Characterization of the Lesions Associated with the Pineapple Gum Disease Caused by the Larva of *Batrachedra comosae* Hodges, 1966 (Lepidoptera: Batrachedridae) in the Cultivar Red Spanish, or Española Roja, in Puerto Rico[1]

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Abstract: The injury associated with Pineapple Gum Disease, or gummosis, limits the Red Spanish, or *Española Roja*, pineapple cultivar for the fresh market and fruit processing industry in Puerto Rico. A lesion on pineapple, *Ananas comosus* (Linnaeus) Merrill, is initiated when a larva of *Batrachedra comosae* (Lepidoptera: Batrachedridae) penetrates through the gap located between the inferior sepal and its subtending bract. Thereafter, the larva begins to feed on the sepal's epidermis during the early stages of fruit development. Although *B. comosae* larvae do not penetrate the developing fruit, the scarred area tends to exude gums and mature earlier, possibly facilitating the entrance of saprophagous organisms. The feeding injuries caused by *B. comosae* larvae on the pineapple are believed to be modulated by the physiological response of the plant, the developmental stage of the fruit, environmental conditions, and the presence of secondary invading organisms. The damage caused by *B. comosus* in Puerto Rico, the lepidopterous larvae of *Thecla basilides* in Central and South America, and the fungal disease, fusariosis, caused by the ascomycete in the genus *Fusarium* in Brazil are distinguished.

Resumen: La lesión asociada con la enfermedad conocida como la gomosis de la piña limita la variedad de piña Española Roja para el mercado de productos frescos y la industria de procesamiento de piña en Puerto Rico. La lesión en la piña, *Ananas comosus* (Linnaeus) Merrill, se inicia cuando la larva de *Batrachedra comosae* (Lepidoptera: Batrachedridae) penetra el área floral a través del espacio ubicado entre el sépalo inferior y su bráctea subyacente. A partir de entonces, la larva comienza a alimentarse de la epidermis del sépalo durante las etapas tempranas del desarrollo del fruto. Aunque las larvas de *B. comosae* no penetran la fruta en desarollo, el área escarificada tiende a exudar gomas y a madurar más temprano, posiblemente facilitando la entrada de organismos saprófagos. Las lesiones causadas por el proceso de alimentación de las larvas de *B. comosae* están moduladas por la respuesta fisiológica de la planta, la etapa de desarrollo del fruto, las condiciones ambientales y la presencia de organismos invasores secundarios. Se distinguen los daños causados por *B. comosus* en Puerto Rico de las larvas del lepidóptero, *Thecla basilides* en Centro y Sur América, y de la enfermedad fúngica, fusariosis, causada por el ascomiceto del género *Fusarium* en Brasil.

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Introduction

Of all the entomological problems that affect the pineapple, *Ananas comosus* (Linnaeus) Merrill (Bromeliaceae) in Puerto Rico, the one with the greatest economic importance is the attack of the fruit by *Batrachedra comosae* Hodges, 1966 (Batrachedridae)[3], an insect known as gum moth that causes a condition known as gum disease or gummosis (Figure 1). In the context of pineapples, the term "gummosis" is used to describe the exudation of a viscous, gummy substance generally produced by the pineapple fruits in the presence of a natural enemy, such as *B. comosae* or several other herbivores and pathogens that attack the fruit (Pérez-Escolar 1957 and Gandía and Samuels 1958, Agrios 1997, Rohrbach and Johnson 2003). Gummosis does not imply a factor and/or causal agent in particular, but rather the response of the plant to the stimulus of these organisms, through the production and/or exudation of a gummy substance. Chemical analyses performed by Simas-Tosin et al. (2013) indicate that the exudate produced by pineapples is a mixture of chemical gums, or carbohydrates, one of the major types of exudates produced by plants (Agrios 1997, Lambert et al. 2008, Santiago-Blay and Lambert 2017) in response to injuries caused by mechanical damage or to stop/destroy natural enemies.

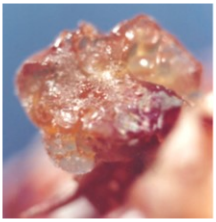

Figure 1. Close-up of a gummy exudate characteristic of lesions associated with gummosis in pineapple. These materials are part of the plant's reaction to the tunneling of *Batrachedra comosae* Hodges, 1966 (Lepidoptera: Batrachedridae) into the developing pineapple fruitlets.

