Chapter

Technological Development in the Use of *Allium sativum* Aqueous Extracts in the Agricultural Field

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Abstract

The advance in agricultural technology could increase their commercialization, being the agronomic management for each crop an alternative. The management of natural products is a relevant and responsible need, in order to improve the quality and production of food, and to protect the agro-ecosystem biodiversity. Therefore, the aim of this chapter is to present our five-year study advances in mango and rambutan agronomic management with aqueous extract of *Allium sativum* and the use of natural adherent such as *Melipona solani* honey that improves the function of the components in the biological processes of the crop. Our results showed that this aqueous extract promotes the emission of vegetative and floral shoots, increases flower development, works as an attractant for pollinators, promotes fruit set, stimulates fruit growth, acts as an insecticide to control thrips and mealybugs and stimulates the production of defense metabolites, such as polyphenol compounds. The use of stingless bee honey as an adherent and the aqueous extract of *A. sativum* could be a key to potentiate the function of its components in leaves, panicles, flowers and fruits.

Keywords: aqueous extract, flowering, growth, pest control, metabolites

1. Introduction

Agronomic management in agricultural maintenance and production varies depending on the type of crop, where improvements or the inclusion of new technologies are already an important need. Development is constant and from twenty years ago to our time, each of the areas of agricultural production has been automating. These constant improvements not only refer to machinery such as a seeder, a sprinkler system, a fruit sorting machine, greenhouse production, among others, it also includes new biological processes and products, such as bio-fertilizers, bioles, leachates, antimicrobial strains among others, that improve the properties of the crops and enrich physicochemically the tissues or increase the generation of fruits; which also given an extra plus to each agricultural product [1, 2].

All the new agricultural technologies with unprecedented innovations push the process of globalization and the integration of commercial blocs, generating new income in all trade areas: national and international. These natural and organic products have generated a continuous offer of renewed, innovative products with new expectations of use or worldwide application. These changes have modified the traditional ways of carrying out agricultural activity, in its production, transformation and commercialization phases [1, 3, 4].

Technological development, as a basis for improving and safeguarding the integrity of field products, is emerging as an alternative with potential use or application to increase production, jointly reducing costs and environmental impact [5–7]. Thus, the use of vegetable extracts from plants is regaining importance, in addition of already demonstrated its functionality for presenting a variety of proven properties in the medical, veterinary, food and cosmetic areas, for being of a biological, vegetable and non-vegetable nature to be generated synthetically, and not generate toxicity to plants, animals and humans [7–9].

1.1 Importance of aqueous extracts of *Allium sativum*

Medicinal plants are a generating source of plant extracts with different and important uses, due to their bioactive components. There is a variation in its concentration and in the type and variety of compounds contained in each elaborated extract. The *A. sativum* aqueous extract contains mainly sugars, nitrogenous mineral substances and essential oils, in which there are bioactive sulfur substances such as allicin and other allyl sulfides responsible for their chemical qualities [10].

The properties discovered in *A. sativum* are attributed to its components, such as amino acids, minerals, vitamins, pantothenic acid, folic acid, niacin, among other compounds that present specific activities and that have provided much interest in the scientific areas of the medical, nutritional, cosmetic, agricultural areas, etc. [11]. The properties that *A. sativum* are used depending on the extraction process, generally considering two types of solvents, polar and non-polar, considering water separately [12].

The components extracted by polar solvents differ from those obtained by non-polar solvents, including whether the process (heat or not). The variation obtained between these types of extract is presented in the quantities obtained, the color of the extract, odor and the activity it exerts on the applied biological models [12–14].

In alcoholic extractions or with non-polar solvents, it is essential to eliminate these solvents and obtain only the dissolved compounds in them, leaving a liquid with a higher viscosity, dark in color, called crude extract [15]. This type of procedure is common in the industrial area, for the generation of commercial products, where one of the disadvantages is that certain molecules are susceptible to high temperatures, drastic temperature variations, the presence of sunlight and a lack of water in the environment [16, 17]. Therefore, this is a disadvantage when used in healing processes in the presence of light, environments above 25°C and excess air currents, considering both animal skin, human beings and solutions and the pH value presented for each case.

Aqueous extracts had less importance due to the lack of use and information that exposes the properties that an aqueous extraction has and the properties, such as benefits, both in medicinal use and in other areas [12, 18, 19]. In addition, all the components that are reported with alcoholic extractions are normally polar and can be extracted with water by the infusion method, without losing their activity, because these molecules support within their chemical limits the heat being the maximum temperature, that of boiling, being called thermoresistant [11, 18, 20]. The importance at the agricultural level of the use of plant extracts is reconsidered and is increasing, due to the risk that agrochemical mean to agroecosystem biodiversity and in particular to pollinators, which are toxic also for human being [20–22].

The purpose of this chapter is to show the results of new technological development during five study years with *A. sativum* aqueous extracts and stingless bee honey as an adherent in two of the most economically important crops in the Soconusco region in Mexico: rambutan (*Nephelium lappaceum*) and mango Ataulfo (*Mangifera indica*).

2. Applications of the aqueous extracts of *A. sativum* in agricultural crops

Recent studies showed that aqueous extracts have a variety of uses in the agronomic management of an agricultural crop, due to their physicochemical properties. These extracts can be used in recent preparations or after having undergone a natural fermentation process. Its potential for use is also increased by being mixed with other synthetic, natural or microbial products.

In particular for fruit trees, specifically in mango cultivation and rambutan, this has become important for presenting biological action in these crops as: a) Floral inducer, b) Increase in fruit setting, c) Fruit growth and d) Pesticide.

The applications indicated in this chapter have been under research development at the field level in commercial farms in areas with two dominant annual seasons, hot and rainy. It was also accompanied by the evaluation of total phenolic compounds, number of panicles, number of flowers formed, number of fruits per panicle, growth dynamics of the fruits and the number of pest insects per panicle.

Location of commercial properties. The geographical locations of the properties provided are placed, with an area of 1 ha as a minimum and 2.5 ha as a maximum, according to the planting distribution of the trees.

In mango it was the "San Juan" orchard in the ejido de viva México on the coastal highway Km 227.5 (Lat. 14°54′25.0"N, Lon. 92°17′43.0"W) in Tapachula, Chiapas, Mexico.

In rambutan it was in the "Toluquita" Canton in the Municipality of Tapachula, Chiapas, Mexico (14° 58′13.001′′ N, 92° 14′2′′ W).

Preparation of the aqueous extract. The elaboration of *A. sativum* aqueous extract was carried out according to what was reported by Bustamante [23], considering a ratio of 1 kilograms of garlic in four liters of water (1: 5), and after extraction with hot water, the rest time of 24 hours at room temperature was adjusted, prior to its application in the manual spray pumps used.

