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Phytohormone regulation on apple fruit maturation

H. HAMAYOUN[1*], M.M. MODASAR[2] AND F.M. MOHAMMADI[3]

[1*]*Department of Quality Assurance and Accreditation, Ghazni University, Ghazni, Afghanistan*

[2]*Department of Agronomy, Agriculture Faculty, Ghazni University, Ghazni, Afghanistan*

[3]*Department of Economic and Extension, Agriculture Faculty, Ghazni University, Ghazni, Afghanistan*

[*]*hamayoun.1383@gmail.com*

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ABSTRACT

Apple (*Malus domestica* Borkh.), one of the largest fruit crops in terms of cultivated area and yield. The fruit is generally marketed after storage, which is of great significance for regulating the market supply in the off-season. Apple-fruit ripening culminates in desirable changes in structural and textural properties are governed by a complex regulatory network. Much is known about ethylene as one of the most important factors promoting apple-fruit ripening. However, the dynamic interplay between phytohormones also plays an important part in apple-fruit ripening. Here, the complex regulatory network concerning the action of phytohormones during apple-fruit ripening has been evaluated and reviewed. Future research prospects have also been discussed.

Key words: Apple, fruit ripening, phytohormone, regulation

INTRODUCTION

Plant hormones are endogenous organic combinations active at very little concentration, produced in one tissue, and translocated to another point in the plant where their effects on growth and development are manifested. A single plant cell can respond to more than one hormone, while a single hormone can affect different tissues in different ways. PGRs also do have effect on apple fruit ripening and maturation (Li et al., 2017). Climatic conditions of Afghanistan are highly adjustable for numerous temperate fruits crops. There are a large number of prevalent horticultural species. Wide range of Agro-ecological zones provides a long season of consistent supply. Afghanistan is an unique center of genetic diversity and significantly contributes to the international horticulture community. Cherry, plum, apricot, peach, pear, apple, walnut, pistachio, fig, grape, pomegranate, almond, are among the species present across the country. Horticultural crops are relatively water effective, contribute to significant production diversification and are a source of much needed nutrients for the human population. Horticulture is land and labor intensive which is an advantage for poor farmers. Considering the regional reputation for high-quality produce, horticulture becomes a prime source of export enhancing country's economy. Horticulture occupies 2.7% of the total cultivated area; 55% of fruit crops, 40% of vegetables and 5% of other products. The main fruit crop regarding area is grape with 51%, followed by almond with 11%, apricot 5.7% and apple 5.1%. Grape (fresh grape and raisin) is the most spread species in the country (14 provinces out of 34) and is by large by value and volume, the highest perennial fruit crop by value and volume. The apple is the pomaceous fruit of the apple tree, species *Malus x domestica* Borkh. in the rose family (Rosaceae). It is one of the most widely cultivated tree fruits in Afghanistan and the most widely known of the many members of genus *Malus* that are used by humans. Apple trees have different ripening rates which may be supplied year-round from time of harvest (Watkins, 2003). As a typical climacteric fruit, apples have a peak in respiration and a burst of ethylene to unleash the ripening process in an autocatalytic response just prior to the initiation of ripening. Apple-fruit ripening is mainly regulated by the phytohormone ethylene (Sunako et al., 1999). Therefore, it appears to be possible to control the storage life of apple fruit by regulating ethylene biosynthesis. For example, treatment with the compound ethephon, which is converted into ethylene in plants, promotes ethylene production and apple-fruit ripening (Li et al., 2016). A better understanding of the hormone regulatory mechanisms in the ripening of apple-fruit is both biologically meaningful and economically significant for generating strategies to improve apple-fruit qualities and fruit nutrition, and reduce postharvest economic losses. Watkins (2003) summarized research advances in the phytohormone regulation of apple-fruit ripening and discussed future perspectives.

