Feddes Repertorium **104** (1993) 5–6, 395–402 Berlin, August 1993

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Early fruit drop in tree crops with special reference to rubber (*Hevea brasiliensis*) – A review

Summary

The present article surveys the possible reasons for early fruit drop in tree crops with special reference to rubber. They are environmental, physiological, embryological or pathogenic. Abortion of pistillate flowers and fruit occurs generally in three distinct periods: due to under developed flowers, failure of pollination and embryo abortion due to embryological and physiological factors. Fruit set can be increased by hand pollination, use of growth hormones or by the application of fertilizers. The failure of seed production results in the loss of numerous potentially good cross combinations thus limiting the progress of genetic improvement of the species. Moreover seeds are the rich sources of genetic variability.

Key words: abscission, early fruit drop, growth regulators, rubber.

Zusammenfassung

In vorliegendem Beitrag werden die möglichen Ursachen für den verfrühten Fruchtfall an Bäumen, mit besonderer Berücksichtigung der Kautschukbäume, näher betrachtet. Die Ursachen können aus der Umwelt resultieren, phytosoziologisch, embryologisch oder pathogen bedingt sein. Das Abortieren pistillater Blüten und Früchte geschieht allgemein in drei getrennten Perioden: auf Grund unterentwickelter Blüten, durch Störung bei der Bestäubung und durch Abfall der Embryonen infolge embryologischer und physiologischer Faktoren. Der Fruchtansatz kann durch manuelle Bestäubung, den Einsatz von Wachstumshormonen oder durch den Einsatz von Dünger erhöht werden. Eine Störung der Samenproduktion ergibt sich aus dem Verlust zahlreicher potentielle guter Kreuzungsmöglichkeiten, wodurch ein Fortschritt in der genetischen Aufwertung der Art begrenzt wird. Überdies sind die Samen die reichen Quellen der genetischen Variabilität.

Introduction

Although the mechanism of reproduction in Angiosperms has long been known, the reasons why the pistil is not fertilized by the pollen of the same species are only now becoming apparent. There is little doubt that, as a result of pollination chemical signals traverse the style and influence floral physiology. In addition, there is some evidence to suggest that in the final stages ovule maturation is induced by pollination. If this is so then it would ensure that the ovules are at the correct physiological stage of development at the time of the arrival of the male gamete.

Seeds are of great importance in breeding programmes for the multiplication of the crop eventhough vegetative means are available in tree crops. But the percentage of fruit set is found to be low in many tree crops. Premature abscission of fruits is serious problem in apples, pears, oranges, rubber and many other crops. Poor seed set due to factors such as the poor growth of pollen tubes or the lack of coordination between ovule maturation or incompatibility. Incompatibility reported in many tree crops, is not yet found in *Hevea*.

Production of more flowers that can be matured to fruit is a common phenomenon in many plants. Thus, many flowers are borne

simply to fulfill the male function (LLOYD 1980; UDOVIC and AKER 1981; MARTINEZ-CORTINA and SANZ 1991) and fruits are aborted to adjust the number to available resources. Numerous factors are believed to affect seed set although their importance and the form of their expression appears to vary widely (STEPHENSON 1981; SUTHERLAND 1986). Investigation in many tree crops (eg., rubber, mango, plum, apple, peach, citrus) has led to identification of the possible reason for early fruit drop.

If all the flowers in a plant produce fruits, a tough competition for food results and all the fruits would be small and might remain under developed seeds. In order to avoid this, the commercial producers of mango spray synthetic growth substances on the fruit to increase abscission, so that the remaining fruits grow larger, increasing their value. In *Hevea*, usually not more than nine healthy flowers per inflorescence are available at a time for controlled pollination, of which six to eight were recommended for hand pollination (HP) by DIJKMAN (1951). The relationship between the number of pollinators per inflorescence and the number of initial fruit set and mature fruits harvested to have been proposed by SEDGLEY and ATTANAYAKA (1986). They recommended to do not more than four flowers be pollinated per inflorescence for better success. According to YEANG and GANDHIMATHI (1984) while intrabranch competition among developing fruit lets is probably not important, the possibility of interbranch competition influencing fruitset. QUINLAN and PRESTON (1971) and HUND and STOSSER (1984) have opined that competition for essential metabolites between fruitlets and vegetative shoots and competitive interaction among individual blossoms within a cluster are responsible for the induction of fruit drop.

