

Needs and knowledge gaps in organic fruit breeding and variety testing across Europe: A survey study

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Abstract

Organic fruit breeding faces significant challenges across all stages of the breeding process. To better understand these issues, the Horizon Europe project 'InnOBreed' conducted the first European wide survey on organic fruit breeding, gathering insights from breeders and variety testers across 11 countries. Key challenges include evaluating and maintaining genetic resources, accessing genetic material and data on genetic material, the establishment of screening methods, and testing under organic and/or low-input conditions. Additionally, evaluating cultivar-rootstock combinations and integrating climate-resilient traits remain critical hurdles. This study highlights the importance of fostering strong networks among genetic resources curators, breeders, and scientific institutes to enhance collaboration and facilitate the exchange of knowledge and genetic material. Promoting participatory approaches, such as participatory breeding and on-farm testing, are essential for ensuring varieties meet growers' needs while being adapted to diverse climates and farming systems. Multi-site testing across different regions is crucial for evaluating varieties under varied climatic conditions and addressing challenges posed by climate change.

Keywords: Organic fruit breeding, genetic resources, robustness, participatory approaches, survey.

Introduction

The growing demand for organic fruits in Europe underscores the need for varieties specifically better adapted to organic farming systems. Organic fruit production faces challenges due to the limited availability of varieties bred for higher resilience to pests, diseases, and suitable in variable environmental conditions. Most commercially cultivated fruit varieties have been developed for conventional farming, prioritizing traits like yield, appearance, and storability, which are not always suitable for low-input organic systems. Organic fruit breeding aims to address these challenges by focusing on traits such as robustness, pest and disease tolerance, and resource-use efficiency, while adhering to organic principles that exclude synthetic inputs and genetic engineering (Nuijten et al., 2017). However, the process is complex and time-intensive, with slower growth cycles, multi-trait selection, and stricter storage requirements adding to the difficulty. As a result, organic fruit growers often rely on varieties developed for conventional systems, which may not fully meet their needs. To identify the specific challenges and opportunities in organic fruit breeding, the Horizon Europe project 'InnOBreed' conducted the first European wide survey on this topic. This study focused on understanding the needs and knowledge gaps in breeding, variety testing, and propagation for organic pip and stone fruits. The findings provide critical insights to guide the development of better-adapted varieties and support the growth of organic fruit production across Europe.

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Material and Methods

Two specific online questionnaires were designed for breeders and variety testers, including multiple choice questions to collect quantitative data and open questions. The survey was completed by 129 respondents from 11 different countries (Austria, Czech Republic, Belgium, Denmark, France, Germany, Greece, Italy, Spain, Switzerland, The Netherlands). A total of 46 answers from breeders and 60 answers from variety testers were collected for all fruit species, with answers for multiple species possible per breeder respectively variety tester.

Results

Respondents

Most breeders answering the survey work with apple, followed by apricot, peach, pear, and cherry (Figure 1). For variety testers as well, most respondents work with apple, followed by pear, cherry, peach, European plum, and apricot. Other minor fruit crops included almond, table grape, and citrus. Most breeders and variety testers (about 60%) work both for conventional and for organic production, while about 20% each work only for conventional or only organic. Most current breeding efforts are focused on table fruit production and only few breeders breed varieties specifically for processing purposes.

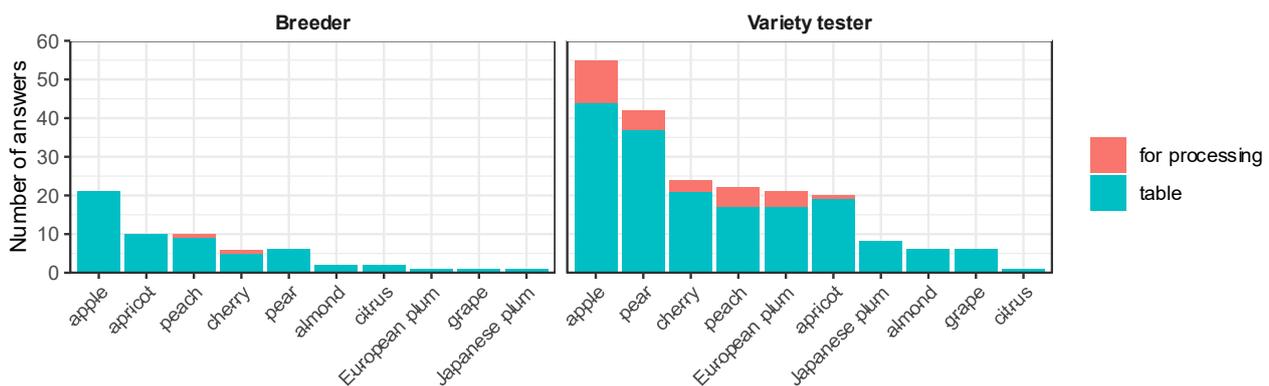


Figure 1: Number of answers per crop for breeders (left) and variety testers (right) (blue = table fruit, red = fruit for processing).

