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Physiological Parameters–A Tool for the Improvement of Fruit Crops

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Abstract

Productivity is governed by photosynthetic efficiency of the plant. Clonal variations have been studied in a number of fruit crops and these efforts have resulted in the development of promising varieties. The majority of the research with fruit trees has been conducted on apple trees and much less information is available for other fruit tree species. Significant differences in growth parameters have been found between the different cultivars of bael. In recent years, photosynthesis of fruit trees had been studied in mango, banana, citrus, papaya, jujube, apple, peach and almond.
Key words : Aegle marmelos, Citrus, Photosynthetic rate, Growth, Yield.

India is bestowed with a wide range of agro-climatic and soil conditions. Therefore, almost all types of fruit can be grown in one or the other parts of the country. Clonal variations have been attempted in a number of fruit crops and these efforts have resulted in the development of promising varieties of mango, apple, banana, grape, guava, papaya, and sapota. However, systematic efforts are still required for the development of ideal varieties through modern tools in fruit crops. Beal (*Aegle marmelos* Correa) occupies an important place among the indigenous fruits of India. It has naturalized in Bangladesh, Myanmar, Pakistan, Sri Lanka, Thailand and many South East Asian countries. The fruit is found in plenty in wild strips in Bihar, Chattishgarh, Jharkhand, Madhya Pradesh, Orissa, Uttarakhand, Uttar Pradesh, West Bengal and in some southern states of India. The bael fruit is most nutritions and provide a lot of vitamins and minerals. It contains 1.8 g protein, 0.39 g fat, 1.7 g minerals, 31.80 g carbohydrates, 55 mg carotene, 0.13 mg thiamine, 1.19 mg riboflavin, 1.1 mg niacin and 8 mg vitamin-C per 100 g of edible portion (1). No other fruit has such a high content of riboflavin (2). It also contains marmelosin which is most probably the therapeutically active principle of bael fruits (3). Pulp of ripe fruits is tasty and can be consumed a fresh or made into *sharbat* one of the most popular drinks in the Indian subcontinent. The plant is hardy and has capacity to adapt successfully to a wide range of habitat from arid, semi-arid to mesophytic condition.

The environmental and edaphic conditions in India are suitable for cultivation of bael. Only a few attempts have been made so far to exploit the physiological parameters that may prove as key factors in increasing yield potential of various crops (4—7). Productivity is governed by photosynthetic efficiency of the plant which, in turn, is affected by duration of photosynthesis, changes of photosynthesis with leaf size and age, efficiency of CO_2 assimilation, the rapidity with which leaf area enlarges to absorb the available solar radiation, plant height, photosynthesis by organs other than leaves and the efficiency of transport of photosynthates to the tissue of economic importance. In recent years, photosynthesis of fruit trees had been studied in mango, banana, grapefruit, apple, almond and jujube. It is necessary that genotypic variation in physiological parameters should be thoroughly investigated and utilized for higher productivity.

Growth Parameters

Three clones of bael i.e., NB-1, NB-5, NB-6 were studied and their fruit weight were found as 920, 1006, and 960 g, respectively (8). Significant differences in growth parameters have been found between the different cultivars of bael. Pant Beal-3 produced the highest height, spread, volume, girth and cross-sectional area of the trunk while the trees of Pant Bael-9 were found to be the lowest in tree height, girth and cross-sectional area of the trunk. The tree spread and tree volume were found minimum in Pant Bael-10 (9). Clones affected the growth, vigour, yield and photosynthetic efficiency. Among the eleven clones, Pant Urvashi, Pant Bael-10 and Pant Shivani were found to be the best on yield and yield characteristics (10). Among 17 genotypes of bael, the plant height varied from (4.8—19.0 m), girth (0.25—1.50 m), canopy spread in N-S (4.8—11.50 m) and E-W (3.1—12.3) (11). The growth, yield and photosyntetic efficiency of bael were studied in foot-hills region of Uttarakhand. Pant Bael 10 followed by Pant Urvashi was superior among the cultivars in growth and yield performance (12). The growth of bael fruits followed a sigmoid curve. Fruit weight and size increased during growth but became static in the later stages of the development (13).