Before applying any solution, the pH value was measured with a portable manual potentiometer for the field, of the undiluted extract and after making the application mixture.

Adherent used. In order to improve the effect of the aqueous extract, a test was carried out with two types of adherent: a synthetic (Inex A ®) and a natural, which was *Melipona solani* honey. The first adherent was used at a concentration of 1.5 mL per 20 liters of water and the second one was 15 mL per 15 liters of water, both separately. A treatment without adherent was used in each fruit crop.

Evaluation of variables in the field. The number of floral buds, number of flowers, number of fruits, fruit size (with vernier), total polyphenolic compounds and presence of pest insects (in the field with a rambután magnifying glass and by

Concentrations	Action	Crop	Control *
1.25% v/v	Floral inducer	Mango	Potassium nitrate
2.5% v/v	Floral inducer	Rambután	Calcinit
2.5% v/v	Fruit set	Mango	Comercial amino acids
2.5% v/v	Fruit set	Rambután	FusióN-H
1.25% v/v	Fruit growth	Mango	SpeleR-K + FusióN-H.
1.25% v/v	Fruit growth	Rambután	Fusión H
10% v/v	Pesticide	Mango	Malathión
10% v/v	Pesticide	Rambután	Cypermethrin

**information provided by each producer. The applications were made from 7:00 to 11:00 am, evaluating the pH of the water in each property.*

Table 1.
Concentrations of aqueous extract of A. sativum for each agricultural action in the agronomic management of the two crops studied.

the table technique dark for thrips), it was carried out by dividing the orchard of each tree into four zones, selecting three panicles per zone, according to Gonzales and Quiñones [24]. The evaluations were carried out every week, during the time that the study lasted and the permanence of production of the fruits until their harvest.

Efficient concentrations used. According to the type of action expected by the *A. sativum* aqueous extract, the minimum concentrations to achieve the desired objective were the following (**Table 1**):

Phenols content evaluation. To obtain phenols, the sample of the main branch of the panicles was rested in a methanol-water solution (1:1). The total phenol content was determined by using the Garrido [25] technique. The Folin-Ciocalteu reagent diluted 1:10 with water and 0.7 M sodium carbonate was used. It was kept in total darkness for 15 min and was read in a spectrophotometer at 765 nm. Methanol-water (1:1) was used as blank. A calibration curve was made with gallic acid at different concentrations in methanol-water solution: 0, 10, 50, 100, 150 and 250 mg L-1. Reported in mg EGA/gr.

Catching bees. The collections of the bees were carried out with aerial entomological nets by beating [26], the collection was carried out in the orchard zone of the mango tree and the collections were made from one day before the application and until six days after applying the treatments. The captured bees were mounted on pins, in an entomological box. Taxonomic identification was carried out in the ECOSUR Bee Team, San Cristóbal de las Casas unit, Chiapas.

Analysis of results. All the variables evaluated were analyzed with analysis of variance and a comparison of means was made by Tukey (0.05), accompanied by a Pearson correlation, in the Infostat program, 2019.

3. Results and discussions

3.1 Flowering stage

The application of the *A. sativum* aqueous extract with or without adherent promoted the induction of vegetative shoots and transformation to floral shoots in rambutan culture and emission of floral shoots in mango, one week before the application of Calcinit in rambutan and potassium nitrate in mango (**Figures 1–3**).

Using *A. sativum* aqueous extract accompanied by Inex A promoted a value of 29.8% of vegetative shoots transformed into floral shoots and this value was lower than that obtained when honey was used as an adherent (44.15% of vegetative shoots transformed into floral) or not used any type of adherent (41.6% transformation to floral bud). These last values were close to what was observed with Calcinit (44.2%). A maximum transformation value from vegetative shoots to floral shoots was observed in rambután when Inex A and honey were used, two weeks before the calcinit treatment.

In the mango crop, the emission of floral buds with *A. sativum* aqueous extract compared with the use of potassium nitrate, it was 58.77% lower when no type of adherent was used, 16.32% lower when using Inex A as adherent and 2.44% less when using honey. In this culture when the aqueous extract was used, the maximum emission of floral buds was observed one week earlier than that presented in the treatment with potassium nitrate.

