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Apples (*Malus domestica*, Borkh.) Phenology in Ethiopian Highlands: Plant Growth, Blooming, Fruit Development and Fruit Quality Perspectives

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Fruit quality is the result of a complex interaction of management and environmental factors. By understanding the impact of environment, culture, harvesting, handling and storage on fruit quality, growers should be able to improve both average qualities in their crop as well as improving the proportion of fruit in the highest quality grade. Whilst management practices such as pruning, training, and crop regulation methods contributed widely for development of quality fruit. The relationships between apple rootstock-scion are important and provide a basis for selecting the best graft combination for particular environmental conditions and high fruit quality. Because these interaction influences

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chilling requirements for bud-break, water relations, nutrient uptake, plant size, blossoming, time for fruit set, fruit quality and yield efficiency. Also, both the degree and timing of pruning can affect crop load, fruit size, and fruit quality. Pruning during the dormant winter period resulted in better fruit quality than when pruning was delayed until after fruit set. Early thinning had a positive effect on fruit quality, resulting in larger, firmer fruit with higher sugar levels. However, all these parameters are directly or indirectly affected by the environment. Responses of apple fruit to different environmental conditions (temperature, rainfall, relative humidity of the atmosphere and various soil types) was given prior consideration before starting fruit culture in some location. Even though growing conditions (environmental and cultural factors) influence cultivar performance, this can be well compensated by different cultural practices required for appropriate orchard management such as tree training and pruning, use of artificial dormancy breaking chemicals (Dormex, Winter oil and others) to promote flowering and fruit setting as well as for better yield of cultivars by overcoming the influence of fluctuating temperature that would result in incomplete or partial chilling. Cultivar introduction must be based on its temperature requirements (i.e. low, medium or high) for successful orchard establishment. In most of the tropical highland conditions where apple is growing, introducing low-chill cultivar is recommended for quality fruit production because these cultivars are easily satisfied by the existing low temperature and able to tolerate temperature fluctuation in most of the highland areas. Alternatively, medium chill-requiring cultivars were supposed to grow when supported by hand defoliation followed by dormancy breaking agents better yield with good fruit quality. This review mainly focuses on increasing awareness of the impact of environmental influence on apple fruit tree physiology and how to find out solutions for effective orchard management practices in Ethiopia/tropical highlands for quality and sustainable fruit production.

Keywords: Apples (Malus domestica Borkh); Apple phenology; Research on apples; Orchard management; Dormancy; Chilling requirements; Floral Physiology; Fruit setting; Fruit quality.

1. INTRODUCTION

Apple trees were introduced into Ethiopia some 60 years ago by missionaries, Ralph Wiegand [1], southwestern Ethiopia (>2700 m.a.s.l.), At such high altitudes in the tropics, average temperatures are lower, which allows easier reaching of chilling conditions, but seasonal amplitudes remain low [2]. Unfortunately, systematic observations have been carried out only once in the Ethiopian highlands, on apple cultivars introduced in 1976 [3]. Some productive low-chill apple trees have been mainly restricted to areas with a humid tropical mountain climate in the southern Ethiopia until the past 20 years. As a result, there is little knowledge available about the physiological responses of apple trees to the other highland areas in the country these having rich potential for apples and other temperate fruits, especially sub-humid central and northern highlands where apple production is becoming popular at present.

Ethiopian highlands are endowed with a mosaic of soils and climate which are suitable for the production of many temperate fruits and nut crops. The country is characterized by having diverse topography and agro-ecological zones, of which over 50% of the total area is highland at elevation between 2000 – 4500 m.a.s.l. with adequate water resources and low temperature during winter that can favor many temperate fruit crops to grow [4]. Within these ranges of elevation, it was roughly estimated by the National Agricultural Research

Institute that the cumulative chilling hours during winter month's ranges from 350 – 850 chill units (CU) over three months time, mainly from October to January, but with exceptions [3]. This indicated that cultivars of apples, especially those requiring low to medium chilling units can easily satisfied by these temperatures for adequate flowering and fruit setting. However, the amount of exposure to such temperatures also varies depending on the species and cultivars of apples and ranges from below 100 hours to about 1000 hours, where a one-hour exposure is termed as one chill unit (1 CU) [5]. For example, at Holetta (2400 m.a.s.l., 10°N) in central Ethiopia, the mean minimum and maximum temperature during dormancy and fruit growing period was 2.7 and 22.4°C, respectively). Under this conditions experience indicates that most temperate fruit cultivars may not undergo their complete chilling requirement that would significantly affect fruit quality. They rather undergo partial dormancy unlike the low temperature signal followed by deep dormancy (rest) they usually experience in the temperate region. For this reason, at Holetta many species and cultivars flower between early September to January, before the cold period begins or is over [6]. The type and amount of chilling temperature is expected to vary considerably with the different areas of the highland domain apparently for reasons such as altitude, temperature, location and moisture regimes and water bodies. These have caused variation in dormancy phenomena. This calls for characterization of the growing regimes for effective chilling temperature and selection of cultivars adaptable to the specific ecological niches. This review emphasizes on considerable information available on the impact of environment and many nursery and orchard management practices on apple fruit tree growth and quality fruit development under tropical highland conditions

1.2 Objectives

1. To review the achievements and constraints of apple research and production in some major apple growing areas of Ethiopia.
2. To produce data basis that can supply adequate information for present and future research and production activities.
3. To review the production experiences from apple growing areas across tropical regions that would be helpful to adopt some important cultivation practices and to backup the existing research and production.
4. To review the existing production practices, constraints, adoption of new technologies, in order to amend the existing practices by supplying the necessary information.

2. MATERIALS AND METHODS

All institutions in Ethiopia (Government, NGOs, and Private Companies) that are involved in apples and other temperate fruits research and production were contacted in 2013 and supplied the necessary information based on their experiences and innovation on apple fruit tree production in Ethiopia. This was supported by interviews with key informants and by reviewing secondary data from reports of the aforementioned institutions. The data showed the past and present situations in apple fruit tree research and production. We focused on producing data base to be made available from past experiences and present situations that would be helpful in predicting future dynamics of apples and other temperate fruit tree production in respect of climate change. So that the information should be web based and accessible by any of the institutions anywhere that helps to amend the before recommendations with respect to the future research and production regime; also defining

environmental variables that can determine fruit yield and quality at different production niches in the country.

Also, reviews on apple research and production from global perspectives were included in this paper to compare the national research trends and to improve its drawback. Databases comprising information from online libraries were browsed using the following main search terms: (i) Physiological response of apples to different growing conditions, (ii) Apple phenology in tropical highlands, (iii) Growth and development of apple trees, (iv) Pest and disease management for apples (v), The influence of rootstocks for better growth and yield of apple (vi), Eco-physiological response of apple trees to different environmental variables (vii), Agronomic management practices for successful apple production, (viii) Tree training and pruning and, (x) Selection of apple tree cultivars for tropical environment.

Readers are referred to original articles on Ethiopian apple research and research articles browsed from online libraries for detailed analytical methods and interpretation of results; all resources used for this review are duly cited.

3. POTENTIAL OF TEMPERATE FRUITS PRODUCTION IN ETHIOPIA

3.1 Environmental Influence of Temperate Fruit Tree Production

Temperate fruits can successfully produced at highland areas of Ethiopia where there is sufficient low temperature requirement to break dormancy and resume growth; that has been quantified as between 0 - 7°C for high chill requiring and 3 - 8°C for low chill requiring cultivars. However, most of the cultivar introduction focused on low chill requiring cultivars to overcome the high temperature fluctuation during winter months that would result in incomplete chilling. Some temperate fruits cultivars can break dormancy at 10 - 12°C, but, the amount of exposure to such temperatures also varies depending on the species and cultivars of fruits and ranges from below 100 hours to about 1200 hours, where a one-hour exposure is termed as one chill unit (1cu).

At central highlands (Holetta), which is 2400 m.a.s.l., 10°N, mean minimum and maximum temperature during dormancy and fruit growing period is 2.7 and 22.4°C, respectively. Experiences indicates that most of temperate fruit cultivars may not undergo complete dormancy due to temperature fluctuation that they rather undergo partial dormancy unlike the low temperature signal followed by deep dormancy (rest), they usually experience in the temperate region. For this reason, at Holetta many cultivars of apple flower between early September to January, before the cold period begins or is over. According to chilling estimation, Holetta receives chilling as high as 650 cu between Septembers to January without taking in to account the reversed chilling due to high day temperatures [6]. The net effective chill unit is expected to be much lower than 650 cu if the high day temperature during this period is considered. Such unsynchronized dormancy breaking and low temperature availability, however, remains to be a problem unless low chill requiring cultivars are introduced. Cultivars that require high chill unit tend to face complicated dormancy problem and cannot easily come out of dormancy with the available chilling temperature. The type and amount of chilling temperature is expected to vary considerably with the different areas of the highland domain apparently for reasons such as altitude, temperature, location and moisture regimes and water bodies. These have caused variation in dormancy phenomena. This calls for characterization of the growing regimes for effective chilling temperature and selection of cultivars adaptable to the specific niches identified.

At relatively higher altitudes like Chench (2700 m.a.s.l.) in the southern parts of the country and others, the chill requirement of high chill cultivars may not be satisfied during the main rainy season as in the case of Holetta in central highlands. However, this requirement is satisfied during the coldest period that is October to January. Thus such cultivars break dormancy after the cold period. Hence based on the provision of amount of chilling temperature, the highland areas can be clustered as high, intermediate and relatively low growing regimes. Thus, at intermediate and higher altitude many cultivars showed promising adaptation.