Significance of hand pollination

Attemps have been made in *Hevea* to increase fruit set by HP eventhough the percentage of fruit set could be raised not more than 5% at Rubber Research Institute of India (MYDIN et al. 1989). In Malaysia, 3% fruit set was noticed in the main flowering season and 8% for the second season during the period 1969–1980 (GANDHIMATHI and YEANG 1984). These workers have suggested a new method of hand pollination to overcome the apparent insufficiency of pollen as a possible cause for low fruit set in *Hevea*. Success in HP depends on various factors such as temperature and rainfall immediately after pollination and during the growth of the fruit, skill of the operator and the fertility of different clones (Rubber Research Institute of Malaya 1953). The failure of hand pollination results in the loss of numerous potentially good cross combinations thus limiting the progress of genetic improvement of the species. Seeds are rich source of genetic variability.

Ability of the plant to produce fruits should be taken as a criterion for selection of parents for hybridization, since the real cause for low fruit set is still obscure. While selecting the plants for HP those plants should complete their juvenile phase as well as given a more or less satisfactory yield for the last few years. WILLIAMS (1965) reported that fruit set greatly depends on events that occurred in the previous year during the bloom and post-bloom periods. Due to climatic variation many of the *Hevea* clones produce flowers 2–3 times in a year; of which the inflorescence may be bushy without apical leafy shoot, or with apical shoot. The field observations that the fruit set is nil in certain period, tempting to speculate that climate has some adverse effect on it.

Many studies on the floral biology of several species try to explain the factors which determine the period during which it is possible to pollinate a fertile flower successfully and obtain fruit. It is clear that the substance released as a result of pollen germination is essential for the normal development of the ovule. Following a successful pollination, the rate of growth of the ovary increases and floral parts such as stamens and perianth are shed. In *Hevea*, the high initial fruit counts two weeks after pollination and later decrease in fruit counts may be due to the retention of any unfertilized flowers upto two weeks and their subsequent abscission coupled with immature fruit drop (MYDIN et al. 1989). Cutting the end of the calyx without injury to the ovule also leads to increase fruit drop. Damage to the stigma following hand pollination has been reported by SEDGLEY and ATTANAYAKA (1986) may be a reason for early fruit drop in *Hevea*. Damage to the stigma reduces pollen tube growth and the amount of damage differs between operators.

Fruit drop periods

Abortion of pistillate flowers and fruits occur generally in three distinct periods. In apple, three normal periods of fruit drop occur: (a) early fruit drop, between the time of initial ovary enlargement and beginning of endosperm development (b) „June drop" of young fruits and (c) „the preharvest drop" (KRAMER and KOZLOWSKI 1979). In pecan, the three periods are commonly referred as 1st, 2nd and 3rd drop (HAMILTON 1942; SPARKS and HEATH 1072). The 1st drop occurs almost immediately after full bloom and consists of weak and underdeveloped pistillate flowers, which is inversely related to shoot vigor (SPARKS and HEATH 1972). The 2nd drop or fertilization drop begins about 14 days after pollination and continues until upto about 40–45 days. This drop is due to the failure of pollination. The 3rd drop or summer drop may be due to embryo abortion (WOODROOF et al. 1928). This embryo abortion is not due to incompatibility as described by SEAVEY and BAWA (1986), but may be due to environmental or physiological reasons. The degree of 3rd drop is usually small. However, the magnitude of the 1st and 2nd drop varies greatly among seasons within a cultivar and among cultivars within a season. Abscission of buds, flowers or fruits of Washington navel oranges in California occurred from February–July (ERICKSON and BRANNAMAN 1960). The timing of abortion and the stage at which abortion occurs can be related to selective forces that have somewhat different origins and effects on the evolution of paternal and maternal reproductive patterns (BAWA and WEBB 1984). Summer drop in orange is caused primarily by a yellowing of the secondary fruit which results after abscission from the central axis of the primary fruit (LIMA and DAVIES 1984).