In pineapple, gum production occurs mostly in association with biotic agents, the typical cases of gummosis correspond to the attacks of the larvae of the butterfly *Thecla basilides* (Geyer) (Lepidoptera: Lycaenidae) in Central and South America (Py et al. 1987), fusariosis caused species of fungus genus, *Fusarium*, in Brazil (de Matos 1987, Py et al. 1987, Rohrbach and Johnson 2003), and

[3] Pérez-Escolar (1957), following Seín (1941) studies, determined that the causal agent of gummosis in Puerto Rico was the larva of a *Batrachedra* moth which, when feeding, caused a lesion where it subsequently exuded gum. In this same study, he ruled out the possibility that mealy bugs were the cause of gum disease, as Bruner (1940) cited based on the speculation of some farmers. Hodges (1966) described the insect that causes pineapple gum disease in Puerto Rico under the name *B. comosae*. Subsequently, Hodges (1983) changed this genus from the family Cosmopterigidae to the family Coleophoridae, subfamily Batrachedrinae. The genus *Batrachedra* has been placed in several lepidopterous families, including the Batrachedidae, Coleophoridae, and the Gelechiidae. The circumscriptions of these taxa have also changed. For a more detailed account, see Anonymous a (no date) and references therein.

gummosis in Puerto Rico, initially caused by the larvae of the moth *B. comosae* Hodges (Lepidoptera: Batrachedridae).

There are reports of gum formation prompted by chemical compounds (Pérez-Escolar 1957) and by the physiological effects of stress (Okimoto 1948). In Puerto Rico, Schappelle (1941) found that the application of 5% solutions of mercury chloride, silver nitrate, ferric sulfate, or copper sulfate, caused great gum exudation in growing fruits. Pérez-Escolar (1957), following these works, induced the exudation of gum by means of oxalic and formic acid in the presence of water and mechanical injuries. He did not observe gum exudation when he applied only mechanical damage to the fruits. Similar observations were obtained when the author, using a machete, caused injuries in fruits of different ages.

This study characterizes the typical lesions of gummosis present in pineapples of Puerto Rican Spanish Red, or Española Roja[4], cultivars and differentiates them from the lesions caused by the larvae of *Thecla basilides* (Geyer) in Central and South America as well as from fusariosis[5]. This information was used in the development of methodology and instrumentation to quantify the damage of this condition for Puerto Rico (Inglés-Casanova 1990).

Methods

From 1987 to 1989, I established four field experiments to study the efficacy of various insecticides in combating the insect that causes gummosis (Inglés-Casanova 1990). I evaluated 1,880 fruits from which I took data on the number and external diameter of the lesions and observed the appearance and consistency of the exudations according to the prevailing humidity conditions and the attack of secondary invading organisms (i.e., fungi, saprophagous beetles, and fruit fly larvae) in the lesions.

In 1989, I studied 100 field-collected inflorescences (Figure 2) in different stages of development using a dissecting microscope. Using a dissecting microscope, I identified the tissue affected by the *B. comosae* larvae and observed the larval movements among the flower structures and the fruitlets. Subsequently, I collected 170 fruits in different stages of development to observe the manifestation of external lesions and the presence of the insect (larva and/or pupa). In this study, I extended the observations to the crown shoot, or areas with new vegetative growth located under the fruit but well above ground, incorrectly called crown suckers (Kraus 1948, Py et al. 1987).[6]

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[4] The pineapple cultivar PR-167, Cayena Lisa is also susceptible to gummosis. I understand that the variety Española Roja is also grown in Cuba although, as far as I am aware, the gummosis-causing *Batrachedra* has not been reported for there.

[5] *Fusarium* is a genus of ascomycete fungus with a complex classification and nomenclature. Both *F. moniliforme* and *F. subglutinans*, binomens given for the gummosis-causing *Fusarium* in pineapple, are anamorphs, or asexually reproducing forms, of *Gibberella fujikuroi*. For a more detailed account, see Anonymous b-e (no date) and references therein.

[6] An image illustrating the different vegetative portions of a pineapple plant is available here: https://www.pineapples.info/how-to-grow-pineapple/

Figure 2. The inflorescence of a young pineapple. Petal (pe), sepal (sp), and bract (br). Source: https://commons.wikimedia.org/wiki/File:Flowering_Pineapple_Sept_4_2011.jpg . Author: Supportstorm. Creative Commons License. What is colloquially known as one pineapple fruit is actually a botanical multiple fruit, that is, one produced by the fusion of multiple fruits, each of which develops the carpels of flowers in an infloresscense.The androecium (male parts of flowers) and gynoecium (female parts of flowers) are not visible in this image.

Results and Discussion

Characterization of the internal lesion of gummosis in pineapple in Puerto Rico

The gummosis lesions in pineapple begin with the attack of the larvae of *B. comosae* during flowering. The different parts of the flower, particularly the lowermost sepal and the subtending bract are further apart facilitating the entry of *B. comosae* larva. The larva penetrates through the lateral transverse fold (dt) that form in the underlying bract (br), allowing access to the lowermost sepal (Figure 3). The larva surface feeds, or scrapes, on the epidermis of the sepal that later begins to invaginate and exude gum (Figure 4). Contrary to what Py et al. (1987) reported regarding this insect, the larva never penetrates the peel.