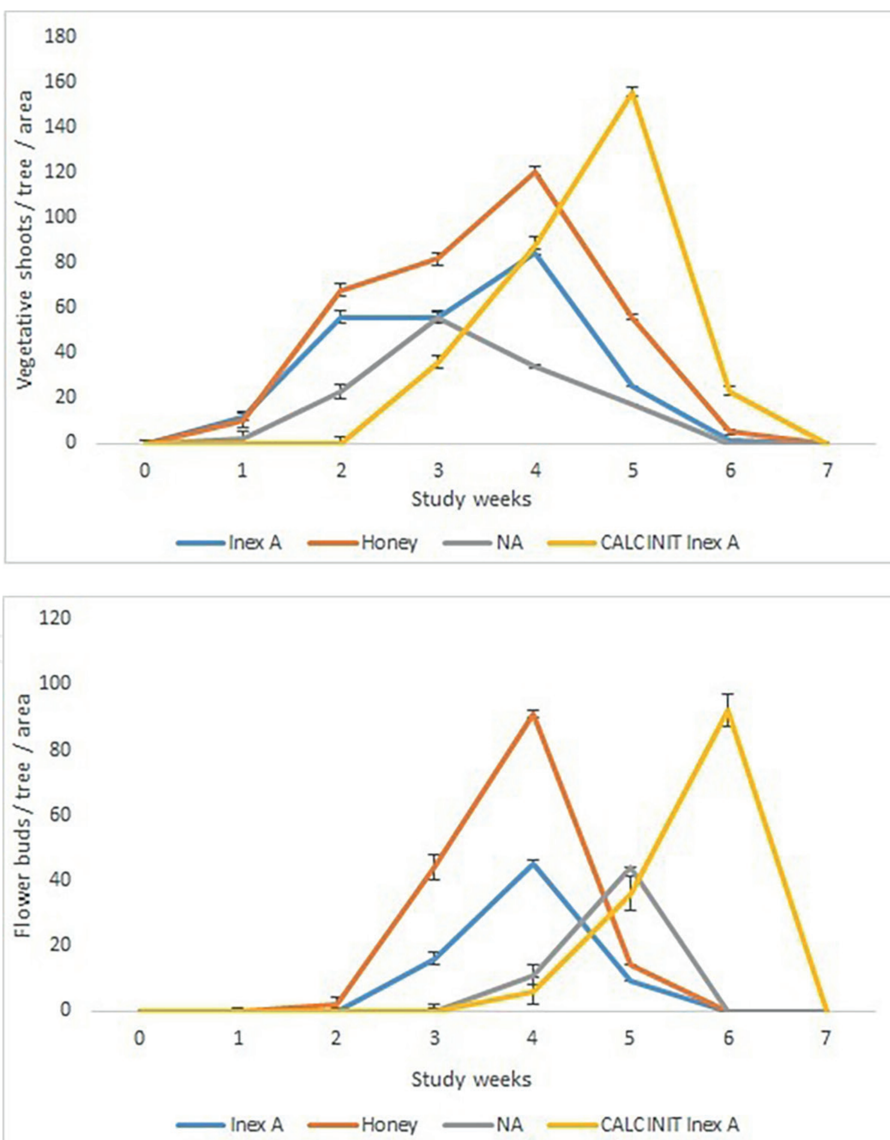


Figure 1.
Dynamics of vegetative shoots (A) and floral shoots (B) that were emitted in the rambután crop (NA: Without adherent).

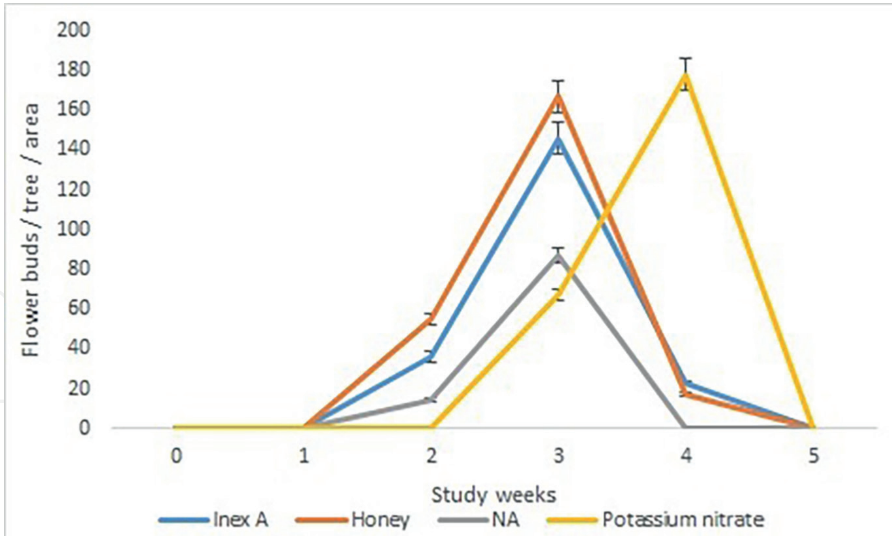


Figure 2.
Dynamics of flower buds emitted in the mango crop (NA: Without adherent).

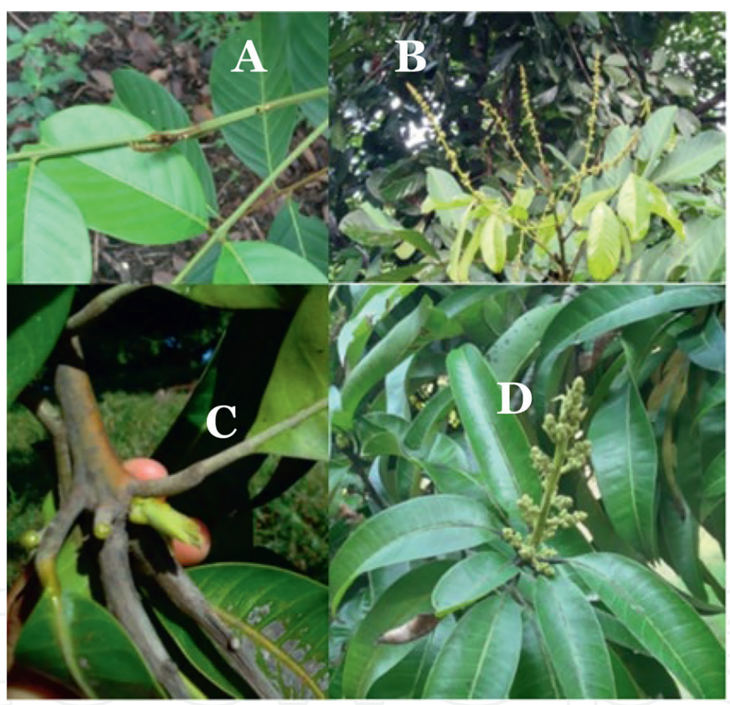


Figure 3.
Images of vegetative to floral shoots in rambután and floral shoots of mango (A: Vegetative shoot in rambután, B: Vegetative shoot transformed into floral shoot in rambután, C: Shoot in mango, D: Growing mango panicle).

Statistically, there were significant differences between the treatments and between the study weeks, in both crops ($p < 0.05$).

These results suggest that when the *A. sativum* extract gets in contact with branches and leaves of both crops, acted as flower bud elicitors [8, 27]. Nonetheless, in mango crop this effect was rapid, unlike in the rambutan crop, where the generation of vegetative shoots was first stimulated before differentiation into floral shoots. The breaking of the abiotic stress in both crops was stimulated by the water factor which synchronized the vegetative and floral induction [28] and the biotic stress was influenced by the components of the plant extract, which were in sufficient quantities

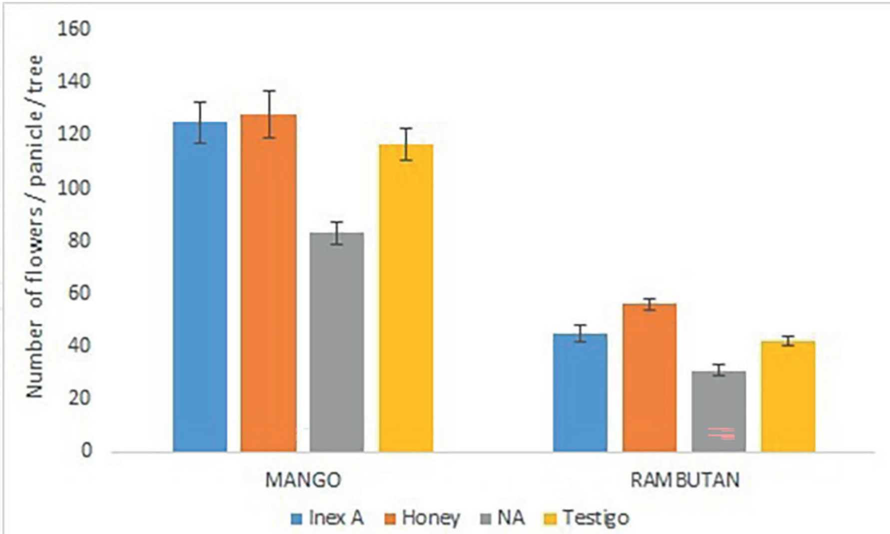


Figure 4.
Number of flowers formed in the mango and rambután culture (NA: Without adherent, control: in the mango culture it was potassium nitrate and in rambután it was Calcinit).

to reach and act as regulators of the metabolism and plant physiology of each tree after coming into contact with their tissue [29–31]. This differs from the nutritional imbalance induced by the agrochemicals used by producers at the foliar level, since they generated accumulation of nitrates in the leaves [28].