The various growth parameters of nine strains of trifoliate orange were studied and reported that highly significant differences between different cultivars (14). A rootstock trial on Jaffa and Valencia Late cultivars of sweet orange using nine rootstocks viz., Jatti Khatti, Karna Khatta, Troyer and Carrizo Citranges, Pectinifera, Pineapple orange, Rangpur Lime, Citrumelo and Cleopatra mandarin were conducted. Jaffa trees budded on Jatti Khatti produced significantly more trunk girth, tree volume (53.8 m^2) and yield (290 fruits/tree) than all other rootstocks tried and growth and yield of Valencia Late trees budded on Jatti Khatti were significantly large (58.2 m^3) than all other rootstocks except Cleopatra mandarin (54.4 m^3) (15). The trees of Valencia Late were the healthiest among the six cultivars under trial with significantly better growth under all parameters than those of Jaffa, Hamlin, Mosambi, Pineapple and Blood Red in the descending order. Maximum stock and scion girth and tree volume were found in Valencia Late trees (16). Twenty five genotypes of mandarin were studied and found that tree height in genotypes ranged from 1.85 m (Fairchild) to 5.00 m (Kondanarum) and tree volume ranged from 13.03 m^3 (Kara) to 84.69 m^3 (kondanarum) (17). Evaluation of eighteen guava germplasm for vegetative and yield potential were studied and found that the tree height ranged from 2.24—3.98 m in the various genotypes (18).

Leaf Area

Maximum leaf area was found in Pant Bael-11 and Pant Bael-5, whereas, it was found minimum in Pant Bael-10 and Pant Bael-2 (9). The total individual leaf area was affected by the various clones of Bael. Pant Shivani produced significantly higher total individual leaf area than remaining clones (10). Leaf blade area of different mango rootstocks was estimated and reported that Moovandan and Goa had the highest and lowest leaf area, respectively (19). Significant differences were found between the grape cultivars in the number of leaves and leaf area (20). The leaf breadth was recorded maximum in Karun Jamir as compared to other species of citrus (21). The leaves form the interior (shade grown leaves) had a larger leaf area but were reduced in weight and thickness when compared with leaves from the outside of the canopy (sun-grown leaves) of the apple tree cultivars, Fuji and Jonagold (22). Tropical Beauty showed the highest value for leaf area among twenty five genotypes of apple (23).

Chlorophyll Content of Leaves

Various clones did not affect the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents significantly in bael (10). The concentrations of chlorophyll *a*, chlorophyll *b* and total chlorophyll were determined in the peel of various cultivars of lemon during various stages of fruit growth (5). The concentration of chlorophyll was determined in the leaves of twelve cultivars of orange and chlorophyll content of leaves in the range of 5 to 15 mg/g on dry weight basis was reported. The chlorophyll content was low between January to June and increased, thereafter, shaded part of trees contained more chlorophyll than unshaded one on the same tree (24). The positive correlation between net photosynthetic rate and chlorophyll content was reported in certain seasonal dimorphic species (25). Pant Lemon-1 had higher chlorophyll (*a*, *b*, total and *a/b* ratio) than Malta lemon (26). Chlorophyll content of different mango rootstocks was estimated and it was reported that chlorophyll a ranged from 0.6661 to 1.2045 mg/g fresh weight of leaves and chlorophyll *b* and total chlorophyll ranged from 0.4868 to 1.1780 and 1.1529 to 2.3825 mg/g fresh weight of leaves, respectively (19). The chlorophyll content was estimated in two month old leaves from identical positions on the mango trees of the cultivars, Malaviya Bhog, Amarpali and Mallika. Similar chlorophyll contents were found in September and December, the period considered to be crucial for flowering in mango (27).