3.2 Production Experience of Fruit Tree Crops in Ethiopia

Fruit production in Ethiopia has been limited to tropical and sub-tropical fruits such as banana, citrus, papaya, mango, avocado etc. in the lowlands. With the exception of South and Southwestern parts of the country, highlanders are not producing fruits that supplement their cereal-based diets with vitamins and minerals [7]. Lack of adequate nutrition in addition to the continuous impoverishment has been causing malnutrition. In addition to balancing the diet, temperate fruit production can contribute to increasing the income of the producers where there is a limited cash crop, diversify crop production, have a positive ecological effect on soil and water conservation, create employment opportunities for many and increases the land carrying capacity.

Production of temperate fruits in Ethiopia is highly promising even though the culture is new to the farming society and is limited to few places in the highland areas. Its development is not yet well integrated into the agricultural system in-terms of use of resources such as land, water, labor, etc. and experience in production, handling, use and marketing of the fruit is minimal. From the various observation and adaptation trials conducted in the country, some promising materials of apple cultivars Anna, Winter-banana, Granny smith, Golden Delicious, Red delicious Gala and Crispin; peach cultivars McRed, Florida Red and Florida Bell, and plum cultivars Beauty, Methley and Shiro were identified for production at central highlands and similar agro-ecologies [8].

Peaches and plums are produced in the highland areas in small patches in home gardens. This is particularly true for growers near urban areas. Currently, however, there is a growing awareness among the highland communities and efforts are being made to expand the production in several highland places by government organizations, non-government organizations (NGOs), and private growers [9]. The major growing areas include Chench, Bonke and Boreda in south, and Degem, Debre Birhan, and Agena, in central Ethiopia where the development of temperate fruit production was started at large.

There is no statistical evidence on the total areas covered and annual production of temperate fruits in the country. At present temperate fruit growing farmers produce the fruits at their home garden in pocket areas like in Gamo Gofa zone (Chench and neighboring districts), in southern region, North Showa zone (Degem, Hedabu Abote, Alidoro, Debre Birhan) in central region, Gurage Zone (Agena, and Mohir and Aklil) in south central region, and some parts of Northern Ethiopia (Kutaber, Debre Tabor, Dabat, Guagsa shekudad, Kosober, Adigirat, Mekelle, and Hagereselam) are benefiting from the production apples and other temperate fruits [9]. Also, fruit production and planting material propagation are becoming important businesses at Chench, Degem, Agena and Kosober areas whilst temperate fruit development is expanding at faster rate in these areas. Fruit produced from these areas are mainly destined to large cities like Addis Ababa.

The practice of temperate fruits production has brought about changes in livelihood of the community at Chencha in south and farmers are benefiting tremendously both from the sale of the fruits and seedlings [1]. The fruits are being sold predominantly to supermarket chains, Embassies and hotels in Addis Ababa whereas the seedlings are sold to farmers and private investors in various parts of the country. Today in Chencha, temperate fruits production is a lucrative business and has therefore become a common practice to the extent that it is common to find one or more varieties of apples, pears and plums in the backyards of farmers [1].

4. TRENDS IN TEMPERATE FRUITS RESEARCH IN ETHIOPIA

4.1 Experiences of National Agricultural Research Institutes (EIAR) In Germplasm Introduction and Evaluation

The national research system should involve in developing adaptable cultivars for different production niches, appropriate disease control measures, cultural practices, post-harvest handling, and extension and marketing studies. Among temperate fruit species, peach is relatively well established in many highland areas. The others species such as apple, pear, plum and nectarine are introduced to the country at different times by researchers and missionaries. The first recorded introduction of temperate fruit germplasms to Ethiopia was made in 1971 from California for preliminary observation to see their adaptability performance [10]. The introduced materials were mainly different cultivars of apple, peach, nectarine, plum, quince, almond, apricot, fig and persimmon. These materials were planted first at Nazareth Agricultural Research Center for establishment and later on further testing was made across locations at different highland agro-ecologies such as Holetta, Kulumsa, Bekoji, Koka, Bako, and Jimma areas [10]. The success in adaptability of these introduced materials was observed at Holetta (central highlands). For other locations except for Bekoji, the trials were terminated because of adaptability problem. At Holetta, the result revealed that some apple cultivars (Anna, and Winter banana), peach cultivars (McRed, Florida Red, Florida Bell) and plum cultivars (Shiro, Beauty and Methly) showed promising adaptation to central highland conditions [11].

EIAR [3] conducted variety testing using those successfully adapted apple cultivars across locations (Holetta, Bekoji and Kulumsa) for further confirmation of their adaptability and yield performance with the aim of recommending cultivars to the growers. Thus, at Holetta and Bekoji, the adaptability was impressive where as at Kulumsa it was found unsatisfactory. Similarly, EIAR [6,12] introduced some apple, peach, nectarine and plum cultivars at different times for adaptability studies at Holetta Research Center in central Ethiopian highlands [12]. From all these observations some selected temperate fruit tree cultivars were recommended for production in the majority of the highlands in the country. These include apple cultivars (Anna and Winter Banana), peach cultivars (McRed, Florida Red and Florida Bell) and Plum cultivar (Beauty). As indicated in research report, apple cultivars Anna and Winter banana gave 310 q/ha and 250q/ha, respectively Whilst peach cultivar McRed, Florida Red and Florida Bell gave 460 q/ha, 266q/ha, and 234q/ha respectively. Plum cultivar Beauty gave 160 q/ha. At present these cultivars are recommended for production at central highland conditions and similar locations in northern and southern regions of the country. However, the problem was observed on fruit qualities due to temperature fluctuation during winter months and little professional experience on orchard and canopy management that contributed for fruit quality.

EIAR [8] re-initiated multi-location variety evaluation at three representative locations (Holetta, Bekoji and Debre-birhan) using the already tested apple cultivars (Anna, Winter Banana, Granny Smith, Mustu/Crispin and Red Delicious) for further checking of their yield potential across locations. The result showed that cultivar Anna performs better, followed by Winter Banana and Granny Smith in these tested locations. Crispin and Red Delicious showed weak performance indicating that these cultivars require more chilling temperatures than other cultivars tested [13]. On the other hand, in some higher altitudes like Chench (2700 - 3200 m.a.s.l.) in the south, apple cultivar 'Bond Red' (BR – 64) on average gave up to 180 q h⁻¹ year⁻¹. In the same location other varieties such as Granny smith, Crispin, Red Delicious were also observed to produce about 20-30 kg per tree [1].

4.2 Research Experience of Higher Institutions

Dereje, et al. [4], investigated five apple cultivars (Golden Delicious, Gala, Fuji, Granny Smith and Jonagold) grafted on M9 rootstocks in two locations of northern Ethiopian highlands of the Tigray region (Hagere Selam and Mekelle), with the aim of evaluating these cultivars with different artificial dormancy-breaking treatments. Trees were subjected to defoliation and different dormancy breaking treatments using hydrogen cyanamide (Dormex) and winter oil at different levels, and a control with no defoliation and dormancy breaking treatments. The results showed positive effects of the dormancy breaking agents on the productivity of the trees after defoliation, with comparable results for the effectiveness of both dormex and winter oil Fig. 1.

Dereje et al. [4] also indicated that yields increased as a result of better flowering time synchronization within a tree (Fig. 2) but even with the dormancy treatments the length of the flowering period was still spread over five weeks, where under a more temperate climate it lasted two to three weeks. The same authors indicated that the average fruit weight of Jonagold and Granny Smith can be considered as a good fruit quality while the fruit of other diploid cultivars like Golden, Gala and Fuji were rather small, which indicates that fruit thinning by hand will be a necessity for these cultivars (Fig. 3). Also, red coloration of the apples on the cultivars Gala and Jonagold was excellent and meets apple quality requirement.

Clearly, for commercial production of apple in tropical highlands, using dormancy-breaking agents have positive effects on the productivity of the trees after defoliation. The defoliation treatment alone was not sufficient to break the dormancy, but, showed good result in combination with dormancy breaking agents [4].

Kebede and Masresha [14], reported the performance of seven apple cultivars (Granny smith, BR-64, Red delicious, Golden delicious, Crispin, Gala and Anna) grafted on MM-106 rootstock at a mature stage in three different altitudinal zones of southern Ethiopia (Chench, Boreda and Bonke), with special focus on their phenological regimes such as leaf shed, blooming, fruit set and maturity. The result revealed that leaves are receptor for short day response that encourages natural defoliation with subsequent chilling temperature requirements in a non-uniform pattern. Thus, the earliness and delay in leaf defoliation depends on cold temperature condition of the altitude in which the cultivars are grown Table 1. Also, floral initiation and bud break depends on the adequacy of cold temperature in which the cultivar grows Table 2. It seems that the development of blooming earlier after cold season indicates that the tree receive sufficient chilling Table, 3 while delayed blooming seems to be inadequacy of chilling temperature which limit cell division, blossoming and leaf development [15]. Accordingly, the bloom time varies with the resumption of growth at

different times Table 4 and categorized into three in such a way that those that bloom in September are considered to be early bloom (E), in October are mid season bloom (M) and November, late season bloom (L) [16].