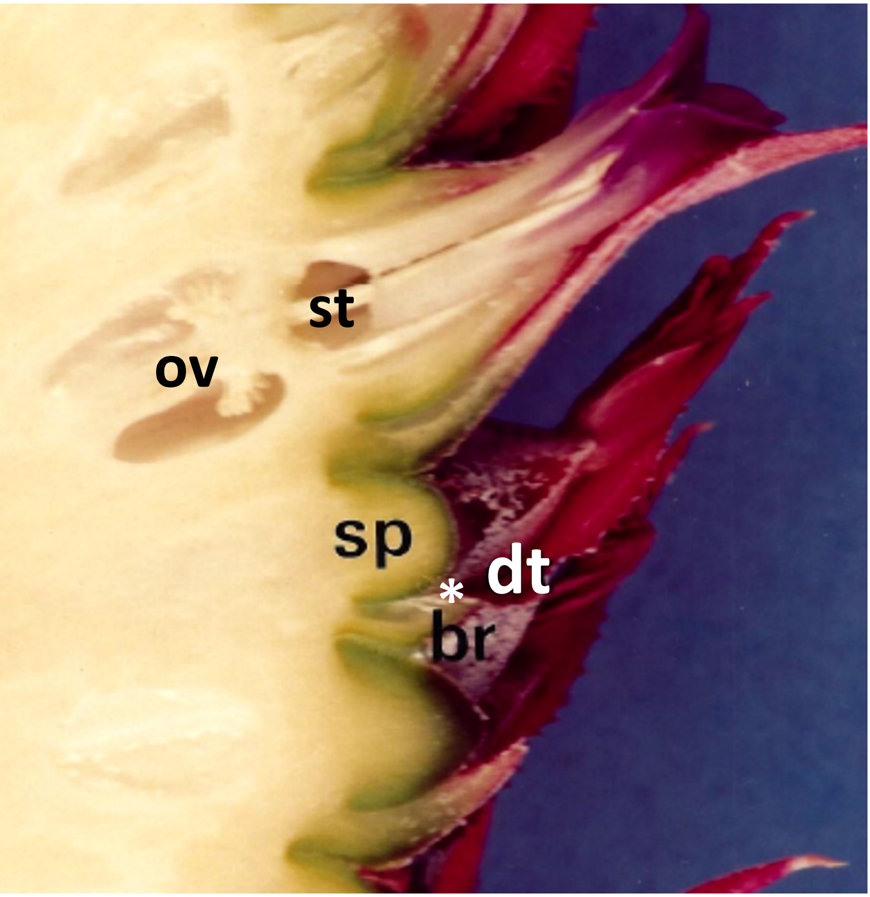


Figure 3. Point of entry (*) of *B. comosae* larvae in a pineapple. The larvae tend to access the developing fruit by creating a transversal fold (dt) on the bract (br) and reaching the base of the inferiormost sepal (sp) during and after flowering. ov = ovary, st = style, pe = petal . Additional morphological details on pineapple flowers can be found in Le Maout and J. Decaisne (1873), Watson and Dallwitz. (1992 onwards), and https://botanistinthekitchen.files.wordpress.com/2017/12/bromeliaceae-pineapple-flr-dissection.jpeg .

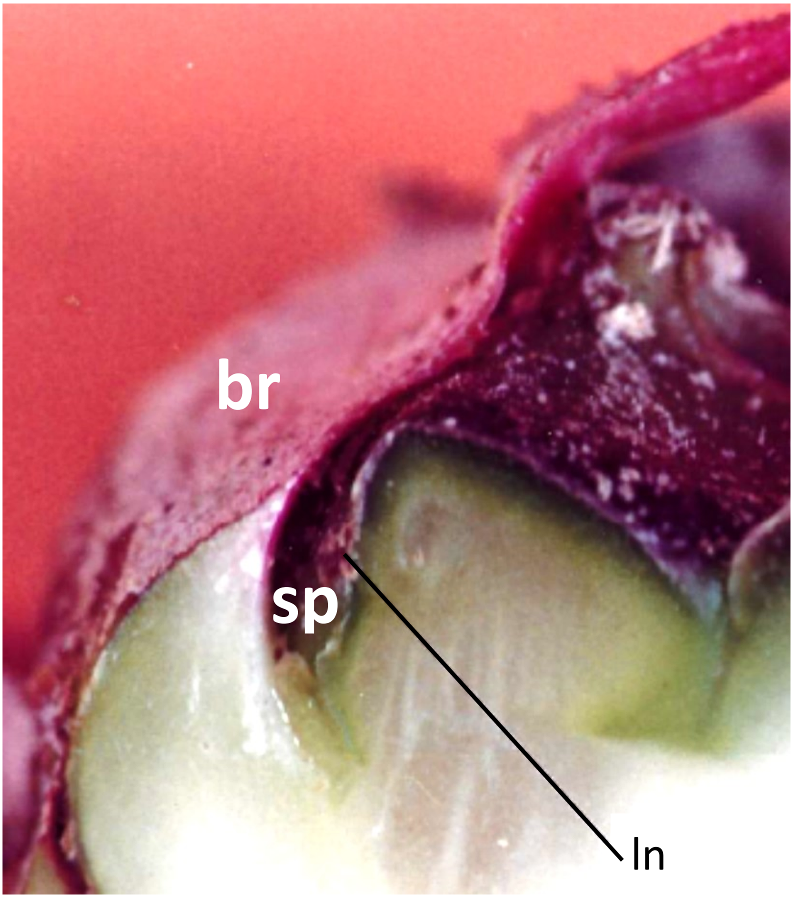


Figure 4. Pineapple berry attacked by a larva of *B. comosae*. Surface feeding lesion (ln) on the inferior sepal of a pineapple flower; br = bract, sp = sepal. Note the response tissue in the form of a callosity formed at the site of damage.

