Making Apple Trees Friendlier for Mechanized Harvesting

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The current commercial apple production system in the U.S. is labor-intensive and costly, as orchard operational tasks, such as pruning trees and harvesting fruit, must be conducted manually. Based on 2007 USDA apple survey data, a recent study in economics found that the total variable costs were $4,039 per acre per year in fresh apple production in established orchards, and labor accounted for nearly 60 percent of the variable costs (Taylor and Granatstein 2013). Findings from an enterprise budget study for a medium density apple orchard indicated that harvesting fruit would make up 44 percent of the variable labor costs, pruning and training 25 percent, and thinning 21 percent (West et al. 2012). Therefore, an absolute majority of the labor costs can be attributed to manual tree pruning and training, fruitlet thinning, and fruit harvesting, which is the most expensive single labor demand.

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It is expected that immigration laws will likely be more strictly reinforced and that immigration reforms will likely take place. As a result, the availability of orchard workers will decrease, which will lead to a significant increase in workers' wages and overall production costs. If the overall production costs increase due to higher labor rates, what can growers do? Can they simply raise their fruit prices and pass the cost on to consumers to maintain their profitability levels? This question may need a dedicated study to be addressed properly. But given today's relatively open global economy, it is likely difficult for growers to do so, as imported apples could possibly be sold at lower prices. For example, on the marketplace for processed apple products, the U.S. apple industry has pretty much lost its competitiveness against the concentrated apple juice imported from China. According to Calvin and Martin (2010), the price received by U.S. growers for juice apples cannot even cover their harvesting costs in some years. The increase in production cost will also suppress industry profitability on the international market. At present, roughly one quarter of U.S. fresh apple production is exported to other countries. In responding to these challenges, the industry has been calling for coordinated efforts to mechanize the manual tasks in orchard operation to maintain its competitive edge in marketplaces, both domestically and internationally.

In this article, I review the state of mechanization in apple fruit harvesting, the effort to develop fully automated robotic systems for picking fruit, and our ongoing studies aimed at making apple trees friendlier for mechanized harvesting.

Mechanization for Apple Fruit Harvesting

Efforts to mechanize fruit harvesting have aimed at two different end-applications: 1) developing motorized platforms that can increase hand-harvest efficiency, and 2) developing fully automated robotic systems that can pick the fruit in a manner comparable to or better than human pickers. The drive for the first end-application largely comes from the observation that apple pickers can only use approximately 30 percent of their time to pick fruit (Calvin and Martin 2010). They must use the majority of their time to move and climb ladders, and to dump sacks of fruit into collection bins. Frequently climbing up and down ladders results in accidents that can cause severe injury to fruit pickers. Development of auto-powered platforms would allow them more time to pick the apples, while reducing the chance of injury-causing accidents.

Currently, one such motorized platform available on the market is the vacuum harvester (Figure 1A) from Phil Brown Welding Corp. (Conklin, MI). According to the company, the vacuum apple harvester not only eliminates the need for ladders, but also addresses three other major problems: bruising, efficiency, and picker fatigue. For reducing bruising, the system uses a small, lightweight bucket-style inlet for pickers to place apples, which prevents apple-to-apple contact all the way into the collection bin. For increasing efficiency, the system enables pickers to just pick the fruit and not worry about other activities needed in conventional ladder picking. The company states that a five-man crew can fill and exchange a 20-bushel bin every 10 minutes, equivalent to 24 bushels per man-hour. For mitigating fatigue, the pickers get a 45-second to 1-minute break every 10 minutes (during the bin exchange).

Another platform is the Pluk-O-Trak apple harvester from Munckhof, Netherlands (Figure 1B). Pickers don't need to touch the fruit once they place it on fingered conveyor belts that take it to a rotating bin filler, minimizing the risk of damage to the fruit. There are two versions, called Pluk-O-Trak Senior and Junior, respectively. Based on the company's literature, Pluk-O-Trak harvesting machines enable trees to be fully harvested from top to bottom without the need to use a second harvesting system. The Senior model is the most suitable for applications in larger orchards having trees up to 13 ft high and in rows 13 ft wide. The system is available in the US through OESCO, Inc. (Conway, MA).