USE OF DIFFERENT HORMONES

Ethylene

Gaseous hormone produced in many plant tissues, autocatalytic (stimulates its own production) volatile gas production stimulated during ripening, flooding, stress, senescence, mechanical damage, infection product of combustion of petrochemicals ethylene, a gaseous phytohormone, plays a central role in climacteric fruit ripening. In the apple ripening process, ethylene production gradually increases to a peak, and then gradually decreases, the fruit then moves into the aging stage (Fig. 1). The ethylene produced in climacteric fruit is divided into two systems i.e. System 1 and 2. System 1 is mainly responsible for ethylene biosynthesis in young fruits. System 1 ethylene is also auto inhibited. System 2 is mainly responsible for ethylene biosynthesis in ripe fruits (Fig. 2-3) and active when climacteric ethylene should be produced (Watkins, 2003).

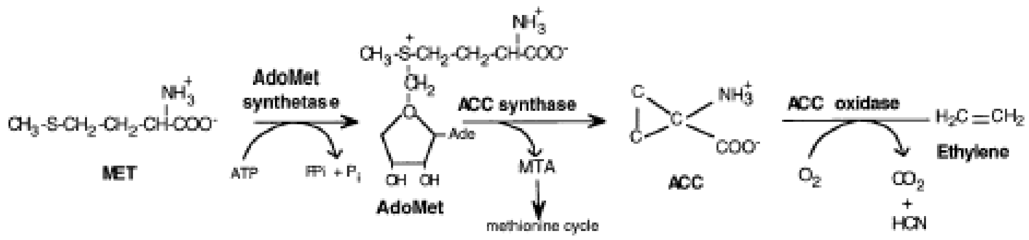

Fig. 1. Stages of production of ethylene

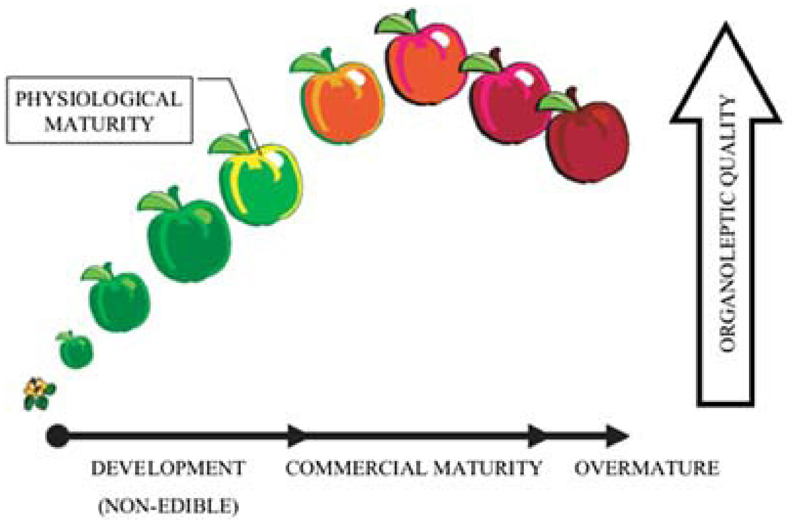

Fig. 2. Stages of maturation in apple fruits

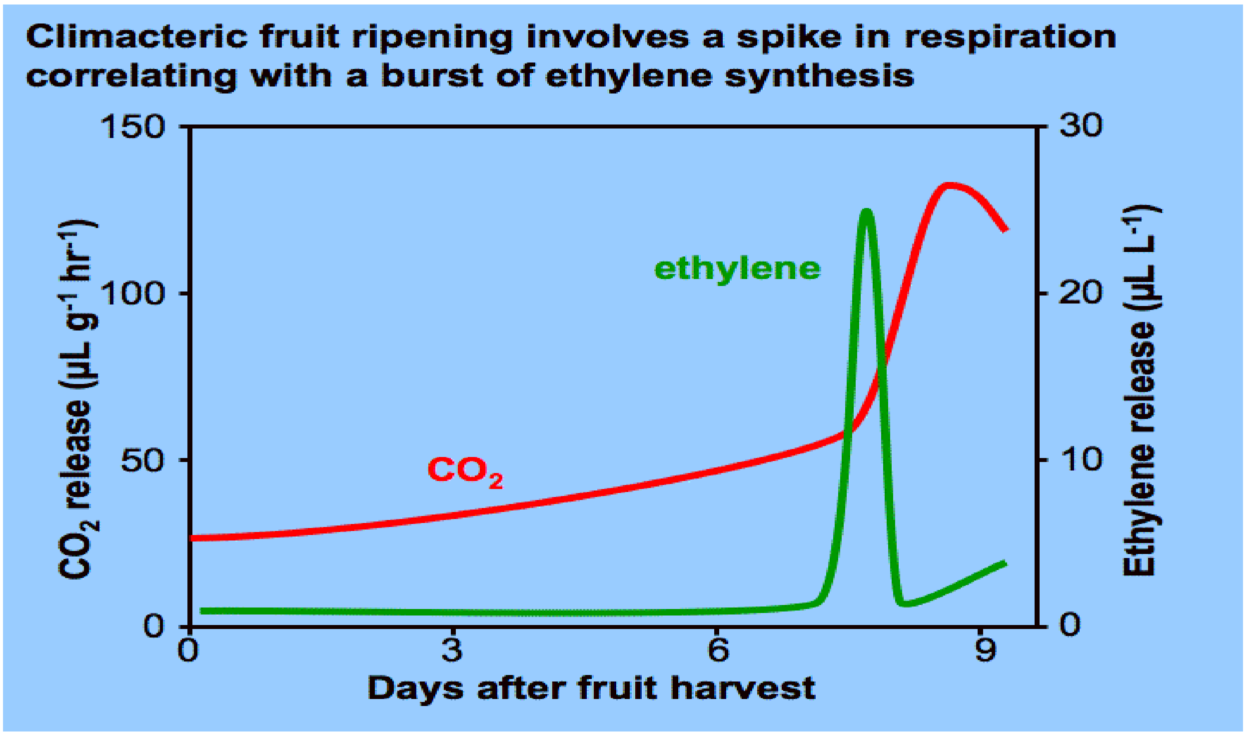

Fig. 3. Rate of CO_2 and ethylene released in ethylene synthesis

Role of Ethylene

1. Most importantly, Ethylene breaks the dormancy of seeds and buds.
2. It enhances respiration rate during ripening of fruits.
3. It facilitates senescence and abscission of both flowers and leaves.

Auxins (Indole acetic acid)

Auxins have been widely studied as growth and development regulators in fruit (Kumar et al., 2014). An increasing number of studies show that auxins also act as a fruit-ripening regulator (Fig. 4). In general, the most abundant free auxin, indole-3-acetic acid (IAA), is seen as the main regulator in fruit. In apple fruit, endogenous IAA contents are extremely high during the initial growth developmental stages, after which IAA contents tend to decline to low levels at the onset of fruit ripening (Yue et al., 2020). Signal transduction by auxin is also well understood. In the absence of auxin, auxin/ indoleacetic acid proteins (Aux/ IAAs) interact with auxin response factor (ARF) and suppress their activity, which prevents the downstream progression of signaling.

Role of Auxin

1. Involved in the initiation of roots in stem cuttings.
2. Reduction of dropping of leaves and fruits at early stages.
3. Regulate xylem differentiation and assists in cell division.
4. Apical dominance may occur in which the growth of lateral buds is inhibited by the growth of apical buds. In such cases, the shoot caps may be removed.

