data sheet and made it difficult to sort statistically significant trends from the data. In terms of the visitation data, we found support for the null hypothesis that there was not a statistical differences among sodium nectar treatments, and we rejected the hypothesis that the greater the sodium concentration in the solutions the greater the pollinator visitation and reproductive output would be. We suspect this is due to there not being enough visitation as a whole. The previous study conducted at RMBL used entire plants for visitation data (VanValkenburg et al., 2024). However, this previous project used a control and a single increased sodium solution, as it would have been logistically unfeasible to apply several treatments to groups of plants for that project. We instead used 6 stalks on each plant. This allowed for treatments to be nested within single plant (i.e., in experimental blocks) and it also had the logistical benefit that a single person to do the majority of the labor for the project while having 6 different solutions. This choice—although seemingly clever at the outset—unfortunately meant that in the end, there was not enough visitation data to see significant differences between concentrations.

Our results do not mean that there were no effects from the varying treatments, just that, as a result of how we designed the project, we were unable to observe a pattern given the data. Some separate reasons for this lack of patterns include: From our many observations, it seemed that the stem position on the plant mattered significantly. As many bees and other pollinators would take roughly similar paths flying through or around the plants. So if a stem happened to be in a convenient location, it could get more visitation, seemingly no matter the concentration of solution it was receiving. This factor was even further complicated by the fact that on many occasions these paths

were rather random and did not always seem to follow what many would assume to be the most logical way through the plants. The pollinator exclusion bags also, in many cases, squished and caused other harm to the stalks, consequently creating the possibility that pollinators would choose unmarred flowers over the chosen stalks.

Fruit and Seed Set.

The seed set is currently still being processed; however, we do have preliminary results for the fruit set. Fruits were counted on each plant by stalk. The results are similar to the visitation data in that there are no significant trends within it. This result is also likely due to there not being enough data overall, and unfortunately, it is not entirely reflective of the number of flowers that received a solution. As fruit data was collected using entire stalks, which did not take into account which flowers had an application applied to them.

Future directions.

We would suggest using entire plants for each solution being tested to get the necessary amount of visitation data. We also recommend choosing an alternative pollinator exclusion method that is not pollinator exclusion bags on top of stalks. These bags lead to damage to the stalks and flowers, while in some cases causing stalks to collapse to the ground from the headweight of the bags. A possible alternative would be using full plant covering structures that isolate the entire plant while allowing it to be anchored and sitting upon the ground to keep any weight off the plant. This structure would allow for pollinator exclusion without harming the plant in any way. Another suggestion would be to allow the plants to be pollinated for more than a single day, as unfortunately, this resulted in many flowers not getting enough pollination. This severely impacted the fruit set and did so rather unevenly. We would also recommend using some way to keep track of individual flowers that were pollinated during the application and observation period. A new sort of tracking is also needed so when it is time to count and collect fruit for the fruit and seed counts, only flowers that have had applications done to them should be included to avoid muddling the data.

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