Because before and during anthesis, or the flowering period, the fruit lacks a strong peel, and its growth is mostly by cell division instead of cell size increase, this is the most critical period for developing the lesion. Following flowering, when the peel has become thicker, harder, and waxier, the larvae feed on the tissue of the bulbils or crown suckers, which remain softer and more palatable to the insect larvae (Pérez-Escolar 1957). This explains the presence of larvae and pupae in the basal part of fully developed fruits, which tends to indicate the possibility of several infestations of the pest in the same fruit (Medina-Gaud and Inglés 1988).

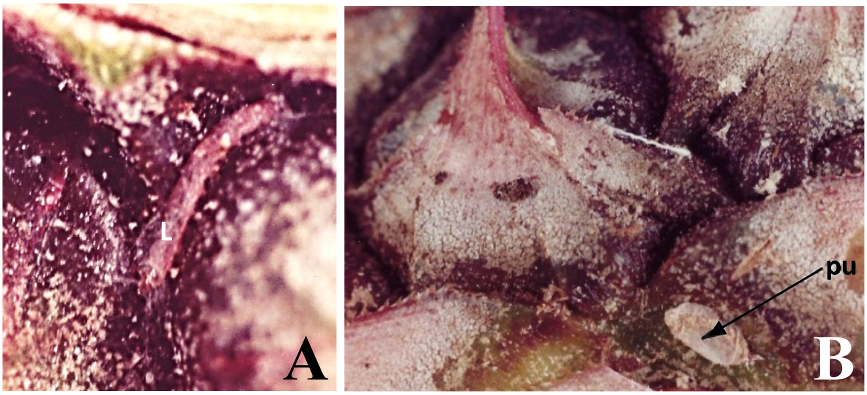


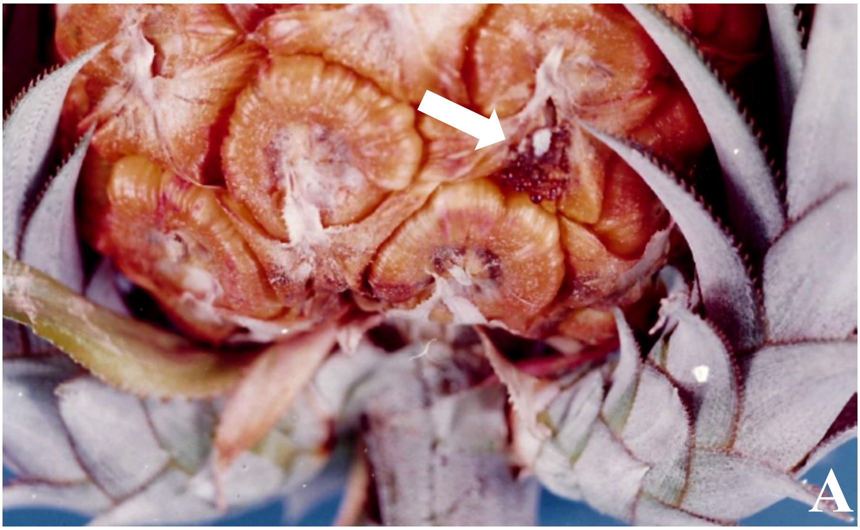
Figure 5. *Batrachedra comosae* A. Last instar larva (L) between two individual fruitlets (fr), berries or, in Spanish, *bayas*, of the developing pineapple. Approximate size of larva 2-3 mm long. B. Pupa (pu) adhered to the base of a bract (br), or subtending modified leaf of a flower, in a fully developed pineapple. Pupa approximately 5 mm long.

Gum exudations can be found in small fruits (85-130 days after flower induction, Pérez-Escolar 1957), but they are more visible and frequent in fruits that have reached their full development (over 140 days after flower induction). In developed fruits, the points of the lesions may be more visible because the area of the rind adjacent to the lesion ripens more quickly, turning to a yellow-orange color, contrasting markedly with the green of the rest of the fruit. When environmental conditions are favorable and there is a high infestation of larvae during the flowering period, it is easy to detect lesions on young fruits. Conversely, if conditions are not favorable, the lesions may go unnoticed until the fruit reaches maturity, the environmental conditions are favorable and/or secondary pests increase the lesions. Although the gum exudations are typical of the fruit, I found small gum spots at the base of some crown suckers in developing fruits in which I had found larvae of the gummosis moth, *B. comosae*. I did not find damage or gum exudation on the foliage, on the pedicle, or in the flower cavity of the fruit, as reported for the *Thecla* attack (Collins 1960) and fusariosis (de Matos 1987), respectively.