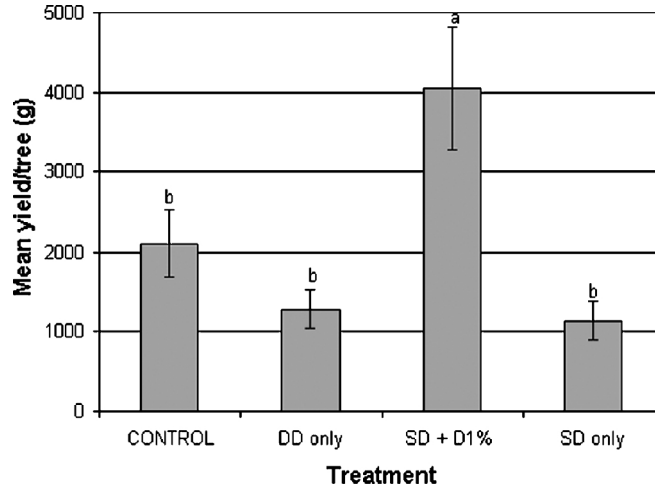


Fig. 1. Effect of Dormex on the mean fruit yield/tree in HS and MU ($n = 128$). SD and DD are single and two defoliations per year, respectively; D1% Dormex application with its concentration (2004/05). Values with the same letter are not significantly different at $\alpha = 0.05$ (Tukey–Kramer HSD test) [4]

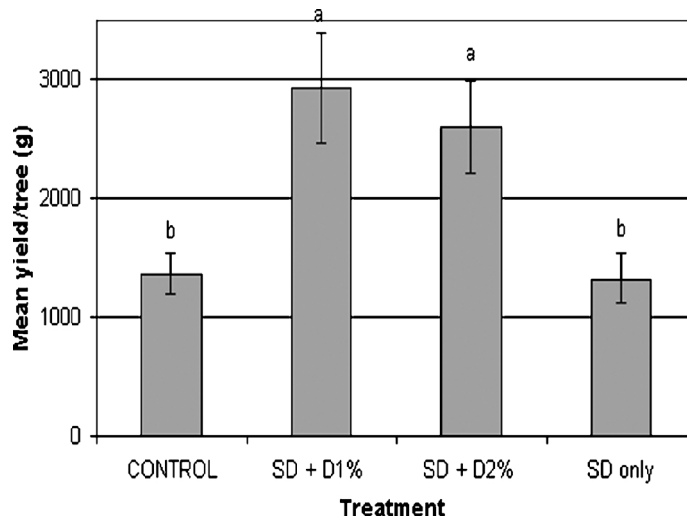


Fig. 2. Effect of Dormex on the mean fruit yield/tree in HS and MU ($n = 144$). SD: single defoliation; D1% and D2%: Dormex application with its concentration (2005/06). Values with the same letter are not significantly different at $\alpha = 0.05$ (Tukey–Kramer HSD test) [4]

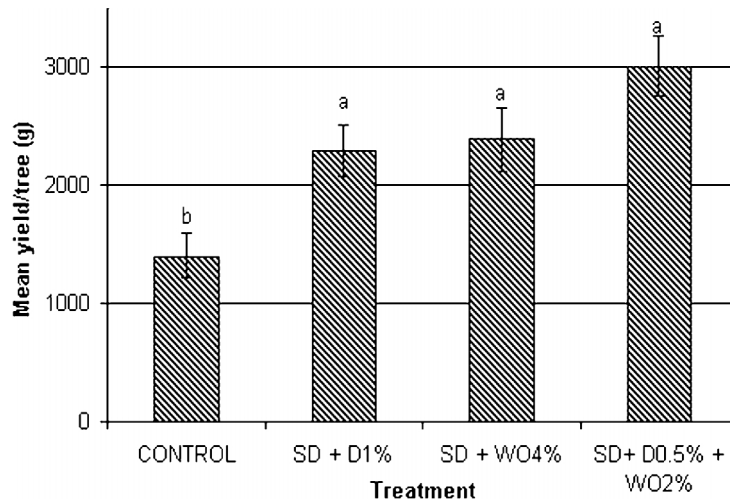


Fig. 3. Effect of Dormex and winter oil on the mean fruit yield/tree in HS and MU in 2005–06 ($n = 208$). SD single defoliation; D0.5%, D1% and D2% Dormex applications and WO4% and WO2% winter oil applications with their concentration. Values with the same letter are not significantly different at $\alpha = 0.05$ (Tukey–Kramer HSD test) [4].

Table 1. Leaf shed performance of the seven apple tree cultivars at three different altitudes [14]

Cultivar	Leaf shed		
	Districts/Time of the year when leaf shade occur		
	Bonke/3200 m.a.s.l./	Chencha/2700 m.a.s.l./	Boreda/2300 m.a.s.l./
Granny Smith	June	June	Jul – Aug
BR-64	Mid- May	June	Jul – Aug
Red Delicious	Mid- June	July	June
Golden Delicious	Jul – Aug	Jul – Aug	June
Gala	Mid – June	June	Jul – Aug
Crispin/Mutsu	ND	June	June
Anna	NK	NK	June

* ND = no data, * NK = not known

Table 2. Leaf development and blooming of apple cultivars at different Altitudes [14]

Cultivars	Leaf development and blooming (months)		
	Bonke/3200 m.a.s.l./	Chencha/2700 m.a.s.l./	Boreda /2300 m.a.s.l./
Granny smith	End of Sept.	Oct.	Nov.
BR- 64	Sept.	Sept.	Nov.
Red Delicious	Oct.	Oct.	Oct.
Golden Delicious	Nov.	Nov.	Oct.
Gala	End of Sept.	Oct.	Nov.
Crispin	ND	Oct.	Oct.
Anna	NK	NK	Sept.

* ND = no data, * NK = not known

Table 3. Duration of blooming of apple tree cultivars at different altitudes (Source: [14])

Cultivars	Blooming shed in weeks		
	Bonke/3200 m.a.s.l./	Chencha/2700 m.a.s.l./	Boreda /2300 m.a.s.l./
Granny smith	2	2	3 - 4
BR- 64	2	2	3 - 4
Red Delicious	3 - 4	2	2
Golden Delicious	3 - 4	2	2
Gala	2	2	3 - 4
Crispin	ND	2	2
Anna	NK	NK	2

* ND = no data, * NK = not known

Table 4. Fruit maturity, fruit size and color of the some apple cultivars at different altitudes [14]

Cultivars	Bloom to harvest (days)	Bloom time			Fruit size	Fruit color
		Bonke/3200 m.a.s.l./	Chencha/2700 m.a.s.l./	Boreda /2300 m.a.s.l./		
Granny smith	180 – 210	M	M	L	Ms- -Ls	Green
BR- 64	180	E	E	L	Ls	Reddish yellow
Red Delicious	180 – 210	M	M	M	S	Red
Golden Delicious	180	L	L	M	Ms - Ls	Yellow green
Gala	210	E	M	L	S- Ms	Red
Crispin	150 – 180	-	M	M	Ls	Yellow green
Anna	120 - 150	-	-	E	Ms	Blushed

N.B. E= early, M= mid season, L= late season, S= small size, Ls= large size Ms= medium size

5. GROWTH AND DEVELOPMENTAL PHYSIOLOGY OF APPLE FRUIT TREES

5.1 Propagation Nursery of Apples

Good quality planting material provision is a prerequisite for successful temperate fruit development in Ethiopia. Temperate fruits are propagated both sexually and asexually. Propagation of planting material is a highly specialized field, which considers site selection, identification of appropriate rootstock and scion materials, and proper skills in raising rootstock plants, grafting, and caring for the grafted plant. As observed in the growing areas, most nurseries propagate apple. Some of the rootstock and scion cultivars under propagation were not selected through proper evaluation for their adaptation. Techniques that are used for propagating the rootstocks and scions in most nurseries vary depending on the skill of the nursery men. Standard method and procedures of rising the rootstocks, selecting the scions, grafting and other nursery cares are not well established due to lack of skills. Due to high cost of planting material, farmers are tempted to involve in the propagation practices without the proper training and availability of land, water and nursery tools. Thus, the planting materials produced and distributed mostly are below standard.

After propagation, planting materials are distributed regardless of the specific requirements of the cultivars (chilling) and locations. For instance, apple cultivars such as Granysmith, Bond Red and Crispin produced at Chehncha (2700 m.a.s.l.) are distributed to lower

elevation areas and vice versa where they may not be adaptable to give good yield and quality fruits. In general, the current situation in Ethiopia reveals that propagation, nursery management activities and distribution of grafted planting materials of temperate fruits were handled in haphazard manner which can hamper temperate fruits development in the future.

5.2 Rootstocks for Apples

It is well known that growth, flowering and fruiting of apple cultivars are greatly affected by rootstocks [17]. Rootstocks possess an important physiological traits that contribute to the scion (cultivar), by controlling tree size, keeping uniformity in tree growth, precocity, earliness to flower, tolerance to temperature extremes, resistance to soil borne pests and diseases as well as influencing fruit size and quality [17,18,19]. Accordingly, an ideal rootstock for apples can be (i) free standing, (ii) high yielding (iii) high quality, (iv) disease & insect resistant, (v) precocious, and (vi) dwarfing, and graft compatible.

The rootstock clones of apple are divided to three groups: strong growing (standard), medium strong growing (semi-dwarf) and dwarfing types. They are derived from different series of origin and from these, the 'M' series is the most popular apple rootstocks worldwide. The 'M' series had been selected in East Malling (M), England. For the identification of each clone in the series after the 'M' every clone has a number. The 'MM' series was created in Merton through cross breeding and their number series is between 100 and 120. The most important apple rootstocks [19] are: (i) dwarfing types: M27, M9, M26 – Height: Between 1.8-3.0 m, (ii) Medium-strong growing (Semi dwarf): MM106, M7, M4, MM104, M2 – Height: around 4.0m, and (iii) Strong growing: MM111, MM109, M10 – Height: Between 4.8-5.5m.

Many authors reported that rootstocks are categorized in series of orders based on the place they were developed as standard rootstocks for apple scions [17-19]. Accordingly the major types valued for production at present are : (i) Malling Series (England) started with prefix MM: M4, M7, M 9, M 26, MM 106, and MM 111, (ii) Poland series started (P) 1, 2, 16, 18, 22, (iii) Budagovsky series (B) 9, 490, 491, (iv) Canada - Vineland 1, 3; Ott. 3, (v) Geneva series: Started with G – 10, 11, 24, 29, 30N, 30T, 65, 202, 210, 935,814, 7707, and (vi) the Michigan – MARK, MAC 1 and 39.