The third platform is the Huron Apple Fruit Systems (Figure 1C) developed by Wafler Farms (Wolcott, NY). The Huron Systems unit comprises a picking platform and a bin trailer. Accord-

Figure 1. Auto-powered platforms for apple fruit harvesting. A. The Vacuum Harvester System, developed by Phil Brown Welding Corp. (Conklin, MI). B. Pluk-O-Trak-Senior Apple Harvester, by Munckhof, Netherlands. C. The Huron Apple Fruit Systems by Wafler Farms (Wolcott, NY).

ing to the developer, the harvest system is specifically designed and developed to work with orchard row spacings of 10–14 ft. The most innovative feature of the system is that it can allow a set of five empty bins to be loaded from the bin hauler automatically, and then released to the ground all together when fully filled with fruit. However, unlike the two platforms described above, workers must unload the bags of fruit into the bins themselves.

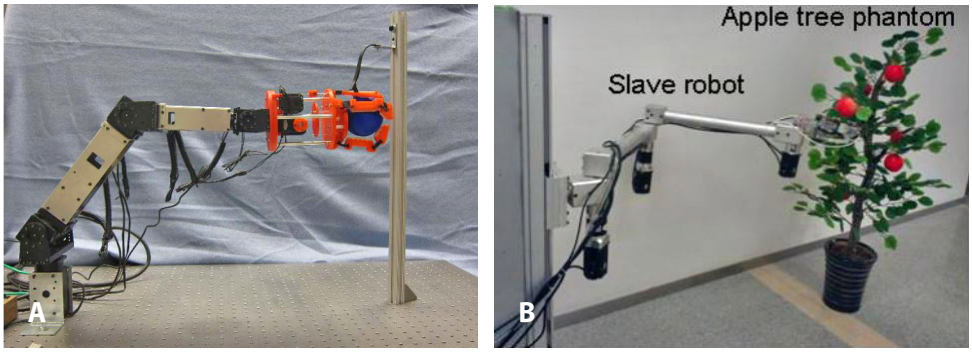

Figure 2. Novel prototypes of robotic end-effectors designed for apple fruit harvesting. A. Davidson and Mo (2015). B. Luo and Wei (2015).

The efforts to develop fully automated robotic systems to fulfill the second end-application is far from being a reality. In most cases, prototypes developed as robotic apple harvesters are simply not up to the intended task. The latest research emphases seem to be on developing and improving the end-effectors of fruit harvest robots. For example, a novel under-actuated end-effector for the robotic harvesting of tree fruit (Figure 2A) has been invented to mimic hand-picking; it uses a shape-adaptive grasper with open-loop control (Davidson and Mo 2015). Another example (Luo and Wei 2015) is to develop a robotic system that is operated in a master-slave manner, which is widely used in surgical robots, for picking apple fruit (Figure 2B). Clearly, much of the research work in this area remains at the proof-of-concept stage.

Making Trees Friendlier for Mechanization Through Genomics Studies in Tree Architecture

As described above, various platforms have been developed to facilitate hand harvesting of apple fruit. Adapting to these systems would certainly lead to considerable savings in labor costs, and reduce the dependence on seasonal workers. However, very limited progress has been made in developing fully automated apple fruit harvesting systems. The major challenge has been the irregularity of the tree canopy, which is complex, tall, wide, dynamic, and highly variable for the existing widely grown apple cultivars. Obviously, shorter trees with a narrower and more homogeneous canopy are friendlier to machines. Such a tree form is also considered to be ideal for optimal light distribution, fruit size and fruit quality. Could we have apple trees that naturally grow with these desirable characteristics? In viewing the tremendous variations in the way apple trees grow (Figure 3), this is entirely possible, although little is known of the genetic and molecular mechanisms underlying the variations in apple tree forms.