The exudations vary in shape and consistency depending on the humidity present. In lower humidity conditions, the exudations become dark and hard giving the appearance of amber, which makes it difficult to remove them from the peel on the affected fruit. On the contrary, in higher humidity, the exudates turn whitish-crystalline and acquire a mucous consistency, becoming liquified if they absorb too much moisture. When I exposed a dry gum exudate in a highly water-saturated medium, it increased more than four times its original volume, indicating its high hydrophilic capacity. The taste of this watery gum is somewhat acidic.

Characterization of the external lesion of gummosis in pineapple in Puerto Rico

External lesions are points or openings in the fruit peel where the gummy exudations typical of the gummosis sprout. Most of the lesions are located from the basal part to the middle part of the fruit (Figure 6 A, B). These injuries can range from almost imperceptible indentations to holes that exceed 0.50 inch (over 1.25 cm) in diameter.



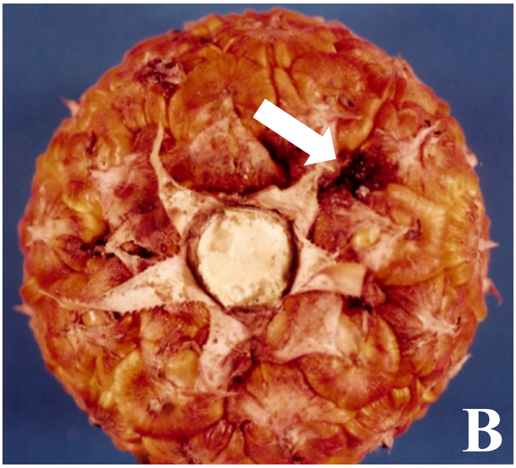


Figure 6. Typical lesions (arrows) caused by *B. comosae* on the pineapple fruit. A. Side view, showing slips (sl) of vegetative material produced by asexual reproduction from which a new pineapple plant can be grown. B. Basal view. The medial inferior portion of the fruit (A) corresponds to the two basalmost whorls (B) tend to be the most damaged by *B. comosae*.

The external size of the lesion depends on physiological factors, climatological factors, and attack by secondary biotic agents: fungi (Figure 7A, B) saprophagous beetles (Coleoptera: Nitidulidae, Figure 7B, C) and fruit flies (Diptera: Drosophilidae).

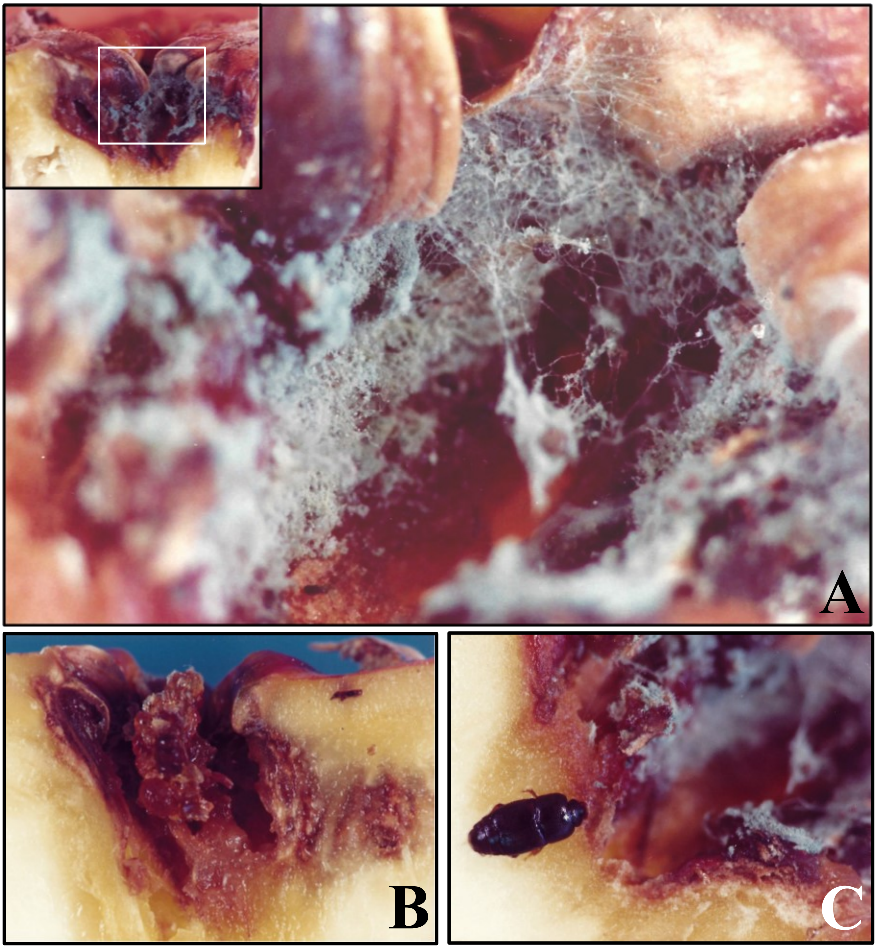


Figure 7. Colonizers on lesions caused by *B. comosae*. A. *Penicillium* sp. (Ascomycota). White rectangle in nsert represents the approximately area expanded on A. B. *Batrachedra comosae* lesion enlarged by beetle larvae. B. Adult *Urophorus humeralis* (Fabricius, 1798), the pineapple sap beetle (Nitidulidae).