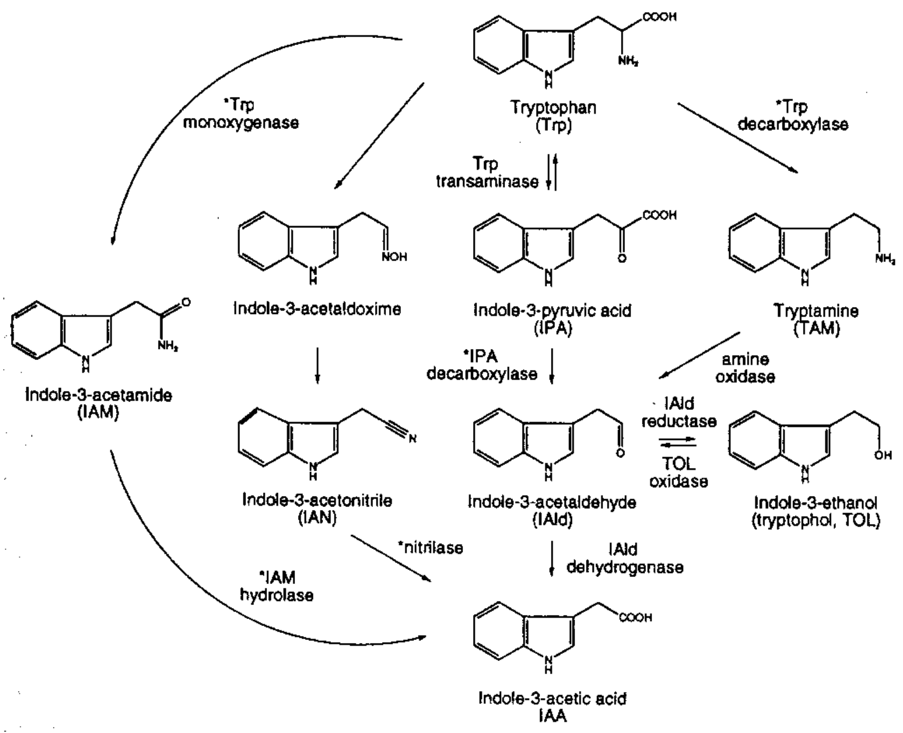

Fig. 4. The action of auxin in plant

Abscisic Acid (ABA)

Abscisic acid (Fig. 5) has long been described to be primarily involved in the ripening process of non-climacteric fruit (Watkins, 2003). In recent years, an increasing number of studies discovered that ABA also regulates the ripening of climacteric fruit. The endogenous ABA concentration is low in green fruit but increases during apple-fruit ripening (Onik, et al., 2018). Studies showed that the maximal endogenous ABA precedes a burst of ethylene in apple fruit. These results indicated ABA may be the other regulatory factor upstream of ethylene for apple-fruit ripening. So far, there is not much information about the mechanisms through which ABA regulates apple-fruit ripening (Onik et al., 2018).

Role of Abscisic acid

1. Helps in the maturation and development of seeds.
2. Inhibits plant metabolism and seed germination.
3. It is involved in regulating abscission and dormancy.
4. It is widely used as a spraying agent on trees to regulate dropping of fruits.

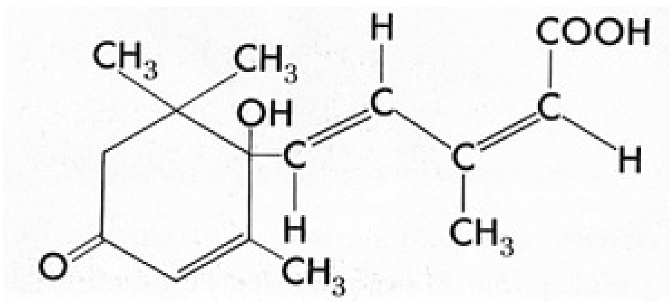

Fig. 5. Chemical formulae of ABA

Gibberellins

Gibberellins (GAs) are a category of tetracyclic triterpenoid hormones (Fig. 6) in higher plants regulating a wide range of developmental processes; reported by Onik et al. (2018). Recent studies on GAs mainly focused on seed development, flowering, and fruit set and development because of the high concentration of GAs found in flowers and immature fruit. Among several hundred plant GAs, only a limited number are bioactive in higher plants, such as GA1, GA3, GA4, and GA7. GA1 and GA4 are highly abundant, whereas GA3 and GA7 are less abundant as reported by Li et al. (2017). In fruit, GAs accumulates during early fruit development but decrease to a low concentration during fruit ripening. Injecting the GA biosynthesis inhibitor prohexadione Ca into mature green tomatoes accelerated the fruit ripening (Li et al., 2017). Additionally, exogenous GA3 treatment can reduce ethylene production and depress the ripening of various climacteric fruit, such as bananas, persimmon (*Diospyros kaki*), mangos (*Mangifera indica*), and tomatoes. These results demonstrate that GAs is an inhibitor of fruit ripening. However, the regulation of GAs in apple-fruit maturation (Fig. 7) and ripening has rarely been studied. In apples, the inactivation of GAs was controlled by a gene encoding gibberellin 2-beta-dioxygenase 1 (GA2OX1) observed to be high in post ripening apples that were harvested at 120 DAFB followed by five days of storage at 20°C. However, knowledge on the mechanisms regarding how GAs regulate apple-fruit ripening remains limited (Li et al., 2017).