Accordingly, in Ethiopia the research report from national research institute [6] indicated that most of the rootstock used is MM-106 rootstock of semi-dwarfing types because of its adaptability to different altitudes and soil types as well as the tree grafted on MM-106 bears within 3 – 4 years Table 5. Also the research report indicates that cultivars propagated on MM-106 rootstock are usually productive, good anchorage, precocious, easily satisfied by the existing chilling temperatures and reasonably gave good yield. Furthermore, Wesley [20] documented that MM-106 rootstock performed well across all areas suggesting wider than expected adaptability in most of the tropical highlands.

Thus, the use of different rootstocks influences differently the vegetative and reproductive development of the trees and probably it would exert influence on the physiological process of the canopy dormancy [13]. Exposing apple rootstocks to chilling privation conditions, with the previous exposition of the scion to chilling, Young, et al. [21] verified deficient development of bud-break of the scion cultivar. Finetto [22] reported that rootstocks can have significant contribution in apple bud-break when scion was submitted to conditions of insufficient winter chilling accumulation. The same author evaluated 'Golden Delicious'

apples grown on different rootstocks in Italy and observed the rootstocks affect the chilling requirement of the scion cultivar when conditions were not sufficient.

5.3 Apples Shoot Growth and Leaf Area Development

Growth in an apple tree takes several forms. It includes the readily visible development of extension shoots, leaves, and fruits as well as the less conspicuous thickening of stems and the development of roots [19]. Accordingly, all forms of growth require the assimilated materials manufactured by the leaves. Lauri and Trottier [23] found that early-season growth is dependent on stored carbohydrate and nitrogenous reserves derived from photosynthetic activity of the previous season. Later in the growing season current photosynthate is utilized to support growth of the tree and crop, and to restore reserves for the coming dormant period and the initial phases growth the following spring [23,24].

The leaf area estimates of apple tree cultivars were measured by non-destructive method, that would be the result of the average leaf length (LL) multiplied by leaf width (LW) [16]. Accordingly, the leaf area significantly influences fruit size and there is a positive and significant correlation between leaf area and fruit size. Similarly, Kebede and Masresha [14] reported the influence of leaf area on fruit size was significant and varied with nature of cultivar via altitude and microclimatic conditions. Accordingly, seven apple cultivars were compared at different altitudes in southern Ethiopia, and the result indicates that the influence of leaf on fruit size is significant in most cases Table 6.

Based on the data obtained from the seven apple cultivars, Leaf area (LA) and new shoot growth performance an attempt was made to compute the Spearman's rank correlation coefficient (r) between the new shoot growth and leaf area at three altitudinal zones [14].

At Boreda, the calculated $r = 0.91$ suggesting that, there is significantly strong positive correlation between the ranking. The new shoot growth ranking is related to with the site of the area in which the cultivars grows. As shown in Table 7. Anna, Crispin and Golden delicious perform better at 2300 m so as they ranked high as compared to BR-64, Granny smith and Gala in the same location.

In Chenchu, the calculated $r = 1$ shows that the correlation between rank is perfect positive. It mean that there was proportional ranking of the performance between the new shoot growth and leaf area (LA). As observed in this altitude, BR-64, Granny smith, and Gala cultivars showed an increase in their growth performance along the higher altitudes indicating that they require more chilling temperature for bud break when compared to other cultivars included in this observation such as Anna and Golden delicious Table 8.

At Bonke the calculated $r = 1$ shows the correlation between the ranks is perfect positive Table 9. There was proportional ranking of the performance between the new shoot growth and leaf area (LA). Thus, at 3200 m BR-64, Granny smith and Gala ranking is high whilst Anna and Golden delicious is low, indicating that the former cultivars seem to be better adapted than the later. The cultivar Red delicious ranks moderate in all sites, however, its leaf area ranks least in Boreda.

Table 5. Comparison of the performance of six apple cultivars grafted on four different rootstocks of the MM- series in southern Ethiopian highlands [14]

Rootstock	Cultivars propagated	Average Plant height (mt)	Age when fruit set (years)	Yield	Vigorosity	Precocity	Tolerance to eliminate soil condition
MM-106	All four cultivars	2.7 – 3.5	3- 4	Very high	Moderately semi-dwarf	Grows as Central leader	High
MM-111	GS, RD, GD,CR	3.3 - 7	5 - 7	Low	Very high	Grow as spreading branch	Moderate
MM-104	GS, Ga, CR, An	2 - 2.8	3 - 4	Low	High	Grow as bushes	Very high
M-27	Anna	1 – 1.8	2 - 3	Very low	Very low	Grow as central leader	Very low

GS = Granny smith, GD = Golden delicious, RD = Red delicious, CR, Crispin, Ga = Gala, An = Anna, mt = meter

Table 6. Influence of leaf area (cm²) on fruit size (cm³) [14]

Cultivars	Altitudes (m.a.s.l.)					
	2300m		2700m		3200m	
	Total leaf area (cm ²)	Fruit volume (cm ³)	Total leaf area (cm ²)	Fruit volume (cm ³)	Total leaf area (cm ²)	Fruit volume (cm ³)
BR- 64	26.79	219.40	36.76	264.10	48.72	297.10
Granny smith	21.70	115.90	34.95	219.40	40.60	273.70
Gala	23.50	108.80	30.50	156.50	36.20	205.70
Anna	37.10	197.70	14.90	83.00	10.30	62.90
Golden delicious	30.47	154.30	12.70	135.00	8.16	107.00
Red delicious	21.27	145.60	17.40	121.50	21.04	135.00
Crispin	25.90	192.50	23.60	167.90	ND	ND

*ND = no data

Table 7. Rank correlation coefficient of new shoot growth and leaf area (at Boreda, 2300 m.a.s.l.)

Cultivars	BR-64	Granny smith	Gala	Anna	Golden delicious	Red delicious	Crispin
Ranks in new shoot growth	4	6	7	1	3	5	2
Ranks in leaf area (LA)	4	6	5	3	2	7	1

Table 8. Rank correlation coefficient of new shoot growth and leaf area (at Chenchu, 2700m.a.s.l.)

Cultivars	BR-64	Granny smith	Gala	Anna	Golden delicious	Red delicious	Crispin
Ranks in new shoot growth	1	3	4	6	7	5	2
Ranks in leaf area (LA)	1	3	4	6	7	5	2

Table 9. Rank correlation coefficient of new shoot growth and leaf area (at Boke, 3200 m.a.s.l.)

Cultivars	BR-64	Granny smith	Gala	Anna	Golden delicious	Red delicious	Crispin
Ranks in new shoot growth	1	2	3	5	6	4	ND
Ranks in leaf area (LA)	1	2	3	5	6	4	ND

5.4 Floral Physiology of Apple Fruit Trees

Apple flowers are borne on two types of shoots, spurs and long shoots Fig. 4. The spur is a short shoot in which extension growth is limited to the production of a rosette with few leaves [1]. The axis of the spur is called the 'bourse' which can continue to produce short shoots from the axillary buds in the following seasons [26]. Long shoots are the extension shoots of the current season's growth, and, particularly in new cultivars, can produce flowers from both terminal and axillary buds [27].

Meristems of developing vegetative buds include several appendages: bud scales, bracts, transition leaves and true leaves. The vegetative buds must be fully developed for the transition to floral buds to occur [28]. The appendages begin developing when growth resumes in spring. A critical appendage (node) number in vegetative buds [29] and reported as 16 for 'Golden Delicious' [30]. Attainment of the critical node number appears to be the prerequisite for a bud to make the transition from vegetative to floral; no compelling reason can be cited but there is experimental evidence supporting this critical node requirement [31,32,33]. The rate of node development needs to be fast enough to ensure the critical node number is reached before the end of the growing season; this is most important at high latitudes with short growing seasons [34].

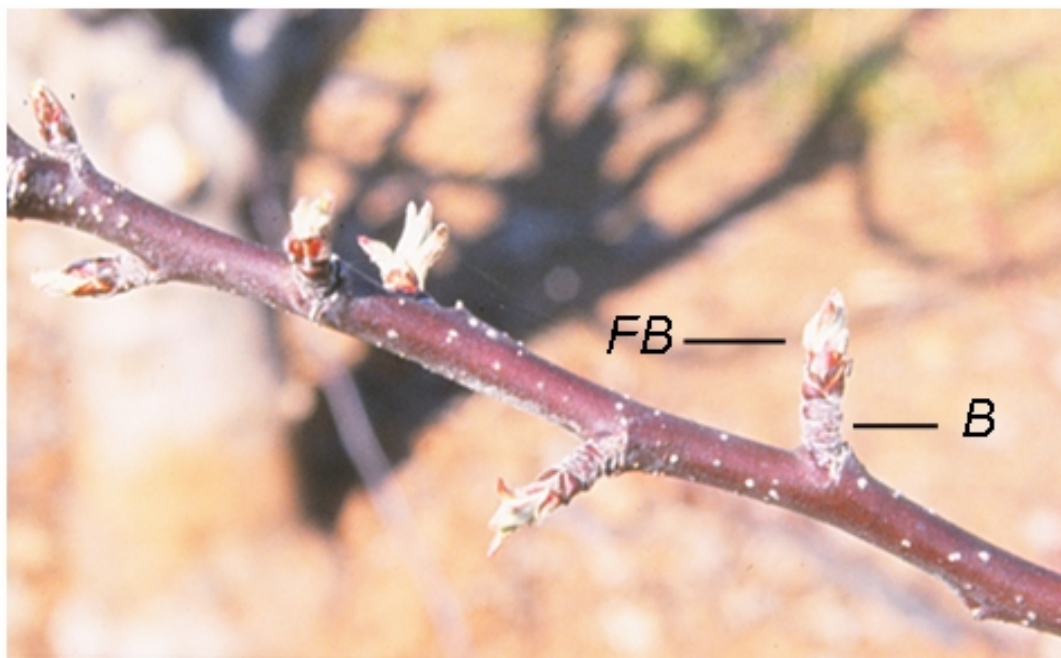


Fig. 4. Apple flower buds (FB) are often initiated on terminal buds of short shoots called spurs, the axis of the spur is called the bourse (B). Flowers are initiated during the growing season before winter dormancy, anthesis occurs in the spring when the chilling requirement of winter dormancy has been satisfied and temperatures are suitable for growth [28]

The first sign of transition from vegetative to reproductive growth is doming of the apical meristem which, in spurs, may occur approximately 50 days after full bloom [35]. Lateral floral meristems and bracts then develop until the terminal and lateral flowers have initiated sepals [35], this differentiation may continue throughout the autumn until the onset of winter dormancy [36]. The flowers are completed after the release of dormancy between bud burst and anthesis [36].