The results obtained in mango and rambutan when using *A. sativum* aqueous extract were a joint effect between the aqueous extract and the type of adherent incorporated into the applied solution. Both honey and Inex A acted as adjuvants and favored the penetration of the components of the *A. sativum* aqueous extract, by increasing cuticular permeability in the leaves [32]. When no type of adherent was used, the penetration of the extract components was less efficient, because the increase in permeability in the cuticle that protects the leaves was not facilitated [33], observing less shoot emission vegetative and floral.

After the stage of floral buds, the development of the flowers in the panicles of both mango and rambután is shown in **Figure 4**. A minimum of flowers was observed in the aqueous extract where no type of adherent was included, in both crops. Despite the fact that the values of the number of flowers formed with *Allium sativum* aqueous extracts in both crops were similar to those obtained with the chemical compound used to promote flowering, the percentage differences indicate that 6.8% and 9.4% more flowers can be generated of rambután and in mango of 7.14% and 33.33%, when including Inex A and honey to the solution, respectively. This is not related to the fact that there is more frequency of fruit set and it is necessary to study the fertility capacity and strength of the ovaries formed by the female flower in the future.

During flower formation, a variety of metabolic events occur that involve a varied production of secondary metabolites involved in the generation of floral hormones, osmotic pressure and ovary biogenesis [34–36]. The *A. sativum* extract stimulated the generation and formation of the rambután and mango flower, in the panicles produced by the components that were dissolved in the aqueous part, and according to Yakin [35] and Venegas-Gonzáles [37], these compounds provide energy, organic molecules that function as metabolic cofactors and elicitors, for the generation and maturation of the flower. Our results agree with the report by Ariza-Flores [36], who indicates that exogenous molecules act as biostimulants, where their rapid or delayed

Species	*Allium sativum* + Honey	*A. sativum*	A. sativum + Inex A	Potassium nitrate
Apis mellifera	8	8	1	4
Oxytrigona mediofura	0	0	0	1
Tetragonisca angustula	0	1	0	0
Trigona fulviventis	6	4	2	1
Trigona fuscipenis	8	2	3	1
Trigona nigerrimia	5	4	3	3

Table 2.
Average number of bee species found in the floral panicles of the mango crop, for each treatment of A. sativum extract (Honey: M. solani honey).

action depends on the concentration applied and absorbed in plant tissue. In this last aspect, the substance included in the final solution, before applying, plays an important role on the efficiency of the aqueous plant extract.

The application of the garlic extract in the mango crop, with Inex A, honey and without adherent, presented on average a higher number of pollinating bees compared to the number found in the treatment that only received potassium nitrate (**Table 2**). The commercial species *Apis mellifera* was the one that had the greatest presence in the mango flowers, observing a double value where honey was used and without adherent, compared to the chemical treatment. The aqueous extract added with Inex A, presented the lowest number of this bee species. The difference between treatments was highly significant ($p < 0.0001$).

The other bee species belong to the Meliponine group and are considered floral visitors, and are recognized as part of the ecosystem services that occur within agroecosystems with reduced environmental damage [38, 39]. The other species were also found in greater numbers in the extracts of *Allium sativum* with and without adherent, compared to the control treatment, standing out the extract of *A. sativum* with honey.

It has been reported that sulfide derivatives such as diethyl sulfide and propyl disulfide, including terpene derivatives, have an attractive action on bees [40, 41]. These compounds are similar to what is contained in the extract of *A. sativum*, according to what was reported by Yakin [35] and Duran [10]. The inclusion of honey in the plant extract strongly favored the attraction of bees or other pollinators, as reported by studies carried out by Kumari and Rana [38], Wankhede [42] and Pashte [43].

3.2 Fruit set

After flowering, the formation of fruits occurred and two stages were considered, one of them being before abscission and the second is after abscission.

In the first stage, in both crops a lower number of fruits was observed than in the treatments applied with a chemical product and in decreasing order according to the adherent included or without it (**Figures 5** and **6**). The percentages of differences calculated between the extract and the chemical product used, according to the binder included or without it, for each culture were: 6.25%, 12.5% and 35.4% in Inex A, honey and without binder, respectively in rambután and 3.4%., 18.9% and 37.9% of Inex A, honey and without adherent, respectively, in mango cultivation. The differences between the treatments were significant ($p < 0.05$).

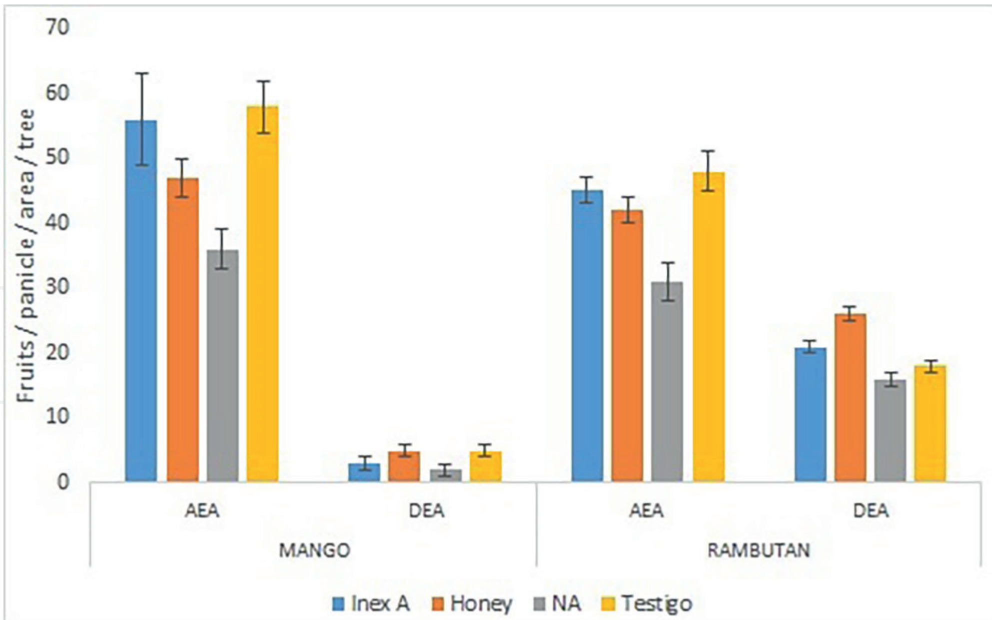


Figure 5.
Number of tied fruits in the mango and rambután crops (NA: Without adherent, control: in the mango crop it was with amino acids and in rambután it was Fusio N-H, AEA: Before the fruit abscission stage, DEA: After the stage of abscission of fruits).