These lesions are located at two points related to the underlying bracts that cover the lower half of the fruitlets. The first point corresponds to the central area of the bract where natural fissures are located through which gum can exude if any of these coincide with a lesion of the lower sepal of that fruitlet (Figure 8 A, B). I called this lesion a bractear lesion (Figure 8A). The second point related to the bracts corresponds to the area at one of the ends of the bracts or where both sepals join. The gum exudation comes out near the junction of the two adjacent bracts. This point corresponds to a lateral lesion of the lower sepal. When the lesion develops, it affects both sepals and adjacent bracts. I called this injury an interbractear injury (Figure 8B).

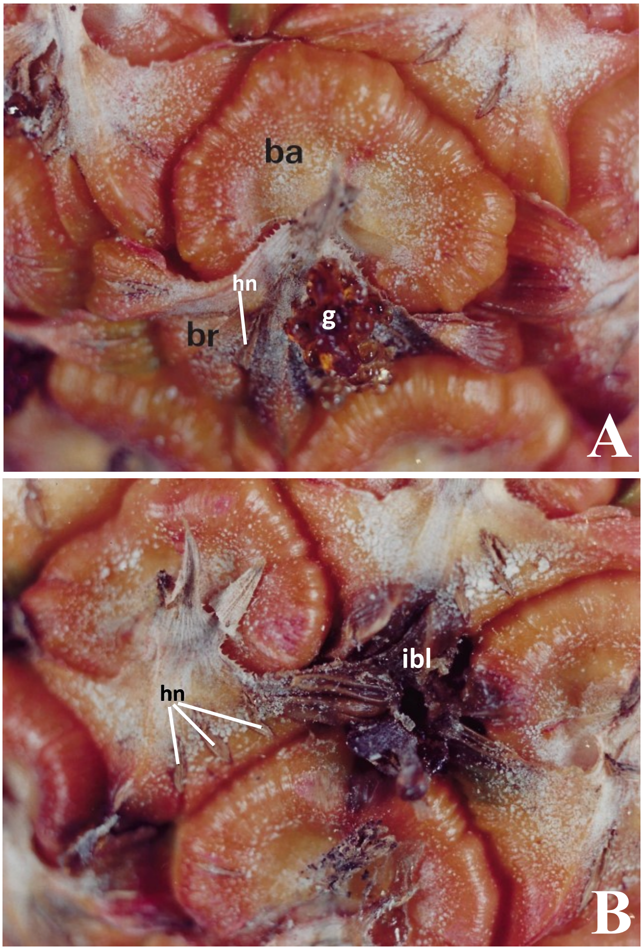


Figure 8. Berries (ba) affected by gummosis. A. Bracteal lesion. Gummy exudate (g) is produced from one of the natural slits (hn) located on the central part of the bract (br). B. Interbracteal lesion (ibl). Gummy exudate is produced from the periphery of the bract affecting adjacent berries.

Characterization of internal injury

The internal lesion forms an elongated conical cavity usually covered with a layer of collapsed dead cells. The tissue continuous to the wall of the cavity matures and softens allowing the lesion to spread easily. The affected tissue extends laterally under the hard and waxy cortex or peel, which does not allow an external appreciation of the magnitude of the lesion (Figure 6A, external lesion; Figure 9, internal lession). The size of the lesion is associated with the physiological reaction of the fruit, its stage of development, environmental conditions, and the attack of secondary biotic agents (fungi, bacteria, saprophagous beetles and fruit flies).

Internal bractear Injury. This lesion affects the ovary of the lower sepal and when it spreads, it damages the fleshy tissue of the underlying bract. In well-developed lesions, it affects the fruitlet.

Internal interbracteal injury. In the case of interbracteal lesions, the affected area corresponds to the tissue of the affected sepal and the sepal of the adjacent fruitlet. In well-developed lesions, it even affects the lower intermediate fruitlet.

In the fruit, the lesions follow the orientation of the ovaries (Figure 9). The lesions on the lateral fruitlets are oriented transversely to the axis of the fruit, causing the cavity to form a cone with a flat top (Figure 10A). In the case of basal lesions, their orientation is inclined to the central axis and the cavity forms a cone with an inclined stop (Figure 10B). Lateral and basal lesions occasionally form an obtuse cone.