Environmental conditions exert some control over floral initiation in apple. Heat unit accumulation could not consistently account for the timing of floral initiation in 'Royal Gala' [32], but the temperature during the growing season can affect the intensity of floral initiation and it may be that temperatures which induce high vegetative vigour that reduce floral initiation [27]. Low irradiance has been shown to inhibit floral initiation on spurs. Flowering on spurs was not affected at up to 30% shading but was totally inhibited when shading increased to 70% of the available light in cultivar 'McIntosh' [37].

5.5 Pollination in Apples

Pollination is a very important and inseparable component in respect of regular and consistent production in a number of fruit crops. In a crop like apple, pollination is of utmost significance and its proportion and magnitude is primarily based upon appropriate selection of varieties [38]. Almost all apple varieties need to be cross pollinated, although some

varieties, such as Liberty, Empire, Jonathan, Jonagold, Gala, Golden Delicious, Rome and Granny Smith are self-fruitful, but they still set more fruit through cross pollination [39].

Usually, in an apple orchard, every four rows is a pollinizer variety or within a row, every fifth semi-dwarf tree is a pollinizer Fig. 5. The maximum allowed distance between the tree and its pollinizer is 25 meters at most [40]. The compatibility between pollinizer and pollinated tree depends on the blooming time Fig. 5. There are three main groups: Early season, Mid season and Late season cultivars. If the grower plants an early season cultivar together with a late season pollinizer, the pollination will not happen. Therefore, during the selection of a pollinizer the grower should consider its bloom time period [40]. Apple pollination also needs a pollinator. The best pollinator is the honey bee. If possible, when the flowers open up, some beehives should be placed in the orchard. The recommended number of beehives per hectare is three for standard size apple, five for semi-dwarf and eight for dwarf type trees [39].

5.6 Physiology of Dormancy (Rest Period) Requirement

Dormancy is commonly separated into a rest period, when the buds remain dormant due to growth-arresting physiological conditions, and a quiescent period, when the buds remain dormant due to unfavorable environmental conditions [41]. This dormancy or sleeping stage protects these buds from oncoming cold weather. Once buds have entered dormancy, they will be tolerant to temperatures much below freezing and will not grow in response to mid-winter warm spells [42]. These buds remain dormant until they have accumulated sufficient chilling units (CU) of cold weather. When enough chilling accumulates, the buds are ready to grow in response to warm temperatures. As long as there have been enough CUs the flower and leaf buds develop normally. If the buds do not receive sufficient chilling temperatures during winter to completely release dormancy, trees will develop one or more of the physiological symptoms associated with insufficient chilling include delayed foliation, reduced fruit set and increased buttoning, and reduced fruit quality [2].

5.7 Chilling Temperatures Requirement

Studies have used different models to calculate chilling unit accumulation: temperatures of 1.5–12.4 in the Utah Model [43], 1.6–13°C, Shaltout and Unrath, [44] and 1.8–16.9°C in the North Carolina Model in the Low Chilling Model [45], which positively contribute to chilling unit accumulation. Sunley et al. [46] carried out comparisons of various chill models (<7.2°C, 0 – 7.2 and Utah) and found a linear relationship among models except for the Utah model. Labuschagne et al. [23] reviewed the chilling requirement of different varieties varies from 200 to 1100 hours, and can be higher according to cultivar requirement and influenced by genetic variation. Bernardi [47] categorized the chilling requirements of the cultivar Gala as low, Granny Smith as intermediate and Golden Delicious, Fuji and Jonagold as high. Legave et al. [48] reported that global warming (in France, 1976–2002) resulted in longer mean duration (3–5 days) needed to satisfy the chilling requirement of apple cultivars.

Defoliation, i.e. removal of mature foliage after harvest, prevents the buds entering into endo-dormancy after growth has stopped and instead stimulates them to regrow [53]. The bud break of apples in the tropics, due to defoliation, is preceded by a large increase in both concentration and amount of gibberellins in the apex tissue of closed buds [54,55] and a decline in abscisic acid concentration [40] in the bud. As reviewed by Edwards [55], if the timing of defoliation is correct, bud burst follows within one to four weeks.

Many chemicals show rest-breaking properties on buds but only a few have gained commercial acceptance [13,54]. Effects of chemicals such as Dormex (hydrogen cyanamide, CH₂ N), potassium nitrate and winter oil [169] on the bud break of apple trees have been evaluated in Kenya, Morocco and Zimbabwe and positive responses produced [51,56,57].

5.8 The Concept of Chilling Hours and Chill Units

Chilling hours and chill units are both used for predicting the release of dormancy. Chilling hours are determined as (i) the number of hours (H_C) with air temperature below 7°C or (ii) the number of hours (H_O) with air temperature between 7 and 0°C [58]. Accumulation of chilling hours begins in the late summer or fall when temperatures fall below 7°C and the cumulative H_C or H_O at bud-burst, specific to a species and variety, are determined over several years. Then the mean cumulative HC or H_O are used to predict bud-burst in future years.

When using chill units (CU), the hours are weighted for the effectiveness at breaking rest depending on the temperature. For example, in the Utah model [43], temperatures between 1.5 and 12.4°C contribute to releasing dormancy. However, the effectiveness of the chilling hour is weighted according to the factors given in Table 10. An hour with the temperature between 1.5 and 2.4°C contributes 0.5 CU = 1h × 0.5 to the chill unit requirement. An hour with the temperature between 2.5 and 9.1°C is fully effective, so it provides 1.0 CU= 1h × 1.0. Below 1.5°C, there is no contribution to meeting the chilling requirement, so CU = 0. For temperatures at 16.0°C and above, the chill factors are negative implying that higher temperatures detract from the chill unit accumulation. For example, 1 h with the air temperature greater than 18.0°C is assigned the value CU = -1.0. The procedure to compute cumulative chill units and the chilling requirements for four classical chill unit models are discussed below [59].

Table 10. Conversions of selected temperatures to chill unit factors for the Utah (UT), North Carolina (NC), and Low Chilling (L) models [59]

Utah model		North carolina model		Low chilling model	
Temperature (°C)	Chill unit factor (CU)	Temperature (°C)	Chill unit factor (CU)	Temperature (°C)	Chill unit factor (CU)
< 1.5	0.0	≤ 1.5	0.0	≤ 1.7	0.0
1.5 – 2.4	0.5	1.6 – 7.1	0.5	1.8 – 7.9	0.5
2.5 – 9.1	1.0	7.2 – 12.9	1.0	8.0 – 13.9	1.0
9.2 – 12.4	0.5	13.0 – 16.4	0.5	14.0 – 16.9	0.5
12.5 – 15.9	0.0	16.5 – 18.9	0.0	17.0 – 19.4	0.0
16.0 – 18.0	-0.5	19.0 – 20.6	-0.5	19.5 – 21.4	-0.5
>18	-1.0	20.7 – 22.0	-1.0	≥ 21.5	-1.0
		22.1 – 23.2	-1.5		
		≥ 23.3	-2.0		

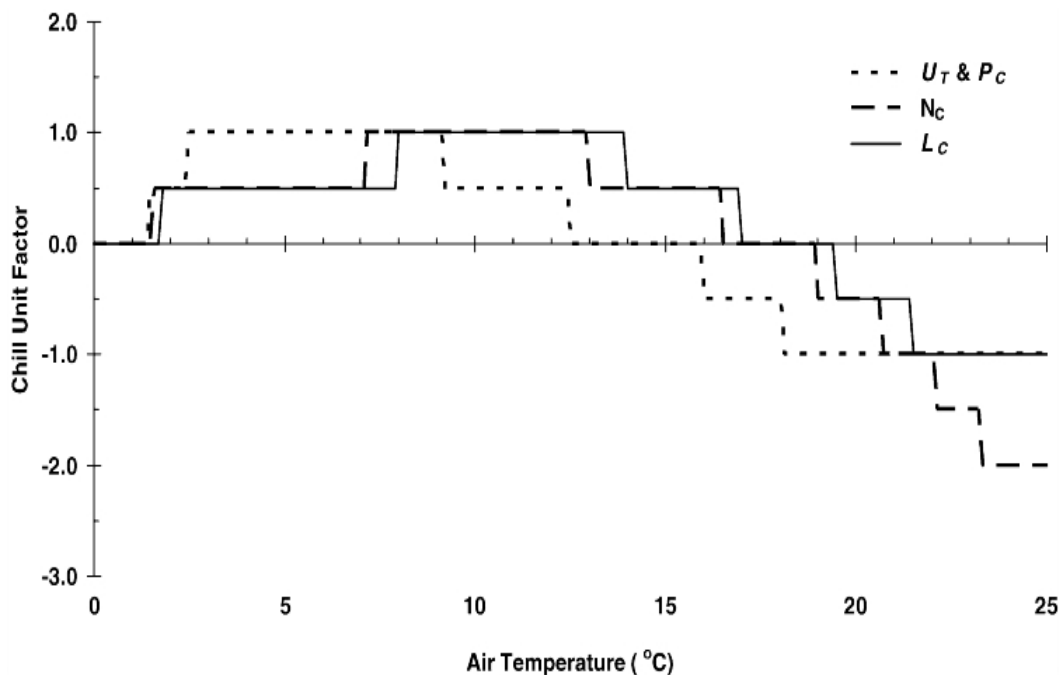


Fig. 6. Chill unit weighting factors for the Utah (UT) and Positive Chilling (PC), North Carolina (NC) and Low chilling (LC) models. [59]

The weighting factors for the four classical chill unit models are given in Table 10 and are plotted as discontinuous step functions in Fig. 6 to illustrate model differences. The weighting functions were mainly determined by laboratory tests and they differ because of species and variety [43,44,60]. The models were used to predict bud-burst for 'Redhaven' and 'Elberta' peach trees (UT), for 'Starkrimson' delicious apple trees (NC) and 'Sungold' nectarine (LC).