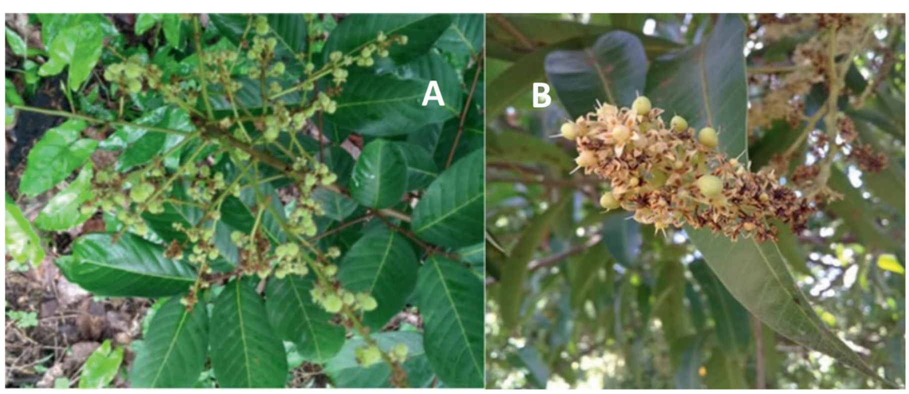


Figure 6.
Fruit set before the abscission phase (A: Panicle with rambután fruits, B: Panicle with mango fruits).

In the second stage, after fruit abscission, it was observed that in the mango crop the number of fruits with definitive mooring was lower than that found in rambutan trees, regardless of the treatment. The percentage of definitive tied fruits per crop, calculated, were: 46.66%, 61.9% and 51.6% when Inex A, honey and no adherent were added, respectively, in the rambutan crop, and in the mango crop they were: 5.35%., 10.63% and 5.55% when Inex A, Honey and without adherent are added, respectively.

Only in the mango crop, when adding honey as an adherent, 2% more filled and harvested fruits were obtained, when compared with the control treatment (8.6%), where amino acids were applied. In the rambutan crop, a minimum of 9% (with Inex A) and a maximum of 24% (with honey) were obtained, more than tied fruits compared to the addition of the Fusio N-H product, in which the percentage of fruits produced was 37.5%.

In the fruit set, Ramírez-Luna [44] indicated that the components that stimulate the fertilization of the ovaries, the elongation of the pollen tube, the cell division and elongation that will generate the fruit are pantothenic acid, folic acid, macro- and micro-nutrients and amino acids. The *A. sativum* aqueous extract, with or without type of adherent, favored fruit set where possibly the components extracted in the elaboration process and those that penetrated the cuticle of the leaves of the trees were sufficient to stimulate metabolic activity and strengthen the process. The foregoing is sustained according to the report by Duran [10] and Ramírez-Concepción [9] who report the components that *A. sativum* has and those found in an aqueous extract, which are sugars, nitrogenous mineral substances, sulfur amino acids, vitamins, folic acid, pantothenic acid, niacin, polyphenols with antioxidant and antimicrobial activities, among others.

The abscission stage in fruit crops is a strategy that trees present to determine which fruits they can sustain, according to the nutritional capacity they present and the production of photoassimilates during the entire process of photosynthesis that supports the constant fruit growth [45, 46]. At this stage, the *A. sativum* extract received in the leaves and the type of adherent included in the mixture made it possible to amortize the effect of the abortion stage, where the components of the extract, received from the leaves, provided nutrients and inducing substances, among others, and including the nutritional capacity that the trees of each crop received before the anthesis stage, played a preponderant role in sustaining the growth of the fruits.

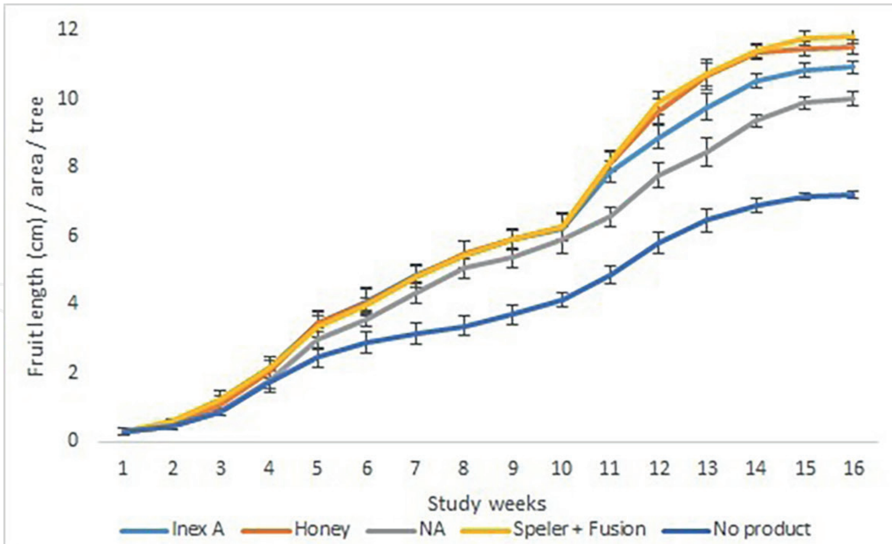
3.3 Fruit growth dynamics

The growth of the mango and rambutan fruits during a period of 16 weeks, without any growth stimulant, presented dynamics with lower growth and the size of the fruits was smaller than those obtained with the garlic extract, which received Inex A, honey and without adherent (**Figure 7**).