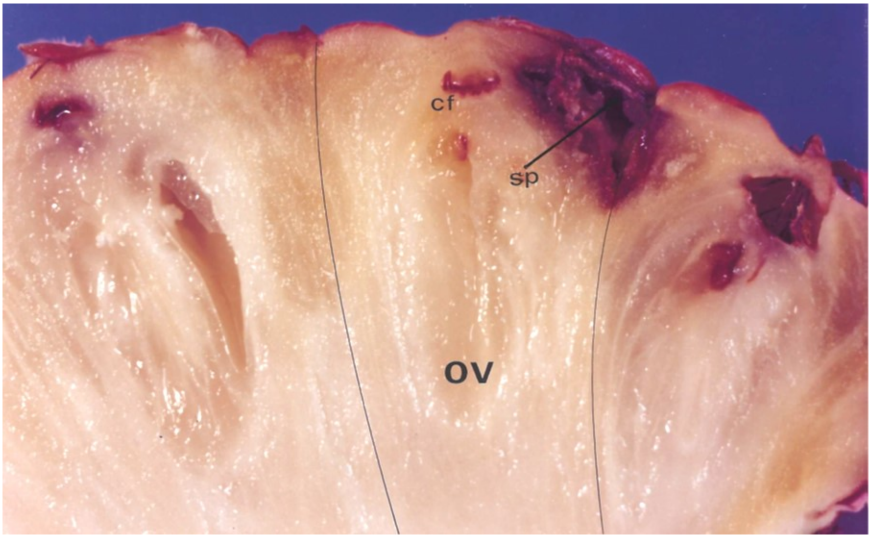


Figure 9. Longitudinal section of a pineapple showing a lateral lesion. The lesion originates at the base of the sepal (sp) and affects internal tissue following the direction of the ovary (ov). The lesions associated to gummosis do not affect the floral cavity (cf).

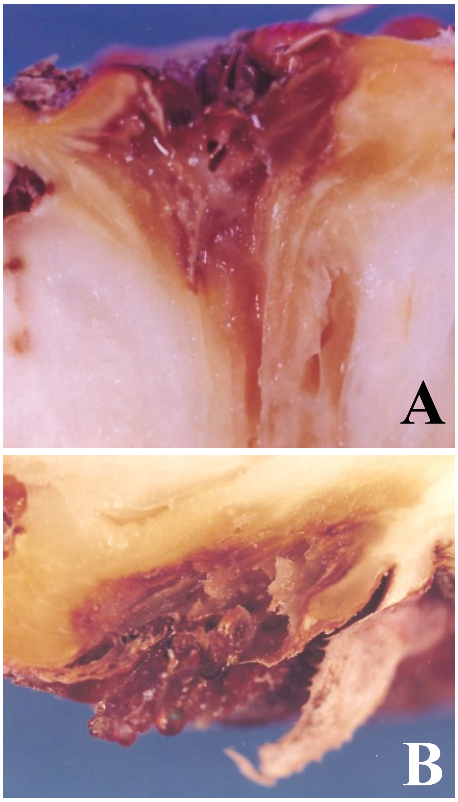


Figure 10. More lessions on pineapple. A. Lateral lesion present on the lateral portion of the pineapple. The lesions resemble a flattened cone. B. Basal lesion typically found at the basal or apical extremes of the pineapple, especially basally. These lesions resemble a slanted cone.

The position and depth of the lesions and the diameter of the fruit at the affected point will determine the magnitude of the loss in the commercial tissue (for slices or juice). Most of the lateral lesions do not reach the processing cylinder (Figure 11A), which reduces their economic effect in this area. In contrast, basal lesions affect commercial tissue more because their position allows the processing cylinder to be more easily affected (Figure 11B).

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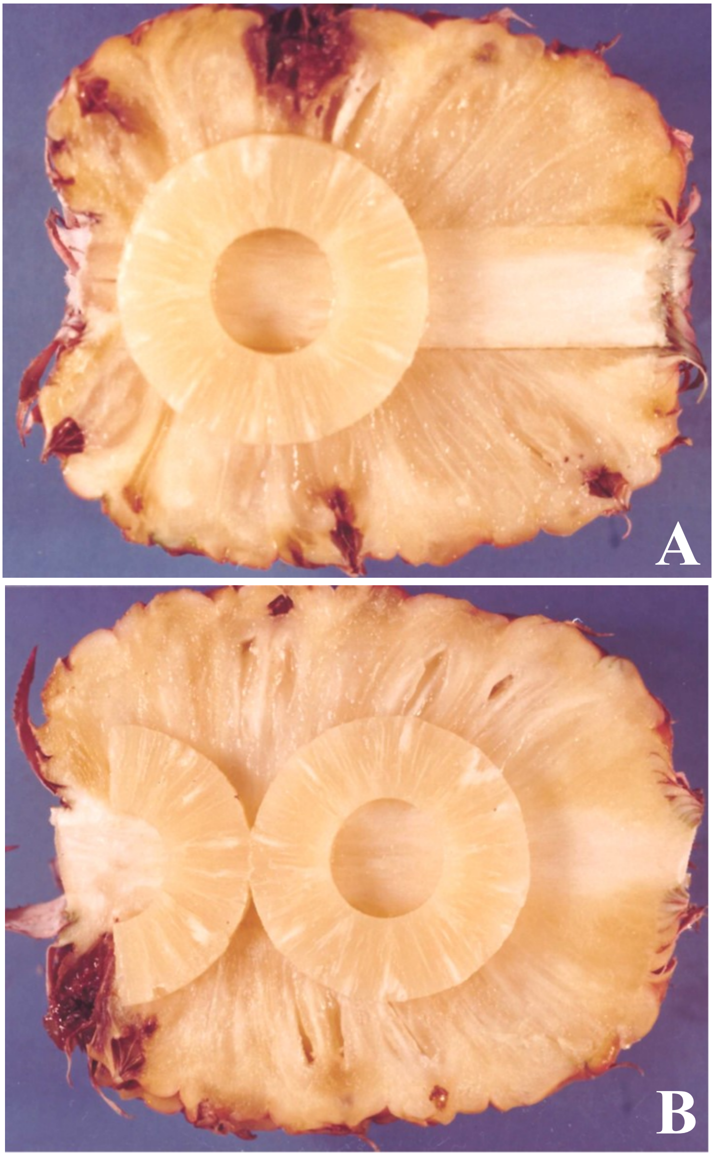