There are two extreme growth habits of apple trees: columnar and weeping. Columnar growth habit was originally discovered from a sport (somatic mutation) of McIntosh (Lapins 1969), called Wijcik McIntosh (Figure 4). Compared with McIntosh, Wijcik McIntosh shows much stronger apical dominance and apical control. Consequently, Wijcik McIntosh has fewer lateral branches, smaller branch angles (growing vertically, in fact), shorter internodes, and a simpler canopy deemed to be more suitable for high density planting and mechanized harvesting. Columnar trees mostly bear fruits on spurs that are branched on "old wood", and thus need little pruning, but strongly tend to bear fruit biannually. Wijcik McIntosh is the only known source of columnar growth habit, and has been used in apple breeding programs to develop columnar apple cultivars. Although many columnar apple cultivars are available, such as Irish Spire, Telamon, and Tuscan, none of them are grown on a large commercial scale. A number of factors, such as biannual bearing, fruit quality, yield, high replacement cost, limited needs for mechanization in the past, among others, might have contributed to the minimal adoption of columnar apples in commercial production. The weeping tree form (Figure 3D) is characterized by downward branches and with significantly more branches. Weeping growth habit has not been used in commercial apple production. However, many crabapples such as Red Jade and Cheal's Weeping are often planted in public gardens and plantations for ornamental purposes.

To make apple trees friendlier for mechanized harvesting and other routine orchard tasks (e.g., pruning and training trees), we have recently initiated a comprehensive research project on fruit tree architecture. The project, "Elucidating the gene

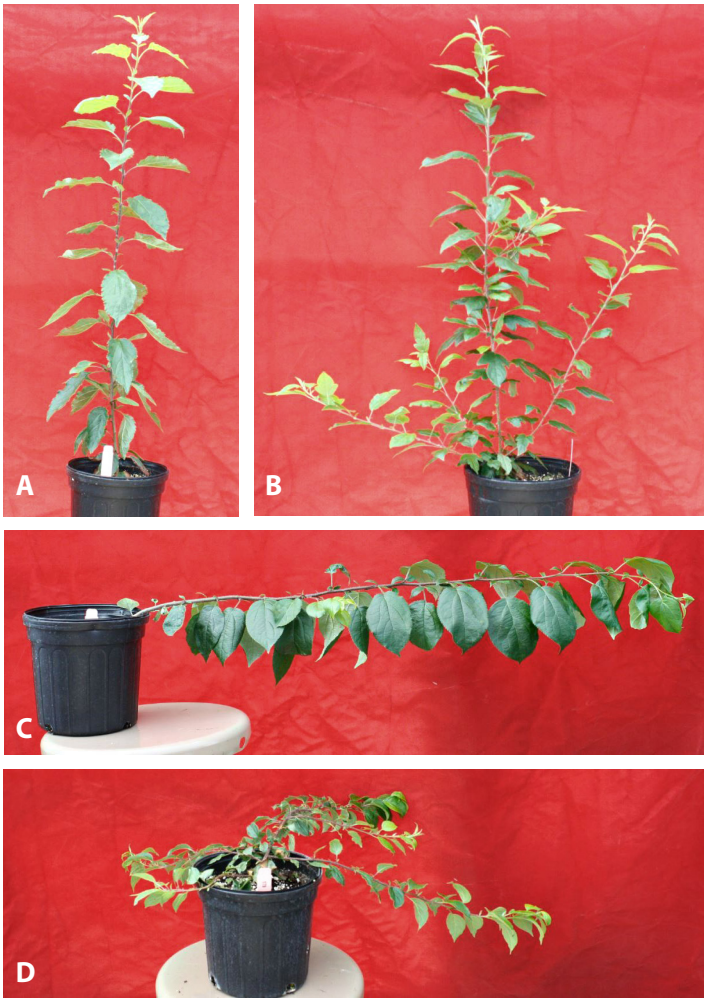

Figure 3. Tree forms of 5-month old apple seedlings. The size and shape of the trees are approximately in proportion. The diameter of the pots at the top position is 7.5". A. Standard without branches. B. Standard with branches. C. Weeping without branches. D. Weeping with branches.

Figure 4. Typical trees of McIntosh (A) and Wijcik McIntosh (B) before fruit harvesting.

Figure 5. A robotic 3D imagine system for tree architecture phenotyping in orchard conditions (Photo courtesy to Amy Tabb)

networks controlling branch angle and the directional growth of lateral meristems in trees" (http://www.nsf.gov/awardsearch/showAward?AWD_ID=1339211), is currently funded by a grant from the National Science Foundation (NSF) Plant Genome Research Program. Plant Molecular Biologist Dr. Chris Dardick and Research Engineer Dr. Amy Tabb are Co-PIs of the project; both are with USDA Agricultural Research Service at the Appalachian Fruit Research Station (USDA-ARS-AFRS) in Kearneysville, WV.