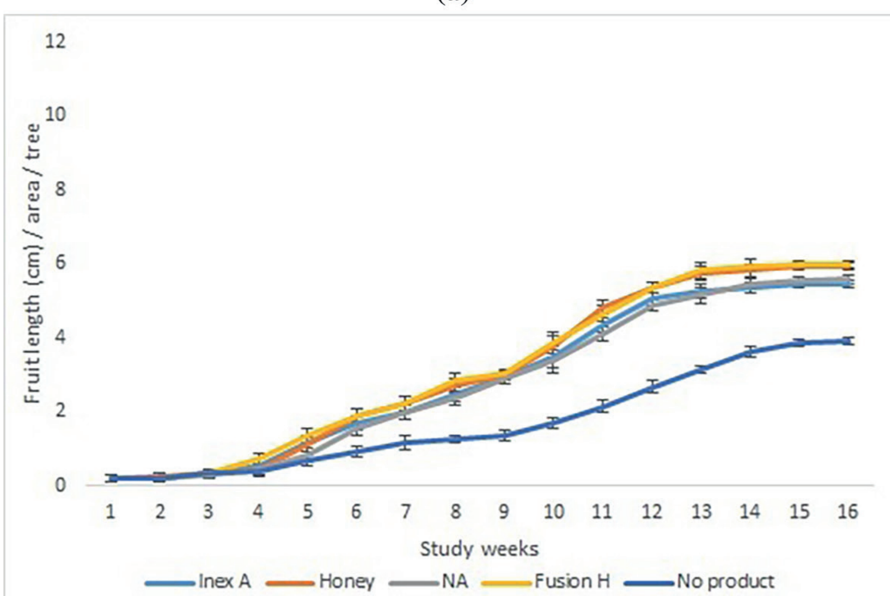
The application of SpeleR-K + Fusió N-H in mango and Fusió N-H in rambutan generated growth induction through cell division and fruit elongation, specifically in the third (21 days) and ninth week (63 days). These weeks are a key in the growth of both fruits, as they denote physicochemical changes and high activity in cell division that influence the elongation of the fruits. According to Caballero-Pérez [47], the first 68 days are a key for the longitudinal growth of rambutan fruits and Pérez and Barraza [48], indicated that the first 70 days of fruit growth after anthesis are key to obtaining good fruit size, and for this reason growth stimulation is recommended on these days, with inducing products that improve metabolism and promote cell division and elongation.

After each application of aqueous extract of *A sativum* in week 3 and 9, the effect was observed the following week, inducing elongation of the mango and rambután fruits. This response was similar to chemical treatment. From week 5, in both fruit trees, it was observed that the *Allium sativum* aqueous extract that did not include any type of adherent to the growth dynamics of the fruit presented lower values. Something similar was observed when Inex A was included, in the aqueous extract, in rambutan fruits. In mango fruits, a reduction in growth dynamics was observed two weeks after the second application. Only when honey was included in the aqueous extract solution, the growth dynamics was completely similar to the treatment that received the chemical product, reaching fruit sizes that differed by 0.5 cm between them. The difference between treatments was significant ($p < 0.05$).

The dynamics presented in the rambutan fruit, for each extract, allowed to see three growth stages (**Figure 7**) unlike what Caballero-Pérez [47] reports and in the mango fruits the dynamics are similar, for which follows that there are also three stages. It is proposed that the three stages are divided according to the stages reported by Martijn ten Hoopen [49], differentiated in times, where from day 1 to day 28 (week



(a)



(b)

Figure 7.
Dynamics of fruit growth in the mango (A) and rambután (B) crop (NA: Without adherent, control: in the mango crop it was with SpeleR-K + Fusio N-H and in rambután it was Fusió N-H, none: non-product was applied).

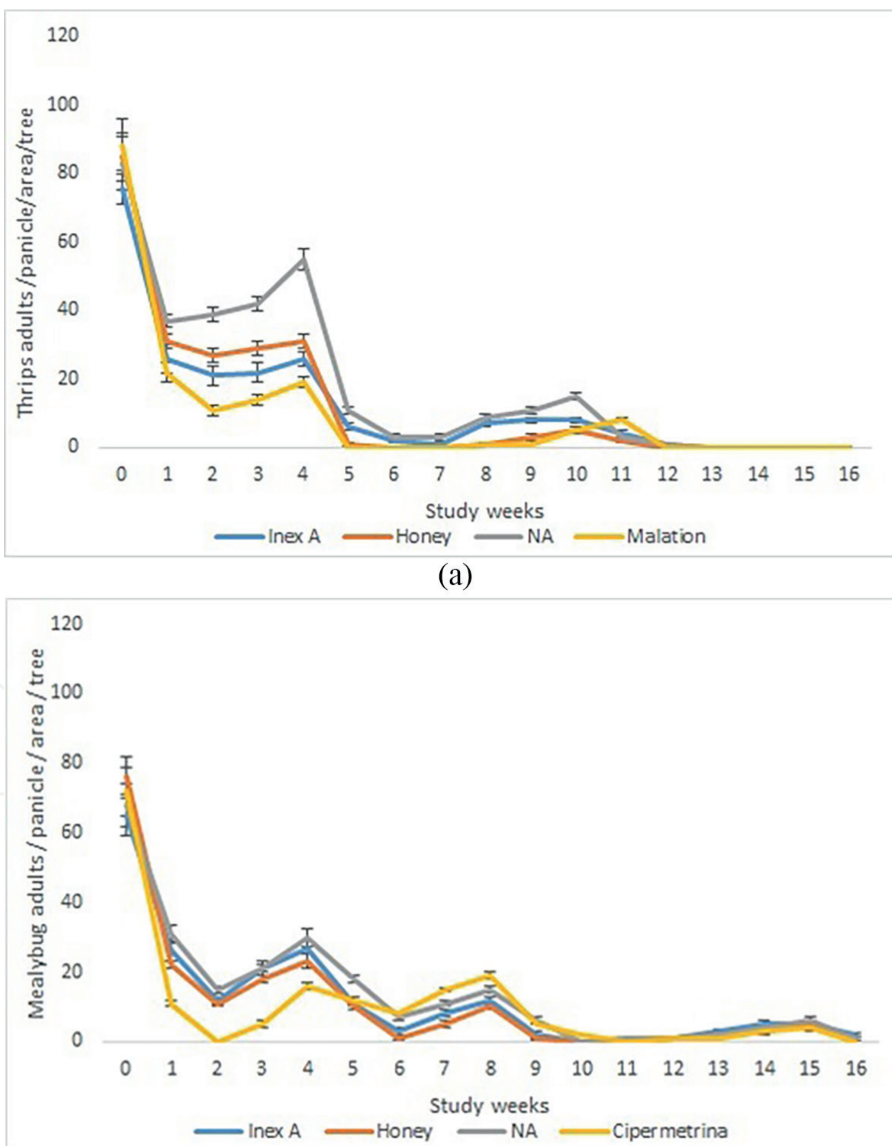
4), is that of cell division and it is when the embryos are not yet growing, from day 29 to 70 (week 10) is the stage of cell elongation and the development of the embryo to generate the seed occurs, and the last stage from day 71 to day 112 or 120 (week 16 or 17), consists of the ripening of the fruit before harvest.