Figure 11. Effect of the position of the ovary and pineapple lesions in the processing of a pineapple slices for marketing (diameter of pineapple slice approximately 6 cm). A. Lateral lesions tend to be smaller affecting the tissues outside the pineapple slices. Those lesions tend to be benign for pineapple slice market. B. Basal lesions tend to be larger and affect the pulp of the pineapple making those fruits less desirable for the sliced pineapple market.

The lesions associated with the gummosis are due to the occurrence of several interacting factors: the causal agent (insect), development stage (flowering) and physiological response to stimulation by the plant and climatic conditions (humidity and temperature), in addition, the attack of secondary organisms (fungi and insects) that increase the injury. These factors cause variation in the magnitude with which the lesions appear in the affected fruits. Taking into consideration these variations and the characterization described in this study, I developed part of a methodology and instrumentation used in the quantification of damage in field studies during the years 1987 to 1989 (Inglés-Casanova 1990).

Other types of gummoses in the Americas

According to Collins (1960), the larva of *Thecla basilides* (Geyer), a species of butterfly not present in Puerto Rico, penetrates the pineapple fruit generally through the floral cavity or through the peduncle until it reaches the fruit. In addition, the larvae can feed on the mesophyll of the leaf. Velasco et al. (1968) report that the affected fruits are totally misshapen, with holes and a large amount of excrement and gummy exudation present within them. They add that flowering pineapples are preferred targets for oviposition by butterflies, which they do on bracts and developing flowers. According to Py et al. (1987), the larva of *T. basilides* penetrates the developing fruit, causing holes of various depths in the fleshy base of the bracts and fruitlets, as well as in the suckers. The reaction of the fruit to the activity of the *Thecla* larva is the formation of an amber colored gum, which hardens on contact with air.

Regarding the fusariosis of Brazil, caused by species of the ascomycete genus *Fusarium*, Py et al (1987) and de Matos (1987) indicate that it can affect all parts of the plant, but the fruit and the suckers are parts of the plant attacked the most. In addition to the characteristic gum exudation, an infected plant may show one or more of the following changes: bending of the stem, usually towards the direction of the wound; changes in phyllotaxis, increasing the number of leaves per spiral; changing the architecture of the plant with the appearance of a funnel; shrinking of the leaves; reduction of plant development; death of the apical meristem, and chlorosis (de Matos 1987). In fruit, the fruitlets invaginate and gum exudation appears (Py et al. 1987). This fungal pathogen can only enter through natural openings or wounds. Flowering is the most susceptible stage of the fruit. In the inflorescence, *Fusarium* can penetrate through natural ducts (nectalifers as well as canals within the style, the elongated portion of the pistil, part of the female part of a flower). Generally, *Thecla* adults are the disseminators of the spores and the spores facilitate penetration through these ducts (Py et al. 1987). Mechanical wounds and/or those caused by arthropods, *Thecla* and others, favor the infection of the fruit by this pathogen (de Matos 1987 and Py et al. 1987). Although this fungus reported for Puerto Rico, lesions in pineapple similar to those described by de Matos and Py et al. have not been reported for Puerto Rican pineapples.

Conclusions

The lesions associated with the gummosis are initially caused by the attack of the *Batrachedra comosae* larvae during the susceptible stage of the plant (flowering stage). The development of these lesions depends on the physiological response of the fruit to the stimulus of the damage. The magnitude of the lesions depends on the state of development of the fruit, the presence of environmental conditions favorable to the development of the lesion (high humidity and temperature) and the attack of secondary organisms (insects and fungi). Gummosis lesions initially occur in the lower sepal; which is covered by the underlying bract. Lesions and gum exudation is only limited to the fruit; although I found small gum spots at the base of a sucker. In Puerto Rico, the gummosis does not affect the foliage, peduncle, floral cavities, or stem as reported for the attack of *Thecla basilides* and fusariosis present in Brazil.

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