6. PROBLEMS ENCOUNTERED WITH APPLE RESEARCH AND PRODUCTION IN ETHIOPIA

6.1 Lack of Adequate Chilling Temperature

Lack of adequate chilling temperature in tropical conditions results in a very long flowering period (more than seven weeks) and a low level of bud breaking for the lateral buds and in a relatively low number of flower buds on the trees [4]. This leads to rather low fertility of the trees with fruits produced only at the end of the shoots. The fact that Ethiopia is in the tropics without real winter season makes it difficult to produce some high chill requiring cultivars of apples, thus, cultivars with low to medium chilling requirements are recommended for production, but with some exceptions for extreme highlands. The other problems observed in apples cultivation are incorrect introduction of germplasms by trial and error, as well as placement of cultivars without considering their true ecological niches as identified, based on their chilling temperature requirements (low, medium or high). Therefore, as indicated in research report [8], new germplasm introduction priority consider suitable ecological niches based on chilling requirement of a given cultivar, so that the environment must be properly

categorized for the different growing regimes and the growing regimes are fully characterized based on their effective chilling for dormancy breaking and post-flowering temperatures for proper fruit development.

6.2 Diseases and Insect Pest Problem

There are experiences of disease and insect problems attacking temperate fruits in Ethiopia. Disease problems such as powdery mildew, scab, crown gall and peach leaf curl are observed and some of these are serious problems in most of the growing areas and become the major production constraints. Despite the above problems so far, no significant research work has been done on the control of diseases and insects on temperate fruits. In some areas, farmers use various indigenous methods to control powdery mildew and scab with some success but the reliability of such practices needs further investigation. At present interested individuals and organizations are introducing planting materials at ease.

There is wider possibility of introducing important diseases that can negatively affect the potential of highland fruit production in the country. Though not serious, insect pest problem such as woolly aphid, peach aphids and beetles were observed in some farms near Holeyta in central highland [8].

Fikre and Messele [61] conducted a systematic survey on important diseases and pests of apples and other temperate fruits in nine apple growing locations of southern and central Ethiopian highlands at different altitudes Table 11. Accordingly, temperate fruit plants are subjected to various diseases such as apple scab, powdery mildew, and leaf curl (on peach and cherry plum) and some insect pests in all the studied areas Table 12. Other diseases of minor importance include collar rot, canker and leaf spots were also reported in this survey Table 12.

Despite the above problems, so far no significant research work has been done on the control of diseases and insects on temperate fruits. In some areas, farmers use various indigenous methods to control powdery mildew and scab with some success but the reliability of such practices needs further investigation. At present interested individuals and organizations are introducing planting materials as easy as possible through the government food security program. So that, there is wider possibility of introducing important diseases and insect pests with genetic materials imported and this will be a threat for present and future production regime.

6.3 Problems Related With Orchard and Canopy Management

Orchard management practices such as spacing, pruning; training, flower and fruit thinning have significant influence on fruit quality. These practices vary considerably among fruit species, cultivars and rootstocks used. For instance, apple and pear trees require light pruning for developing the desired form of the canopy where as peach and plum, require regular heading throughout their life to promote growth. These are important differences in pome and stone fruits for proper flower and fruit development. Though researchers and developers recommended some cultural practices in Ethiopia, these are not properly followed by farmers in the different locations. Such sub-optimal management operations to young and fruiting trees at farmer's home garden considerably affect tree growth, yield and quality of fruits [1]. Also, contribution of the national research institutes in this field has been far from adequate.

Table 11. Type and status of diseases and insect pests [61]

Common name	Scientific name	Status
Apple scab	<i>Venturia enaequalis</i>	Major
Powdery mildew	<i>Podosphaeria lecotrcha</i>	Major
Collar rot	<i>Phytophthora sp.</i>	Minor
Leaf spots	<i>Alternaria sp.</i>	Minor
Leaf curl	<i>Taphrina deformance</i>	Major (on peaches & cherry)
Aphids	Sp. not identified	Minor
Scales	Sp. not identified	Minor

Table 12. Incidence and severity of apple scab and powdery mildew diseases in different altitudinal locations of southern Ethiopia [61]

No.	Location	Altitude (m.a.s.l.)	Apple scab		Powdery mildew		Sample size
			Incidence (%)	Severity (%)	Incidence (%)	Severity (%)	
1	Chencha	2500 – 2800	93 – 100	5 – 49	71 – 90	14 – 45	29
2	Boreda	2700 – 2800	77 – 100	6 – 25	43 – 75	2 - 19	8
3	Bonke	2300 – 2600	55 – 80	8 – 23	28 – 50	5 – 20	7
4	Kamba	2000 – 2700	73 – 90	4 – 35	14 – 70	8 – 24	12
5	Ijsa	2300 – 2560	48 – 75	12 – 26	23 – 67	16 - 37	5
6	Gumer	2570	40 – 70	7 – 20	-	-	1
7	A/ berbere	2580	-	-	10 – 25	20	1
8	Misha	2300	85 – 100	19 - 39	49 – 85	11 - 26	4
9	H/ selam	2640	46 - 78	5 - 32	14 - 35	7 - 16	2

7. FRUIT QUALITY DEVELOPMENT IN APPLES

7.1 Apple Fruit Quality

Factors used to describe fruit quality are considerably more extensive and include: freedom from pesticide residue; size; shape –length/diameter ratio, prominence of crowns, flattening, uneven or lopsided development; skin background colour (green to yellow); colour in red cultivars (% redness); skin finish – freedom from blemishes (russet, wind rub, insect damage, disease) and greasiness; freedom from bruises; flesh texture (firmness, crispness, mealiness); juice content; flavour; acidity; sugar content; flesh firmness; mineral and vitamin content. Looney [62] suggested that large fruit size, attractive appearance, characteristic or distinctive flavour, and pleasing texture are amongst the most important fruit quality attributes. In many world markets deficiencies in any one of these key quality attributes can render a product valueless. Retailers and wholesalers consider that there are four main quality problems with apples: immaturity, over-ripeness, poor grading (mixed colour/sizes), and marks and blemishes [63]. Two groups of quality components have been identified by Link [64]. Group 1 characteristics include attributes such as size, colour, skin performance, firmness and sugar and acid content of the fruit. Group 2 characteristics were described as being represented by inorganic components, especially calcium and potassium which are implicated in the susceptibility of fruit to physiological disorders.

7.2 Fruit Quality Attributes

The first assessment of fruit quality is usually visual, being determined by size, shape, skin colour and freedom from blemishes. Textural quality factors include firmness, crispness, juiciness and mealiness, while flavour or eating quality depends upon sweetness, acidity, astringency and aroma [65]. Many of these attributes are subjective in nature while others can be measured directly.

7.2.1 Size

Size differences in fruit are primarily due to differences in the number and individual size of cells within the fruit cortex and pith [66,67]. According to Smith [68], the characteristic size for each cultivar is determined primarily by the degree of cell multiplication occurring after pollination, however he stated that the relation between increase in fruit weight and cell enlargement was not the same for each cultivar.

Cell numbers are determined within the first few weeks of fruit development [67]. Bain and Robertson [69] reported that cell division in the flesh (pith and cortex) of the fruit stops about 4-6 weeks after blossom. This time period agrees roughly with the findings of Stanley *et al.*, [70], who concluded that a potential maximum fruit size is set by about 50 days after pollination and is determined by total fruit cell number, resulting from a temperature responsive cell division growth phase. Under ideal conditions, where there are no limiting factors after the cell division phase, all fruit cells would expand to their optimum size to provide the maximum fruit weight achievable for that cell number. They reported that factors limiting carbohydrate availability, such as higher crop loads and shading of trees reduced final fruit size.

While crop load and the genetic biological carrying capacity (source-sink relationships) determine the potential for fruit size development in apples, the environment within which the

fruit grows attenuates this potential [71]. Genetics, environment and cultural practices all interact to determine eventual fruit size. Of the genetic factors, cultivar plays the dominant role, with rootstock having a smaller more subtle effect [72].

Rom and Barritt [73] have identified spur age as a factor affecting fruit size, reporting that spurs over four years old produced smaller fruit and Wilton [74] recommended removal of older spurs by pruning to improve fruit size. Goffinet et al., [75] suggested that a fruit retained at any of the positions within a cluster has a similar potential for achieving the size and weight typically seen in king fruit. Wilton [76] concluded that fruit bud quality and strength of the wood carrying the buds are more critical than the actual wood age itself, stating that even lateral buds of one year fruit wood will size well if carried on strong wood. Robinson *et al.*, [77] also reported that the age of spur upon which the fruit is borne was much less important than light exposure as a contributor to variation in fruit size and quality.