Location of abscission

The location where the abscission of fruit occurs is also vary from species to species. Pome fruits abscise at the base of the pedicel (BERUTER and DROZ 1991). Two abscission zones occur in sweet cherry with fruits separating either between the pedicel and peduncle or between the peduncle and spur. The flowers and small aborted fruits of cherry often separate at the basal abscission zone (NELLSON et al. 1984). *Hevea* fruits abscise at two loci: from the base of the fruit, and the region where the peduncle attached to the pedicel.

Possible reasons for early fruit drop

JAUMIEN (1986) claimed that excessive fruit fall in the pear ‚Doyenne due Comice' is principally due to degeneration of the embryo sacs and ovules. Other factors are (1) ovule longivity (2) stigma receptivity (3) immature stigma and (4) rapid fall in receptivity over time. OLOPADE and SALAWU (1986) pointed out some of the possible reasons for low fruit set in *Hevea*. They are (1) few pollinating insects of the right kind (2) non-coincidence of opening of male and female flowers or lack of flowers which occurs in the flowering habit of some clones (3) suitable time for pollination of the flowers especially in HP is short. It has been reported that the flowers open between 10 AM and 2 PM (ONOKPISE 1976). Anthesis in rubber shows wide variations. It is reported that in PRII 33, a clone of *Hevea brasiliensis* anthesis of male flowers takes place between 1.30 and 1.45 PM and that of female flowers between 3.15 and 4.00 PM (SARASWATHY AMMA and PANIKKAR 1990). The combined actions of pollen limitation and selective seed maturation can include variability in the number of seeds per fruit as well as differences in seed size (WILLSON and BURLEY 1983). Mature fruits of *Hevea* containing less than three seeds are rare, suggesting that the pollen must germinate in each of the stigma, but in experiments on the artificial pollination technique found that 70% of the flowers had no pollen at all on at least one stigma (WEBSTER and PAARDEKOOPER 1989). GANDHIMATHI and YEANG (1984) also reported that insufficiency of pollen grain is one of the factors for low fruit set in *Hevea*. Other possible reasons for low fruit production are: (1) pathogenic infection to flowers and fruits (HOSIN et al. 1981). (2) unhealthy flowers on the inflorescence produced in the unfavourable season, (3) influence of soil moisture, humidity and temperature (4) plant density (WYCHERLEY 1991).

Environmental factors

Other factors found to be associated with change in fruit setting or sheeding are previous

fruiting (WANG et al. 1980), climatic condition and field management. WANG et al. (1980) reported that rain, high relative humidity and insufficient light intensity were detrimental to fruit setting. Low temperature in the flowering period delay growth of pollen tube in plum hindering fertilization. Extreme low or high temperatures cause pollen sterility in some plants. In warm years the faster development of the ovule is not harmful and fruit set increases considerably (THOMPSON and LIU 1973). BROCKMANS (1957) observed a positive correlation between fruit production and dry season rainfall thirty months earlier in oil palm. Once fruit development is under way competition for water may be partially responsible for the abscission of immature fruit. Flowering and fruit development in *Hevea* is accompanied by extensive refoliation creating a severe competition for assimilates. The fruit set in citrus is favoured on leaf inflorescence, while abortion of reproductive organs is nearly total on leafless inflorescences (ERNER and BRAVDO 1983). Condition is somewhat similar in *Hevea* too. High levels of fruit set is noticed in leafy inflorescence is due to a better supply of photosynthates from the young leaves to the adjacent fruit lets (MONSELISE 1986). ZUCCONI et al. (1978) have reported that fruit lets borne on leafy inflorescence were significantly larger than those borne on leafless inflorescence.

Shading experiment

Shading experiments have shown that fruit crop yield is reduced by low light intensity as a result of inhibition of floral initiation, fruit set and of increase in size of fruits. The experiment support the view that the supply of assimilates is essential for fruit retention in the early stages of fruit development (JACKSON and PALMER 1977; BYERS et al. 1985). Shading reduced flower bud initiation in apple and apricot.