Significant difference was found in chlorophyll content between sun-grown and shade-grown leaves of two apple cultivars viz., Fuji and Jona Gold (22). Total chlorophyll was determined in one year old potted green fruted pear cultivars, Bartlett, d' Anjou and Clapp's Favourite and their respective red fruited sports viz., Red Bartlett, Red d' Anjou and Kalle, respectively. Total chlorophyll content did not differ significantly between green fruited parents and red fruited sports and tended to be higher in parental series which was consistent with higher net photosynthesis (P_n) in green fruited parents than in the red fruited sports (2). There is a clear positive correlation between chlorophyll content and photosynthetic rate (28). The responses of photosynthetic capacity, chlorophyll fluorescence and chlorophyll content of nectarine (*Prunus persica* var *Nectarina* Maxim) were studied to green house and field grown conditions. A reduction in chlorophyll *a/b* ratio in leaves of green house grown plants with significant increase in chlorophyll b content (29).

Photosynthetic Rate

There has been increasing research directed towards understanding the photosynthetic response of fruit tree leaves to their environment. Most of this research has involved measurement of the effect of factors such as light, temperature, water stress, ambient CO_2 concentration, pest and externally applied chemicals on photosynthesis. Although a large body of literature is available in the comparative studies of varietal and seasonal differences in photosynthesis rates in cereals and pulse crops but meager literature is available on the photosynthesis rates in fruit crops and only one report is available in bael fruit. The majority of the research with fruit trees has been conducted on apple trees and much less information is available for other fruit tree species. The photosynthesis was studied in the leaves of lemon cultivars and reported higher rate of photosynthesis in high yielding Pant lemon-1 than in Malta lemon leaves (26). Significantly higher photosynthesis rate was recorded in autumn than in spring flush leaves of Pant lemon-1 (30). The rate of net photosynthesis was higher in Pant lemon-1 cultivar of *Citrus limon* Burm. maintained at 0.45 m mol/m^2/s solar photosynthetic photon flux density (PPFD) than those maintained at 7.50 m mol/m^2/s solar PPFD (31). A comparative study was made to net photosynthesis in some citrus species and its relatives. Comparisons were made between Campbell Valencia (*Citrus sinensis* Osbeck) and Gabon cherry (*Citropsis cabunensis* Swing.), Frost Lisbon lemon (*Citrus limon* Burm.) and 'Eremolemon' (*Eremocitrus gluca* Swing × *Citrus limon* Burm.) withrespect to the influence of temperature on net photosynthesis. Photosynthetic measurement were made by keeping the plants in a growth chamber in which the plant used for these studies were initiated and grown until maturity. Net photosynthesis significantly lower in 'Cherry Orange' than in Valencia orange. Net photosynthesis of both the species declined with increase in temperature above 30^{o}C. 'Eremolemon' had significantly higher photosynthetic rates than 'Lisbon' lemon (32). Significant variation in net photosynthetic rate, transpiration rate, stomatal conductance and mesophyll efficiency were generally observed among the productive branches of 10 year old mango trees (33). Leaf photosynthesis was studied in eight almond tree cultivars. The highest net photosynthetic rate was 20.3 μmol/m^2/s in Falsa Barese (5).

Out of 14 citrus species studied, natsudaidai (*Citrus natsudaidai*) and pummelo (*Citrus grandis*) showed the highest net photosynthesis rate, p_n (19 mg CO_2/dm/h) and Satsuma mandarin (*Citrus unshiu*), Yuzu (*Citrus junos*) and ponkan (*Citrus reticulate*) the lowest (12—14 mg CO_2/dm^2/h). Generally, P_n was the highest in species of subgenus archicitrus, the lowest in Metacitrus and intermediate in hybrids such as Kiyomi tangor and Minneola tangelo. The lower P_n of grape plants may be caused by photoinhibition but not the stomatal limitation (34). Under the condition of high temperature and irradiation, the midday reduction of net photosynthetic rate should be mainly attributed to stomatal conductance, which mainly resulted from the increase in vapour pressure deficit (35). The net photosynthetic response to increasing photon flux densities was similar for different foliage position and stage of leaves (36). The net photosynthesis was more pronounced in flowering branches of tree which was topped from 1.5 m height as compared to the non-flowering ones in cultivars of guava (37).