The components present in the aqueous extract stimulated the development of stage 2, which corresponds to cell elongation, and induce stage 3, which corresponds to cell differentiation and tree maturity. This effect of elongation at two different moments in the observed dynamics is related to the nutritive capacity of the tree, the production of photo-assimilated in the leaves and the transport of these to the fruits, to support their growth [45, 46].

The stimulation provided by the components contained in the *A. sativum* extract (sugars, nitrogenous mineral substances, sulfur amino acids, vitamins, folic acid, pantothenic acid, niacin, polyphenols, among others) [9], which was favored by the adjuvant that allowed these components to pass through the cuticle of the fruits, were inducers of cell elongation and division in stage two. According to Caballero-Pérez [47], in the growth stage that involves division and expansion, there is competition for carbohydrate sources, according to Pérez-Barraza [48], during the cell expansion of the fruit metabolic components are needed to synthesize hormones and compounds that allow the generation of tissue, and Elakbawy [50], indicates that organic compounds from plant sources, exogenous or endogenous to the tissue influence physiological processes that control cell division and the differentiation of the growth process, in which cell elongation is involved, finding the participation of sulfur amino acids, auxins and cytokinins.

3.4 Pest control

After the first application, the thrips population was reduced by 65.78%, 63.52%, 55.42% and 75% with *Allium sativum* extract mixed with Inex A, honey, without



(a)

(b)

Figure 8.
Dynamics of adults of thrips in the mango crop (A) and of mealybugs in rambután (B) (NA: Without adherent, control: in the mango crop it was with malathion and in rambután it was cypermethrin).

adherent and chemical, respectively, in mango cultivation (**Figure 8a**). In rambutan, the reduction of the mealybug population was 60%, 71.05%, 54.41% and 84.7% with *A. sativum* extract including Inex A adherent, honey, without adherent and the chemical product, respectively (**Figure 8b**).

Subsequently, in both crops, the population of pest insects gradually increases in week 3 and 4, regardless of the adherent or without it. After the second application, in week 4, 31.57%, 36.47%, 40.96% and 25.0% more were reduced in the mango crop with the *A. sativum* extract mixed with Inex A, honey, without adherent and the chemical product, and in the cultivation of rambutan, a reduction of 35.38%, 27.63%, 35.29% and 4.16% more was with the *A. sativum* extract that was mixed with Inex A, honey, without adherent and the chemical product used by the producer.

The population dynamics in week 7 and 8 show an increase in the number of individuals of both pest insects. After the third application of the aqueous extract, in the mango crop, no thrips insect was found in the trees, unlike the rambután crop, where the population gradually increases until week 15 and after week 16, when it starts fruit harvest, no mealybugs were found.

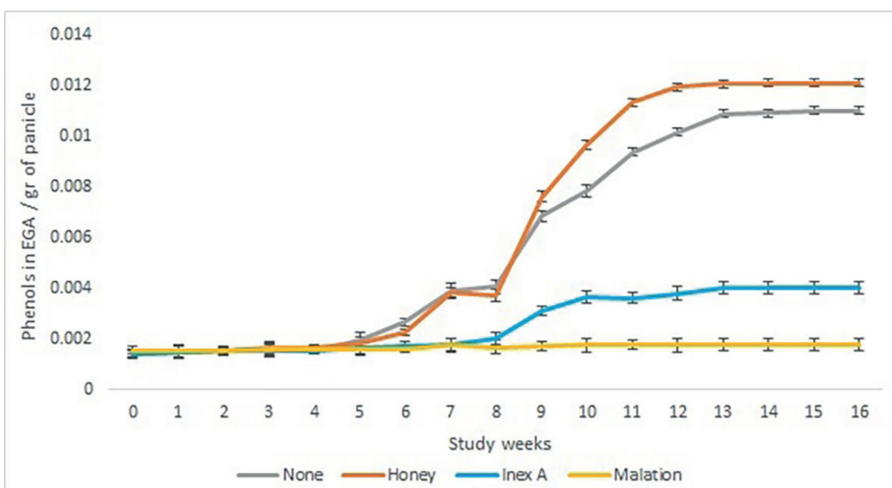
The correlation found between the growth of the mango fruit and the number of thrips was $r = -0.65$ between the first 8 weeks, later the value increased, reaching $r = -0.92$, between weeks 9 and 16. The correlation found between the growth of the rambután fruit and the amount of mealybugs was $r = -0.58$ between the first 8 weeks, later the value increased, reaching $r = -0.90$, between weeks 9 to 16. The third application helps the rambután fruit no longer receive any damage from the mealybug larvae, and in mango the thrips larvae and adults are not affected significantly either, allowing a maximum induction of fruit growth. There were significant differences between the treatments ($p < 0.05$).

To control the two pests of both fruit trees, where the life cycle in time is similar and the arrival events for each crop begin a few days before the anthesis event occurs, attracted by volatile secondary metabolites emitted by mango trees and of rambután [51–53], is knowledge that should not be overlooked when designing control strategies. The application of the aqueous extract of *A. sativum* in time and form, for the control of mealybugs and thrips adults significantly reduced the population, with a minimum of 50% and a maximum of 70%, depending strongly on the type of adjuvant or not, similar to what was reported by Flores Villegas [54] and Jaramillo [55], both authors agreeing that the concentration used of plant extracts can reduce the population of pest insects by 50% by increasing the concentration of these or by reducing it, to which the insecticidal or repellent effect strongly depends on the extracted metabolites.