Effect of fertilizer

Application of complete fertilizer mixtures (HAINES 1946) and continuous soil application of ammonium sulphate to widen the N/K ratio of the leaves (WATSON and NARAYANAN 1965) have produced significant increase in seed production in rubber. Another approach reported to increase seed production is to apply extra nitrogen fertilizer (SIVANADYAN and GHANDIMATHI 1989). Folier spray of aromatic nitro compounds (VASUDEVA and VENKATARAMANAN 1981) and ascorbic acid (VASUDEVA and RATAGERI 1981) were useful in controlling the premature fruit drop and increase the crop yield. In a preliminary study SASIKUMAR et al. (1987) have found that direct application of phosphorous as foliar spray have considerable role in preventing early fruit drop in rubber. SAMARANAYAKA et al. (1979) suggested that deficiency of boron is a factor in reducing fruit set and blossom wilting (HANSON and BREEN 1985). Foliar application of boron is reported to increase fruit set in pear, citrus etc. (BRAMLAGE and THOMPSON 1962; CHAUTURIYA 1974). Spray of 1% orthophosphoric acid helped to retain 82.8% of the fruits initially (MYDIN et al. 1990). Fruit drop due to nutrient deficiency have been reported in many plants including mango (MUKHERJEE 1953) and coconut (RAMADASAN and RAJAGOPAL 1987) together with other factors such as water logging or heavy rain fall. Male reproductive success may be limited by the quantity of matings and female reproductive success by available resources for the nourishments of embryos (WILLIAMS 1975).

Calcium metabolism have significant role in early fruit drop in many plants. The accumulation of calcium oxalate crystals in the abscission zone may be indicative of the breakdown of pectic materials in the middle lamellae and the simultaneous release of associated calcium ions.

Pathogenic fruit drop

Another major problem encountered with low fruit setting is related pathogenic infection. Major pathogens to cause fruit drop are *Phytophthora*, *Colletotrichum*, *Botryodiplodia*, *Coryneum* etc. (NAIR and MENON 1983). Mahali or nutfall, caused by *Phytophthora* is common in coconut and arecanut. Inflorescence blight in cashew and clove is very severe when cloudy weather prevails. This is caused by *Colletotrichum*. Another disease of cashew is floral shoot die-back caused by *Botryodiplodia*. The flowers are shed and no fruit set takes place. The infection may spread to the young nuts and

apple, become black and remain attached to the shoot. In nutmeg, fruit rot caused by *Diplodia* is common in monsoon. The affected fruits are shed in numbers. In many parts of Jawa, the premature dropping of nutmeg due to *Coryneum* is so common. Black pod rot of cocoa is caused by *Phytophthora*. Major pathogens to rubber are *Oidium* and *Phytophthora*. *Oidium* affects the flowers during January-March and *Phytophthora* attack the fruits during rainy season (Rubber Research Institute of Malaya 1967). A relationship has been established between fruit set and incidence of leaf fall disease as the fruits are the preferred loci of initial inflation for the pathogen. For flower protection prophylactic treatments using sulpher and other fungicides were found to be effective. Alternative method to escape from pathogens is by the early induction of flowers by bark ringing.

Meteorological evidence

Meteorological factors like evaporation and solar radiation determine fruit set success to a limited extend (YEANG and GHANDIMATHI 1984). Treatment of plant tissue with red light will inhibit dark-induced fruit abscission from apple trees (GREENE et al. 1986). Althought the mechanism by which light regulates the abscission process are unknown. Phytochrome has been suggested as the light sensing system (CURTIS 1978).

DECOTEAU and CRAKER (1983) suggested that the abscission process in plants may be regulated by the balance of red and far-red light striking the abscising organ. Although production of ethylene has been closely associated with abscission, it is indicated that light regulation of abscission does not involve this gaseous hormone.

Physiological and biochemical aspects

Much effort in anatomical, physiological and biochemical aspects in relation with early fruit drop have not been carried out in *Hevea*. But in other crops a series of work has been performed. Plant hormone levels play a major role in the control of abscission process. High hormone production is correlated with low fruit drop and suggested that synthesized in endosperm more through the pedicel and inhibit induction of abscission (BERUTER and DROZ 1991). Abscission in the apple takes place in a characteristic layer of cells situated at the pedicel-stem juncture and IAA was noticed in the pedicel during the June drop period (EBERT and BANGERTH 1985). The location of abscission layer of fruits varies with species. When applied gibberellic acid (GA), prevent abscission to the inflorescences (GARCIA-MARTINEZ and GARCIA-PAPI 1979), which increased abscisic acid (ABA) content has been correlated with *Citrus* abscission (SAGEE et al. 1980). MOSS et al. (1972) suggested that inflorescence leaves in *Citrus* can enhance fruit set by supplying photosynthate.