The photosynthetic responses were studied in three citrus species to environmental factors and found that maximum rates of CO_2 assimilation were approximately 9.8, 12.8 and 13.0 m mol/m^2/s respectively, for 'Valencia', 'Murcott' and 'Tahiti' and these differences were related to stomatal conductance and instantaneous carboxylation efficiency (38). The decline in the net photosynthetic rate related to inactivation of PS II reaction centres may be due to the enhanced number of active oxygen species in the citrus leaves (39). Photosynthetic pigment system was studied in leaves of apple tree cultivars 'Auksis' on twelve rootstocks viz., Bulboga, Purel, York 9, B. 9, B. 396, B. 416, B.491, M.9, M.26, P2, P60, P22 and found that in average lower chlorophyll a/b ratio was established for apple tree on P22, higher ratio on rootstocks P60, B.9 and B.146 (40). The increase in pistachio leaf photosynthesis was accompained by a decrease in internal CO_2 pressure and an increase in leaf mesophyll efficiency (41).

Transpiration Rate and Stomatal Conductance

The rate of water supply to the leaves may be an important factor in determining the maximum transpiration rate and thereby mediating control of stomatal conductance and the resultant midday depression in CO_2 exchange rates in citrus trees (42). The transpiration rate increased as temperature rose up to 30 C, decreasing at 35 C to a certain extent depending on the citrus species (43). In the short term and at leaf scale, stomatal movements control the trade-off between net CO_2 assimilation rate (An) and transpiration (E) and hence water use efficiency (WUE) which is the ratio between carbon gain and water loss (44). The increase in stomatal conductance was negatively related to photosynthetic rate per unit area in Satsuma mandarins (45). Old leaves had a higher stomatal conductance (g_s) followed by fully expanded new leaves as compared to that of new leaves (not fully expanded). The physiological behavior of some subtropical species viz., avocado, cherimoys and feijoya were studied in Mediterranean area and found that gross photosynthesis and CO_2 net balance were greatest in avocado leaves and lowest in feijoa. The latter exhibited the lowest water use efficiency and the greatest stomatal conductance and transpiration rate (46). Two apple cultivars differed in transpiration rate may result either from variability in branch structure which affects light interception within the tree crown or from differences in leaf physiological functions or from both (47).

Photosynthesis and transpiration were studied in young Larix Kaempferi trees (C_3 plant) and found that transpiration rate increased continuously with rising temperature between 15 and 21 C and then decreased rapidly above 21°C (36). The net photosynthesis was positively correlated with stomatal conductance, transpiration rate and relative humidity and negatively correlated with intercellular CO_2 concentration (48). 'Braeburn' was more conservative in water use than 'Fuji' due to stomatal limitation of net CO_2 assimilation rate (An), higher intrinsic water use efficiency and lower leaf carbon isotope discrimination (Δ^{13} C) (47). Irrigation frequency significantly increased transpiration rate and stomatal conductance (49). Model validation was studied for estimating the leaf stomatal conductance in Cabernet Sauvignon grapevines and found that the A-g_s model was able to estimate g_s of vine leaves with a root mean square error (RMSE) of 0.05 mol/m^2/s (50).