Jackson [78] reported that fruit of 'Cox's Orange Pippin' borne on 3 or 4 year old wood were larger than those on younger or older spurs, and that spur age accounted for less than 10% of the total within-tree variation for fruit weight. According to Myers [79], a prerequisite for creating high spur quality is optimal light, which is achieved by tree training and pruning practices. Fruit size tends to be smaller on one-year-old wood compared with older spurs [78,80]. In studies of inflorescences on one- and two-years old wood, Marguery and Sangwan [81] found that, while cell division began a few days later on the younger wood because of the later blooming time, the mitotic period stopped simultaneously on both ages of wood (40-50 days after full bloom (dAFB) on the 2nd year wood). They concluded that fruits from one-year-old wood were smaller than other fruits because they had fewer cells, probably due to later flower opening and pollination.

Many environmental and tree physiological factors influence fruit cell number and size. The availability of water is of vital importance as this influences cell expansion in the later stages of fruitlet development [67]. Crop load, time and severity of thinning, tree/soil water relationships, tree vigour, tree nutritional status and stress all impact on number of cells within the fruit and individual cell size, and thus affect final fruit size [34,70,82,83,84,85,86, 87].

Temperatures within the orchard, at and for several weeks after bloom, may affect cell division and hence cell numbers and fruit size at harvest [67]. Under high temperature conditions, trees tend to stop producing sugars as a result of shutting down photosynthetic activity and these then impacts on fruit size [63]. In the later stages of fruit growth this is likely to affect cell expansion. Several studies have shown a strong positive correlation between temperatures, immediately following bloom, and fruit size at harvest [88,89,90]. In studies with potted apple trees in controlled environments, both Tromp [85] and Warrington et al., [87] provided further evidence that temperature during early fruit development is a key driver of fruit development.

Warrington et al. [87] also reported that the duration of cell division appeared to be inversely related to mean temperature (i.e. prolonged under cooler conditions). Similarly, they suggested that the impacts of temperature on apple fruit growth are further complicated by varying responsiveness to temperature at different phases of growth. In order to maximize yield, it is important to know the phases of growth that are most susceptible to environmental manipulation [91]. Both Magein [92] and Schechter et al. [91] suggested that the growing season can be divided into three phases: phase one, beginning at bloom and lasting about 40 days, corresponds to the period of maximum fruit growth rate and is dominated by cell

division; phase two is characterized by a considerable reduction in growth rate – this stage never exceeds 2 weeks; and phase three is the period of the largest volumetric growth rate and spreads over the rest of the season. According to Baumann and Henze [93], the development of fruits during the third phase results mainly from the enlargement of cortex and pith cells, and from the increasing volume of intercellular spaces.

In Australia, Bain and Robertson [69] found that large apples had more cells than small fruit from the same tree but there was no difference in cell size. Westwood et al., [82] reported that heavy hand thinning resulted in larger king fruits with larger cells than lateral bloom fruits which had the same leaf : fruit ratios, however they could not explain the difference in cell size between king and lateral fruits on the basis of leaf:fruit ratio. The difference in fruit size between trees bearing light and heavy crops has been found to be due to cell size rather than cell number [94].

Seed number has also been shown to have a direct influence on fruit size [95,96]. According to Williams [95], at least seven seeds per fruit are necessary for maximum fruit size. Brookfield et al., [97] related the number of seeds per fruit to pollination, reporting that seed number was lower in fruit without a nearby pollen source. Hand pollination of trees away from the pollen source restored full seed number.

7.2.2 Shape

Fruit shape in apples is controlled by both climatic and non-climatic factors [98]. Seeds also influence fruit shape, with the absence of seeds in carpels resulting in asymmetric fruit development [97,99]. Other factors such as rootstock, cultivar, crop density and position of the fruitlet in the cluster also tend to influence fruit shape. The interaction of these factors in combination with environmental conditions determines the typiness of apple fruits in particular environmental conditions. Similarly, Day/night temperature differences, air and soil temperatures, and relative humidity have also been shown to affect fruit shape [100,101]. Although both inherited [102] and environmental factors [100] play a major role in fruit typiness, application of synthetic hormones can also have an important and immediate impact. Localized application of gibberellins (GA) can induce asymmetric growth of apples as a result of tissue enlargement [103]. Dennis and Nitsch [104] and Hayashi et al. [105] demonstrated that gibberellins promoted cell elongation and division in apples. There has been considerable discussion on the ability of gibberellin and cytokinin mixtures to increase the length of apples and make them more typy [106,107,98,26,108,109].

Greenhalgh et al. [110] found that in both New South Wales and Western Australia, typiness of 'Delicious' apples can be improved by the use of blossom applications of GA₄₊₇ and 6-benzyladenine (BA), stimulating an increase in the length/diameter (L/D) ratio of the fruit and development of the calyx lobes. While their findings confirmed that both GA and BA influence the development of form and shape in 'Delicious' apple. They found that sprays combining GA₄₊₇ and BA in equal proportions provided little additional benefit to that obtained with BA alone at the equivalent strength. Jones [111] indicated that improved fruit typiness and increased the length of fruit, without increasing the width, with full bloom (FB) applications of Promalin (a 50:50 proprietary formulation of GA₄₊₇ and BA in a 2% solution, Abbott Laboratories). In trials over two seasons Veinbrandts [98] demonstrated that Promalin applied to runoff as a single spray shortly after FB improved fruit shape by increasing the L/D ratio. In addition Promalin improved the prominence of the calyx lobes equally at all concentrations. In Australia the plant growth regulator Cytolin (registered as Promalin in the USA) is commonly used to elongate and improve the shape of 'Delicious' [112,113,114,115].

7.2.3 Color

According to Australian Horticultural Corporation [116], skin colour has two components; background colour and red colour (or blush in green cultivars). Background colour is used as an index of maturity, with a subjective estimate of the change from mainly green colour on unripe apples to the more yellow tones on ripe apples. Accordingly, Red colour is not regarded as a reliable indicator of maturity, but is normally taken as a quality factor unlikely to change substantially as fruit progresses through the last stages of development. Fruit is picked either when the red colour meets a grade standard, as for 'Delicious', or when red colour is sufficient and background colour indicates that an appropriate level of maturity has been reached. Poorly coloured fruit is usually downgraded from fresh market to processing grade or left on the tree.

The extent and intensity of colour in red cultivars is affected by many climatic and cultural factors [117], with poor red colour limiting the pack-out of first grade fruit. Weather conditions have been reported by several authors to impact on fruit skin colour [117,118]. There also appear to be differences in colouring ability between cultivars. Kikuchi et al., [119] stated that 'Fuji' apples require a higher intensity of light than other cultivars to produce the same amount of anthocyanin (red colour pigment). Marsh et al. [120] found that red colour tends to be poor in younger trees, with a general improvement in the fruit colour profile with tree age. Increased red colour can be accomplished by (1) selection of sports or mutations, (2) bagging fruit, and (3) management practices such as irrigation, fertilisation, pruning and thinning [119]. A survey conducted by Marsh et al., [120] in New Zealand confirmed that tree vigour, tree nitrogen status, and growing region are important factors determining the extent and intensity of red colour development in 'Fuji' apple. They reported that increased vigour generally results in a decline in the extent of red colour development, the result of an indirect effect caused by shading.

7.2.4 Skin finish

According to Australian Horticultural Corporation [116], problems with fruit skin finish can be divided into blemishes or skin damage. A blemish is defined as any superficial disfigurement of the skin that is not likely to affect the keeping quality of the apple. Blemishes include russet and healed injuries caused by limb rub, insect damage, abrasions and scratches. Skin damage is any unhealed physical injury to the surface of the apple, and includes bruising and any injury that leaves the skin broken and unhealed such as stem punctures or recent hail damage.

Fruit skin russet is a natural phenomenon, occurring when the cuticle, or waxy outer portion of the skin, is damaged [121]. This can be caused by either outside forces such as frost, chemical or disease damage, or by internal forces such as rapid epidermal growth, which cause the protective cuticle to rupture [122,123]. In both cases, a layer of cork cambium develops, pushes outward and replaces the cuticle as the outer protective layer of the fruit. Unlike the smooth waxy cuticle, cork cambium is rough in texture and gives the fruit a russeted, scabby appearance. Creasy and Swartz [122] also suggested that this occurs in the early weeks after anthesis, when fruit is most susceptible to damage.

It is well established that cold or wet conditions can increase the incidence of russet [118]. High humidity, precipitation and frost have also been associated with increases in the disorder [118,122,124], as have altitude and light [125,126]. Chemical sprays such as ethephon [127], captofol fungicide (3a,4,7,7a-Tetrahydro-2-[1,1,2,2-tetrachloroethyl]thio]-1H-

isindole-1,3(2H)-dione) [128], and copper fungicide sprays [127,129] have been implicated in russet development. Other chemicals that have been reported to induce russet include: urea [130], dodine (ndodecylguanidine acetate) [131], fungicides based on dimethyldithiocarbamyl compounds [132], daminozide (butanedioic acid mono-[2,2-dimethylhydrazide]) [122], thiram and the non-ionic surfactants Citowett and Tween 20 [133]. Boucher [84] also reported that any chemical spray applied under the wrong weather conditions during the critical fruit development period from pink bud to 6 weeks after full bloom (wAFB) is capable of causing russet.

7.2.5 Starch content

Starch changes to sugar as the apple ripens, with starch hydrolysis beginning in the core area and progressing outwards. Starch is one of the standard measures of fruit maturity [134,135], with starch levels declining rapidly from about the start of the respiratory climactic. According to Little [134], the hydrolysis of starch corresponds reasonably well with increasing ethylene status within apples during the harvest period. Starch is not regarded as a quality component in its own right, but is used in conjunction with other maturity indicators.