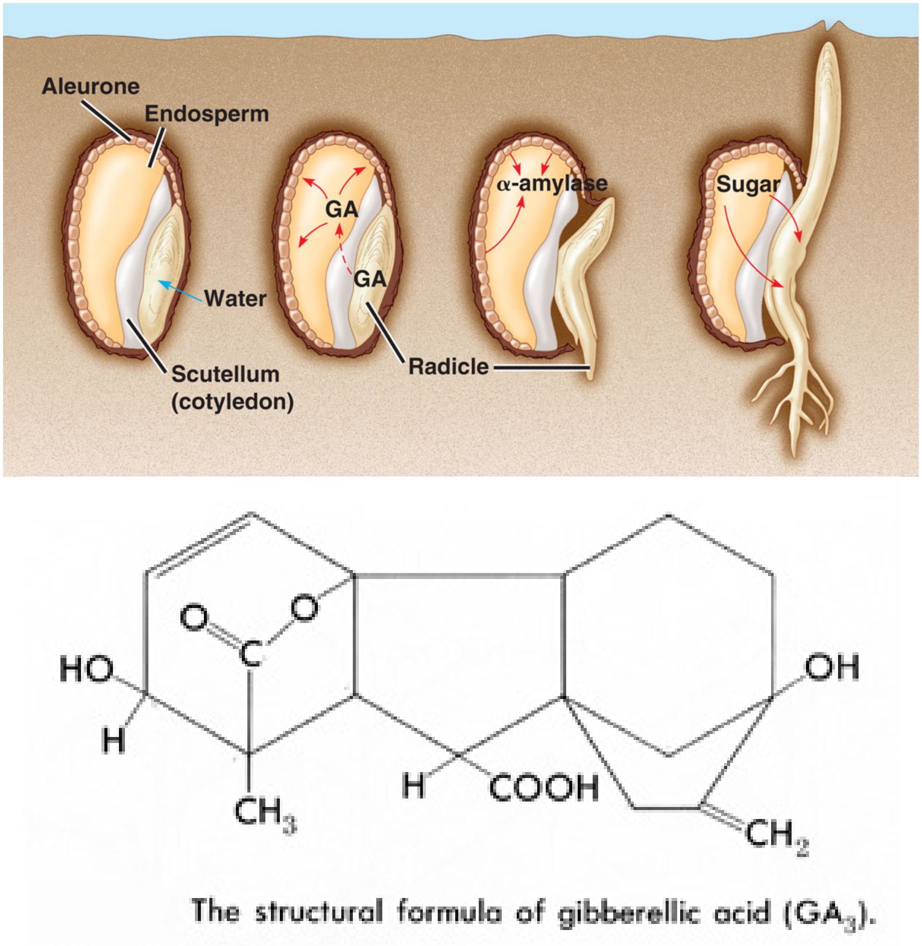

Fig. 6. Structural formula of GA

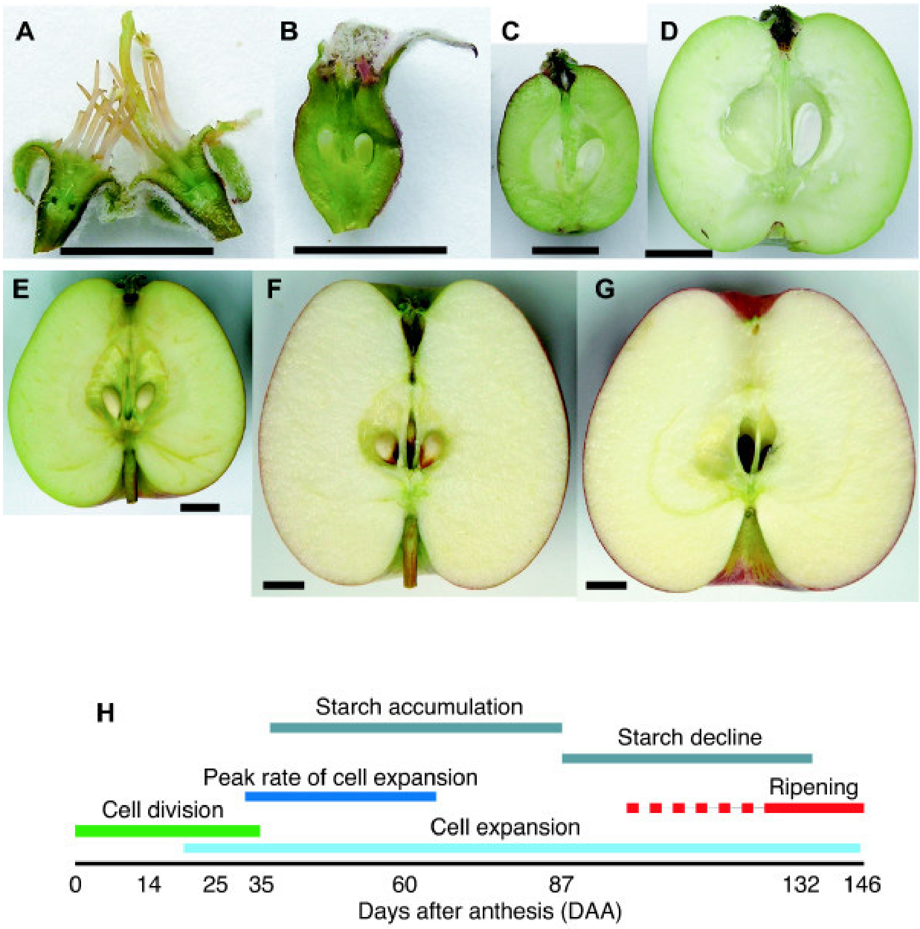

Fig. 7. The maturation stages of apple (A to G)

Role of Gibberellin

1. Delay senescence in fruits.
2. Break bud and seed dormancy.
3. Facilitate elongation of fruits such as apples and enhance their shape.
4. Helps in increasing the crop yield by increasing the height in plants such as sugarcane and increase the axis length in plants such as grape stalks.

RESULTS AND DISCUSSION

Plant growth regulators play an important role in the production of high-quality trees and fruit. Read the product. Plant growth substances also help to bring rapid changes in the phenotypes of the plants and also improves the growth, translocation of nutrients to economic parts and ultimately improve the maturation and productivity of fruit crops. Due to the shorter ripening period, apples are harvested at the commercial maturity stage for a longer shelf life and proper marketing supply. The transition from growth to maturation of fruit is characterized by alterations in the phytohormones profiles to drastically terminate fruit expansion and promote fruit ripening. A clear understanding of these phytohormonal shifts in apples is meaningful and crucial for regulating the period from commercial to physiological ripening. Moreover, phytohormonal regulation in apple ripening is of great significance for regulating the market supply in the off-season of fruit production (Li et al., 2017). Fruit ripening is a complicated physiology and biochemistry reaction involving well-organized regulation by multiple hormones, and accompanied by subtle changes of metabolic and physiological traits. Ethylene is specifically required for the ripening of climacteric fruit. The biosynthesis of ethylene in climacteric fruit is divided into systems 1 and 2. However, the mechanism for system 1 ethylene shifting to system 2 ethylene is not clear (Fig. 7). Understanding this mechanism is a major focus of research on fruit ripening. Current information indicates that ethylene could be the destination of hormonal crosstalk during apple-fruit ripening. Ethylene signaling in apple-fruit ripening is tightly coordinated under the influence of multiple phytohormones. Cytokines (CKs) have crucial functions in various phases of plant growth and development as a major phenomenon (Li et al., 2017), but studies on the effects of CKs on apple fruit ripening are limited. Other plant hormones primarily act through minor adjustments to ethylene's action during apple fruit ripening. However, available information is limited about the crosstalk of multi hormones during apple-fruit ripening. Given the complexity of apple-fruit ripening processes, exploring the basic molecular mechanisms of their regulation by crosstalk among hormones is more difficult. More work is required to elucidate the molecular basis of multi-hormonal cross talk, and this is becoming a major focus of research on fruit ripening.

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