Yield and Yield Contributing Characteristics

Very little information is available on yield potential of Bael cultivars. The fruiting capacity of four cultivars viz., Kagzi Etawah, Sewan Large, Mirzapuri and Deoria Large were studied. Three hundred to four hundred kg fruits per tree in Kagzi Etawah, 250—300 kg fruits per tree in Sewan Large, 300—400 kg fruits per tree in Mirzapuri and 200—250 kg per tree in Deoria Large variety were found. The number of fruits per tree may go upto 200—400 at the age of 10—15 years (51). Maximum harvest of 44 fruits per tree at the age of 20 years was found (52). Three clones of bael i.e., NB-1, NB-5 and NB-6 were studied and found fruit weight as 920 g, 1006 g and 960 g, respectively (8). Pant Urvashi and Pant Bael-10 showed significantly higher yield efficiency, while Pant Bael-10 and Pant Bael-15 gave higher number of fruits per unit volume of tree (12). Pant Beal-10 and Pant Bael-1 produced higher number of fruits per tree while Pant Shivani produced higher yield in terms of fruit weight per tree followed by Pant Sujata (53). Among 17 genotypes of Bael yield varied from 60—525 kg/tree in Bihar and Uttar Pradesh regions (11). Five varieties of bael were studied and found much variation in fruit weight (563.5—1649.62 g) (54). Comparative studies on seven collections were done and reported variations in fruit weight from 1283—1818 g per fruit (55) On the other hand, variation in fruit weight from 1.55—2.81 kg was recorded (51). Twenty four types of bael from Calcutta, Varanasi, Agra and Delhi were collected and fruit weight ranging from 360 to 1640 g (3). Annual yield in terms of fruit weight per tree was the highest in Pant bael-5, however, yield in terms of number of fruits/tree was found the highest in Pant bael-10 and Pant Bael-1. Annual variation in yield was observed in every strain of Bael (9).

Correlation Studies

There has long been a need for some simple measurement which accurately reflects total size. The simplest field measurement is trunk diameter or circumference. Early workers (56—59) showed that such measurements were related to tree weight and fruit yield. In orchard experiments, yield based on a unit of trunk circumference were more meaningful than yield per tree. This was due to variation in tree size within the given test (59). Tree growth resulting in a doubling of trunk circumference resulted in a 7.3 fold increase in weight of young apple trees (56). A constant and predictable correlation between the volume of a shoot system and cross sectional area of the stem supporting it (57). The both yield and tree growth to be related to trunk circumference was squared or cubed (58). The relationship was expressed by the equation $W=AG^b$, where W=tree weight, G=trunk girth, b=some power of girth and A=a constant. It was showed that 'b' was quite constant within a given trial (60). When this equation was used on other worker's data, it obtained values of 'b' ranging from 2.6—2.87. Trunk diameter and tree height are also important criteria of the tree vigour. To determine correlation between these components of vigour and yield appear to be quite useful for the early prediction of yield (61). Relationship of growth with the yield in different fruit crops have been reported (62—64). In mango, a significant relationship was found between the tree size and yield in Haden and Pairee cultivars (65). The fruit yield/tree was positively and significantly correlated with fruit weight and fruit length in guava (66).

The importance of carbon input to crop productivity is self-evident since 90—95 per cent of the dry weight of the plant is derived from photosynthesis (67). However, attempts to increase yield by the selection of genotypes with high photosynthetic rates have met with only limited success. Significant correlation between net CO_2 assimilation rate (A) and yield have only rarely been observed across cultivars (67—69). This lack of association is thought to result from the methods by which photosynthesis is estimated (70) and complexity of the physiological process governing fruit production i.e., flowering, fruit set, fruit growth, carbon partitioning and photosynthesis. Association between the photosynthetic potential and rate of photosynthesis with yield, earliness and fruit quality in nucellar seedling of the Unshu (=Satsuma) was reported and suggested that the photosynthetic traits might be useful criteria for evaluating breeding material in the early stage of ontogeny (71). High photosynthetic potentials are not necessarily associated with high productivity unless these high rates are sustained during critical periods. One cultivar may have a lower maximum net CO_2 assimilation rate than a second cultivar but still out produce it, if the first cultivar is more responsive to environment or developmental change. Variability in CO_2 assimilation rate was associated with yield, while working on seven cultivars of strawberries (72). Significant correlation was found between photosynthetic efficiency and yield efficiency in Bael clones (10).

Future Aspects

There was a wide range of variation and significant differences among cultivars of various fruits for different traits. The most promising cultivars those have desirable characters can be profitably exploited in commercial production while the physiological traits need to be considered in relation to climatic adaptation and breeding of new cultivars. A wide range of genetic variation has been noticed in dry subtropical belt of North India, North-Eastern and parts of North-Western India. The information about the nature and magnitude of variability in physiological characteristics and associationship among different yield contributing traits would be helpful in formulating an effective breeding programme for its genetic improvement.

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