7.2.6 Total soluble solids content

As noted previously, starch converts to sugar as the apple matures. Once the ripening phase starts, starch levels decline and sugar levels increase rapidly. Total soluble solids (TSS) content, 98.8% of which are sugars [134], is another standard index of fruit maturity. According to Kupferman [136], sugar levels depend on the leaf to fruit ratio, hence anything that increases leaf size and optimises photosynthesis throughout the canopy will aid in accumulation of sugar in the fruit. Collins [137] suggested that sugar content can be influenced by a range of factors such as irrigation, nutrition, weather and position on the tree. Eccher and Noè [138] have reported that the altitude at which apples are grown influences sugar content. However it is difficult to see how these authors could have maintained the same environmental and management conditions at different altitudes to allow them to separate altitude from other factors associated with altered sugar levels.

7.2.7 Flesh firmness

Fruit flesh firmness, usually measured as the resistance of the apple flesh to penetration using a penetrometer (with an 11 mm plunger), is another indicator of maturity. A gradual decrease in flesh firmness occurs as the apple reaches full size and starts to mature [139], but according to Westwood et al, [82], flesh firmness is not a good index for early harvest of apples because it does not relate well to maturity. However, this author suggested that firmness tests have value for later harvest and during storage, particularly when used with other indices. Apples less than 5.5kg firmness at the point of sale are considered to be lacking in firmness and not acceptable to the average consumer [140].

Firmness is related to both the size and number of cells within the fruit. Large cell size generally means softer fruit [140]. Firmer fruit can be achieved by increasing cell numbers while keeping cell size to a minimum [141]. Seasonal and orchard variability, tree vigor, fruit size, nitrogen and calcium levels in the fruit and use of growth regulators are some of the things known to influence firmness of apples [142]. Following observations that fruit firmness was higher on older spurs, Robinson et al. [77] suggested that this increase in fruit firmness with increasing spur age was a result of the decrease in fruit size associated with increased spur age or delayed maturity.

7.2.8 Light management in orchard can influence fruit quality

Adequate distribution of light within a canopy is an important determinant for total yield and aspects of fruit quality such as size and colour [143]. Also, Jackson and Palmer [144] reported that shading results in reduced fruit size, weight and red colour. Webster and Crowe [145] suggested that, if red colour is reduced by shading to a level where grade is lowered, production costs may actually exceed income from the sale of fruit. They worked out that in 'Delicious' apple, shading has been shown to reduce yield, red fruit colour, soluble solids concentration, starch content, and fruit length, width and weight. Accordingly, shading altered fruit shape of 'McIntosh' apple, with apples located on wood exposed to sunlight being less elongate than those developing on shaded wood [145]. Sansavini et al. [146] found fruit firmness to be negatively correlated with light levels. This was supported by Robinson et al. [77] who found apple fruit firmness and total acidity were increased by reduced light levels produced through shading. Also, planting density and tree row orientation can influence fruit quality with respect to light demand.

According to Jackson and Palmer [144] shade influences fruit initiation, and reduces fruit retention, fruit size and percentage dry matter. They also found a residual adverse influence of the percentage flowers that set fruit the following year. Also they reported that specialized production systems that shade fruit but not leaves, such as enclosing apple fruit in bags during development as widely practiced in Japan, can have a marked effect on fruit quality. While bags create a physical barrier that reduces damage from insect and fungal pathogens, sprays, sunburn and russeting, there also appears to be a physiological effect on fruit development. Similarly, Mattheis et al., [147] reported reduced soluble solids content, titratable acidity and firmness at harvest and during storage following bagging of 'Fuji' fruit.

7.2.9 Crop load

Webster [49,148] reported the single most important factor influencing final fruit size is the crop loading on the tree. Accordingly, excessive numbers of fruits (i.e. very high fruit:leaf ratios) cannot be sized adequately, even with copious irrigation. The only reliable solution is to reduce the crop loading by: (i) reducing blossom numbers by winter pruning or by inhibiting flowering, (ii) preventing a proportion of the blossoms from setting fruit (blossom thinning), either by hand or mechanical methods or by using chemical sprays (iii) removing a proportion of the fruitlets (fruitlet thinning), by hand, or with chemical sprays.

The time at which crop load is reduced plays a role in final fruit size and quality. Goffinet et al. [75] reported that fruit from 'Empire' trees thinned near bloom were larger with more cells than those of trees thinned later. They suggested that fruit thinning appeared to increase fruit size by allowing remaining fruits to continue cell division under less competition during the first weeks after bloom, and not by extending the cell division period, increasing cell size or increasing the proportion of intercellular space. Thinning has been shown to increase leaf:fruit ratio [149]. Fallahi and Simons [150] suggested that trees with low yield had a higher leaf: fruit ratio which led to a higher accumulation of photosynthates in the fruit, thus increasing the fruit weight.

Investigating the effects of time and level of hand thinning for 'Royal Gala' and 'Braeburn' apple trees growing on dwarfing rootstocks, McArtney et al., [151] found that mean fruit weight of 'Royal Gala' was reduced by 16% when thinning was delayed by 3-4 weeks after full bloom. They concluded that thinning at flowering was desirable, particularly in cool regions and for small fruited cultivars.

Forshey and Elfving [152] recommended that fruit thinning should be limited to the minimum that ensures acceptable fruit quality and adequate return bloom for a full crop. They suggested that large fruits should not be the primary objective because they may be attainable only through over-thinning that may, in turn, stimulate vegetative growth. There is a delicate balance between cropping and vegetative growth in apple trees, with vigorous growth having a negative influence on fruit quality. Fruit quality on trees with excessive vegetative growth is frequently poor, and the storage potential of these fruit is generally diminished [153]. According to Jones et al., [154], calcium related fruit disorders are particularly prevalent in vigorous trees, and it is difficult to produce quality fruit from strongly growing trees. While fruit removal by hand can improve fruit size if carried out early enough, hand thinning is expensive and impractical during flowering and the early fruit development stage. Hence hand thinning is normally carried out after flower initiation has taken place [155], and as a consequence flower formation for the next year is inhibited by the high number of young fruitlets present on trees during flower initiation. This late thinning result in reduced fruit size and quality and the trees tend towards biennial bearing [156]. In commercial orchards, chemical thinning agents are applied either during the blossom period and/or up to 5-6 weeks after flowering [157]. In particular, blossom or fruitlet thinning early in the season improves fruit size at harvest and increases return bloom, thereby reducing the biennial bearing habit of apple trees [158].

In general, the earlier thinning is performed, regardless of the method, the larger the fruit size at harvest. However, there are some situations where chemical thinning can result in no size benefit at harvest – this can arise where chemicals such as NAA cause a 'check' to vegetative, and thus fruitlet [155] growth under some circumstances, or where blossom thinners remove the earlier opening flowers, leaving only weaker flowers which have a reduced potential to set large fruit [152]. Although early thinning has been shown to increase cell numbers and consequently fruit size, the choice of thinning chemical can have an impact on fruit cell numbers. Martin et al. [159] described an increase in cell numbers following the application of dinitro ortho cresol (DNOC) as a blossom thinner at FB.

Although increased thinning normally results in larger fruit, there is evidence to suggest that some thinners depress fruit growth, inhibiting achievement of optimum fruit weight. Both Link [160] and Wertheim [161] expressed concern about the use of high concentrations of ethephon or NAA reducing fruit growth while Flore [162] reported that high concentrations of NAA reduced fruit size. Also, Jones et al. [163] documented the lack of size response of 'Golden Delicious' apple to higher levels of NAA treatment.

7.2.10. Foliar damage

In general, the development of a complete and healthy early season canopy of spur leaves, and later addition of bourse leaves, is essential for fruit set, fruit growth and quality [164]. Desiccating chemicals are becoming increasingly popular as chemical thinning agents; however there have been reports of foliar damage resulting from their use [165].

Several studies relating to foliar feeding by pests have shown that leaf damage impacts on both size and quality of fruit. Ames et al. [166] reported reduced fruit growth rates in Starkrimson 'Delicious' trees following European red mite injury of leaves. Other reported effects of mites and other foliar feeders on apples include poor fruit colour, reduced sugar concentrations, and delayed maturity [167].

Proctor and Palmer [168] found that, while spur leaves were not necessary for flower initiation and expression, removal of bourse leaves had a dramatic effect in reducing return bloom in the three cultivars they studied. Although a number of researchers have shown that spur leaves are necessary for flower initiation and return bloom, they have failed to distinguish between leaf types, thus not allowing for the role of the bourse leaves to be revealed.

8. SUMMARY AND CONCLUSIONS

Careful planning by considering environmental and physiological factors before orchard establishment will enable minimization of management problems. Environmental factors/Site factors can play a role in pest/disease load, recommendations for pruning, shading and crop load management as well as for a range of situations. Under sub-tropical climate, such as Ethiopian highlands, the apple flower induction and differentiation tend to extend a long growth cycle due to incomplete or partial chilling temperatures to satisfy the bud-break and flowering. This particular situation might lead to an alteration in the tree physiology, making necessary a differentiated orchard management on tree training and pruning. Thus, cultural and climatic conditions alter positively or negatively the flower bud development and have a direct influence on fruit development and quality. In general, in fruit tree orchards, when trees are grown under climatic regions different from their origin, some cultural modifications like dormancy breaking treatments, may result in changing phenological regimes, and have important impacts on flower bud development, pollination, and fruit-set efficiency.

Contrary to the potential and opportunities for apple production in Ethiopia, the benefit from the production is far from satisfactory due to little research effort made in clustering environments according to cultivar preference based on temperatures requirement. The current development effort is also not adequately supported by the research and production expansion is not based on information about specific requirement of cultivars for different growing areas. Various stakeholders are working independently in the production of fruits and grafted materials with scanty information from some Agro-consultants and research institutes in the country. These however, require further investigation to identify suitable production regimes in relation to the cultivars placement in its better performing ecological niches. In addition, due to the exotic nature of the crops, inadequate knowledge on orchard management and nursery practices that can directly affect fruit quality and influence the competitiveness of the growing fruit industry.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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