The overarching goal of the project is to develop detailed knowledge about how trees adopt specific architectural forms, specifically with regard to apical control of the lateral branch angle and directional growth. In particular, the project will address the following questions in apple and peach:

1) What gene expression networks differentiate the shoot apical meristem from lateral meristems? What changes take place when a lateral shoot meristem transitions to becoming the apical meristem? How are these expression gene networks altered in branch angle mutants including columnar (apple)/pillar (peach) tree forms and weeping types?
2) What is the genetic and molecular basis for these columnar/pillar and weeping tree forms? What are the identities of the mutated genes?
3) With regard to the identified genes, what protein-protein interaction networks are they associated with? Through which pathways do they exert their effects on tree form?

To accomplish the project goals and objectives, we have so far characterized the *Co* (*columnar*) locus that determines columnar growth habit in detail (Bai et al. 2012) and genetically located the *W* (*weeping*) locus controlling weeping phenotype in apple. Currently, we are focusing on conducting a series of genome-scale experiments to study the two extreme growth habits (columnar and weeping) and standard trees to identify the entire gene-networks responsible for their differences in branch number, angle, size and shape.

Since it would be challenging to manually evaluate how tree branches grow at the level of whole trees in the orchard, we must have a better means to take the measurements of branches. For this reason, Dr. Amy Tabb has developed a robotic 3D imaging system to meet this need (Figure 5). The system is designed to reconstruct the 3D models from tree images, allowing detailed phenotyping of tree growth annually.

It is expected that this project will yield a large amount of useful information, enabling us to better understand the genetic and molecular mechanisms underlying the tremendous variation in apple tree growth habits, branch directional growth and the formation of canopy. With such detailed knowledge, it is possible to develop new apples with a narrower and more homogeneous canopy that is friendlier for mechanized fruit harvesting and tree pruning. It would also even be possible to improve the tree architecture of existing apple varieties through genome editing. It should be pointed out that when automated apple harvesting systems are developed some day, they will not eliminate the need for hand harvesting, due to diverse orchard sizes and varying preferences of consumers. Coexisting of platform-assisted harvesting, automated robotic harvesting, and hand-picking of apple fruit will likely be the picture in 5–10 years.

In summary, apple fruit production is labor-intensive due to the need for manual fruit harvesting as well as tree pruning. The rising labor rates and declining availability of seasonal workers have driven the industry to seek solutions to mechanize these manual tasks. Several labor-aiding platforms have been made available for growers with large acreages. Development of fully automated apple fruit harvesting systems remains in the early stages. Our in-depth research project on the genomics of tree architecture will generate detailed knowledge about how apple trees adopt specific architectural forms, which will enable us to make apple trees friendlier for mechanized orchard operations.

References

Bai, T., Zhu, Y., Fernández-Fernández, F., Keulemans, J., Brown, S., and Xu, K. 2012. Fine genetic mapping of the Co locus controlling columnar growth habit in apple. Mol. Genet. Genom. 287: 437–450.

Calvin, L., Martin, P. 2010. The U.S. Produce Industry and Labor: Facing the Future in a Global Economy, ERR-106, USDA Econ. Res. Serv., Nov. 2010 (57 pp.).

Davidson, J. R., Mo, C. 2015. Mechanical Design and Initial Performance Testing of an Apple-Picking End-Effector. ASME 2015 International Mechanical Engineering Congress and Exposition. Am. Soc. Mech. Eng. pp. V04AT04A011–V004AT004A011.

Lapins, K.O. 1969. Segregation of compact growth types in certain apple seedling progenies. Can. J. Plant Sci. 49: 765–768.

Luo, H., Wei, G. 2015. System design and implementation of a novel robot for apple harvest. INMATEH-Agric. Eng. 46 (10 pp.)

Taylor, M., Granatstein, D. 2013. A Cost Comparison of Organic and Conventional Apple Production in the State of Washington. Crop Manag. 12 (7 pp.).

West, T., Sullivan, R., Seavert, C., Castagnoli, S. 2012. Enterprise Budget Apples, Medium Density, North Central Reg., Or. State Univ. (5 pp.).

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