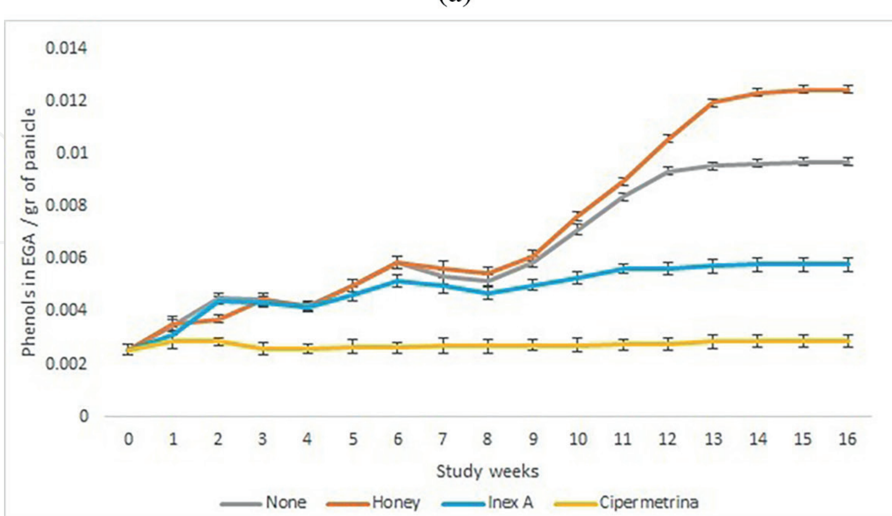
The control of pest insects, thrips and mealybugs, strongly depends on the flowering and fruiting periods of the crops, these stages being dependent on nutritional, physiological and environmental conditions [48, 51, 56]. Having started the applications at the beginning of the flowering stage and making three applications, every 4 weeks, kept the population of thrips low and prevented the number of individuals from increasing significantly, and this effect was maintained by including honey, Inex A in the mixture or without them, observing that in mango cultivation (**Figure 8a**), this effect is reduced when no adherent is applied. The reduction in the number of thrips at an extract concentration of 10% was similar to that obtained by Monje [57] who reported a mortality of adult thrips similar to chemical treatments, who used Spinosad, Imidacloprid and Thiamethoxan, without the use of adherent, being among the most efficient the extract of *A. sativum* and onion. Nava-Pérez [58] and Vázquez-Luna [59] indicated that the metabolites present in the extract of *A. sativum* present repellency, feeding and growth regulation of the larval growth faces of the insect plague. The extract of *A. sativum* has also had repellent effects against a variety of pest insects, where the mealybug is considered one of them [60]. Martinez and Rivera [61] and Marcano and Hasegawa [62] indicated that the lethal dose of the *A. sativum* extract depends on the population density that exists in the crop at the time of implementing its use as part of phytosanitary management, and in the same way the expected effect, where it can be biocidal or repellent.

3.5 Phenol production

The induction of phenols in mango panicles, regardless of adherent or non-adherent, started after the second application, unlike the treatment that received malathion (**Figure 9**). After week 8, when the third application was made, in the trees that received the aqueous extract, the production of phenols increased the concentration of phenolic compounds in the panicle. Only when Inex A was included in the application, after week 10, the increase in the concentration of these compounds decreases.



(a)



(b)

Figure 9.
Dynamics of phenol production in the main branch of the panicle in the mango crop (A) and in rambután (B) (NA: Without adherent, control: in the mango crop it was with malathion and in rambután it was cypermethrin).

After week 9, the extract that received honey and without adherent increases the concentration of phenols, observing that the dynamic that stands out with the highest production is the one that received honey as adherent. Only the aqueous extract that was mixed with honey reached concentrations higher than 0.011 mg EGA / g of panicle, equivalent to 8.94% more phenolic compounds than the extract without honey, 66.88% more phenolic compounds than the extract mixed with Inex A and 85.34% more phenols than the treatment that received malathion. A Pearson correlation value of r = −0.90 was found from week 4 to week 16, between the population density of thrips and the concentration of phenolic compounds found in the mango panicle.

In the rambutan crop, unlike the mango crop, the induction of phenolic compounds began one week after application with Inex A, honey and no adherent in the *Allium sativum* aqueous extract, reaching a maximum value at the second week and reducing its concentration in the third week. A similar dynamic was presented after the second application, observing that after the third application the dynamics of phenol production was different.

Only when Inex A was included in the application, after week 11, the increase in the concentration of these compounds decreases, similar to that observed in the mango crop after week 9, the extract that received honey and without adherent increases the concentration of phenols, observing that the dynamic that stands out with the highest production is the one that received honey as adherent. The aqueous extract that was mixed with honey reached concentrations higher than 0.0100 mg EGA / g of panicle, equivalent to 22.18% more phenolic compounds than the extract without honey, 53.53% more phenolic compounds than the extract mixed with Inex A and 76.84% more phenols than the treatment that received cypermethrin. A Pearson correlation value of r = −0.98 was found in all study weeks between the mealybug population and the concentration of phenolic compounds obtained from the rambután panicle.

The *A. sativum* aqueous extract contains a wide variety of secondary metabolites, among which are phenolic compounds, sulfur molecules and amino acids, which have been shown to have an eliciting action for secondary metabolism in cells or tissues where they are applied exogenously and penetrate to act endogenously [9, 10, 44]. According to Bailey [63] and Al-Oubaidi [64] the induction of phenolic compounds in biological models is a response to biotic or abiotic stress promoted by an organism or molecules that came into contact with the tissue or the cell of a host or receptive plant. The compounds of the extract of *A. sativum* generated induction in the production of phenolic compounds, which favored the control of the population density of both mealybugs and thrips, in both crops, being more efficient in rambután for observing a rapid response. Compared to that found in the mango crop, Delgado-Oramas [65] exposes something similar, who mentions that eliciting production of secondary metabolites is to avoid pest attack, it is a form of resistance induction, causing the host plant to present a different taste or smell, and on other occasions, they serve as repellents for phytophagous insects.

Based on the results obtained, fruit set, fruit growth and behavior of the pest, we propose that the production of phenolic compounds changes according to the physiological age or function that the organ is performing, which in this case are the panicles of both crops, according to what Albores-Flores [66] and Viveros-Legorreta [67] report, who agree that the concentration of phenols depends on the growth stage of the organ, varying in the types of compounds and their concentrations, depending on the function they perform, among these would be as a cell wall component, for biosynthesis of other molecules or as part of defense mechanisms, during cell division, cell elongation or cell differentiation.

This result will vary according to the crop, because in mango the induction of phenolic compounds was after the second application, unlike the rambutan crop where the phenol induction response was rapid. These results are related to the penetration capacity of the molecules in the cuticle of the tissues of each organ [33], and it is possibly lower in mango, because there was more hydrophobicity with its components, and faster in rambután, where the condition was less hydrophobic due to the types of compounds that constitute its cuticle.

4. Conclusions

The *Allium sativum* aqueous extract presents potential for use in agriculture as it shows a variety of functions in mango and rambutan fruit crops, to replace chemical products, be included in agronomic management and improve their production.

The extract of *A. sativum* with and without adherent can be used for flower induction, pollinator attraction, fruit set, fruit growth inducement, secondary metabolite inducement such as polyphenolic compounds and control pests in the fruiting stage.

The biological action of the aqueous extract of *A. sativum* is further potentiated when a chemical adherent or a natural product is included in the mixture, such as *Melipona solani* honey at a minimum concentration of 0.001%.

The extract of A. sativum can be used as an agricultural technology in the production of fruit trees without affecting the variety of pollinators, such as bees.

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Conflict of interest

The authors declare no conflict of interest.

Acronyms and Abbreviations

ECOSUR	The College of the Southern Border
NA	without adherent
EGA	gallic acid equivalents
AEA	before the fruit abscission stage
DEA	after the stage of abscission of fruits

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