Biochemical aspects of seeds have been considered as a major factor affecting fruit drop in young apples (CRANE 1969). They are sources of high hormone production and believed to be strong mobilising centres for carbohydrates. The high hormonal activity found in the growing seed is indirectly correlated with fruit drop, but can increase the metabolic activity of the growing seeds (BERUTER and DROZ 1991). High levels of these substances in the seeds are thought to cause diversion of metabolites to the fruit and enable it to complete more efficiency with other growing organs of the plant (CRANE 1969). BERUTER and DROZ (1991) suggested that fruit drop may be regulated by other factors such as the level of accumulated carbohydrates in the young fruit. They found that the concentration of glucose in the pedicel during fruit development was normally above the concentration found in fruiting wood proximal to the abscission zone. The abscission as a result of induction during June drop period showed some level of glucose both in pedicel and fruiting wood. The presence of stored sugars may protect fruit from abscission by maintaining a sufficiently high level of sugars in the pedicel distal to the abscission layer of a growing fruit. The fruit which remain on the tree have reached a stage in their development at which sufficient amount of sugar have accumulated to prevent abscission. In inflorescences with fruit, carbohydrate and dry matter accumulation in the sprout was highly dependent on the stage of fruit development (MARTINEZ-CORTINA and SANZ 1991)

Premature fruit fall can be reduced by auxin application, but if applied too early the result may be reverse i.e., increase fruit abscission, apparently results from auxin-induced embryo and seed absortion (GREULACH 1973). Auxin can effectively retard the process of abscission by preventing structural weakening of the abscission zone; however, once weakening of this specialized layer of cells has begun, auxin enhances the abscission process. Auxin can prevent the ethylene action by preventing the beginning of the weakening process. LECONTE et al. (1984) have got encouraging results on rubber fruit set following use of growth regulators like NAA and GA 3. Investigations at the Rubber Research Institute of India (RRII) and Rubber Research Institute of Malaysia (RRIM) showed that application of GA 3 at 20 ppm and other growth hormones to be promising but it did not bring about significant improvement in fruit set in rubber compared to that by conventional hand pollination procedure (Rubber Research Institute of Malaya 1962; MYDIN et al. 1989). Exogenous application of gibberellic acid may result in a significant promotion of fruit set in orange and other species (LIMA and DAVIES 1984; GREENE 1989).

The fruit set period represents a critical stage in many tree crops, since the percentage of fruit set is one of the factors determining final yield, and this process is thought to involved nutritional and hormonal aspects (MARTINEZ-CORTINA and SANZ 1991). It is obvious that additional key factors such as cytokinins from the roots, auxin from the shoots and other unknown factors coming from the fruitlet or the plant, together with water transport and mineral supply, may be involved in fate of the single fruit let to abscise or persist (SAGEE and ERNER 1991).

Future line of work

Since there are a series of problems encountered with fruit set, the following aspects have to be elucidated in tree crops to increase seed set, as suggested by OLOPADE and SALAWU (1986) in *Hevea*. They are:

a) Better understanding of floral biology, fruit development and maturity in the flowers in order to determine best time for stigma receptivity, pollen storage method and control approach for voluntary abortion in developing fruits.
b) Screening for male and female sterile clones, thereby they can be omitted from breeding programme.

Flower induction by ring barking is a useful tool to increase fruit set in rubber according to TAN (1987), which offers the following advantages:

a) It enables breeders to conduct hand pollinations throughout the year.
b) It enables some crosses to be made involving parents which are not normally synchronous in flowering.

Embryo culture was considered as a possible means of rescue, because ovules of the abscissed fruit occasionally contained embryos in various stages of development. Ovule abortion is due post-zygotic rejection (SEAVEY and BAWA 1986) or the combination of physiological and environmental factors. According to SEARS (1937) self-rejection is a function of an incompatibility reaction between self pollen tubes and the integuments of the ovule rather than an intrinsic inability of the embryo and endosperm to continue development.

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Manuscript received: October, 22nd, 1992.