Breeding and testing criteria

For pip fruit and stone fruit, fruit quality, including visual appearance, aroma and firmness, remains the main breeding and testing criteria (Figure 2). The next most important criteria are disease susceptibility and regularity of yield. For pip fruit, additionally, storability is an important trait, while for stone fruit it is self-fertility.

When asked which novel traits might become more important for organic production in the future, respondents cited adaptation traits to climate change (abiotic stressors), such as better tolerance to drought stress and sunburn, resilience to spring frost, and adaptation of chill requirements. While breeders in Northern and Central Europe most often reported frost as major climate stressor in their region, breeders in Southern Europe reported heat waves more often. Therefore, breeding objectives differ according to regions, e.g. hardiness of dormant buds for northern-limit zones and low-chill requirements for regions with warmer climates. Susceptibility to new diseases and pests (biotic stressors) was mentioned second most frequently, e.g. Marssonina apple blotch (*Diplocarpon coronariae*), anthracnose (*Elsinoë piri*) or the Brown marmorated stink bug (*Halyomorpha halys*) for apples.

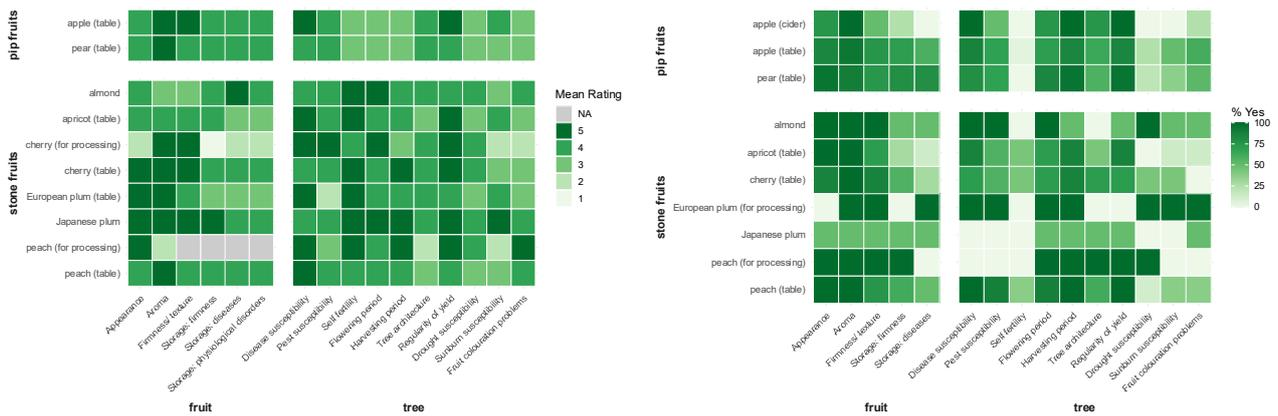


Figure 2: Rating of the importance of the breeding (left) (1 = not important at all; 5 = very important) and testing criteria (right) (assessed yes/no (% Yes)).

Main pests and diseases assessed during breeding and testing

In fruit breeding, markers are currently available only for few important diseases (apple scab (*Venturia inaequalis*), powdery mildew (*Podosphaera leucotricha*, *Sphaerotheca pannosa*), fireblight (*Erwinia amylovora*), Plum pox virus (sharka), peach leaf curl (*Taphrina deformans*), bacterial leaf spot (*Xanthomonas spp.*)) and for some aphid species, including the Rosy apple aphid (*Dysaphis plantaginea*), and the Green peach aphid (*Myzus persicae*). For pip fruits (apple and pear), breeders and variety testers prioritize apple scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*) in apples (Figure 3). Other diseases, such as European canker (*Neonectria ditissima*) and fireblight (*Erwinia amylovora*), are less frequently screened for or assessed. In pear, fireblight is the primary focus, followed by pear scab (*Venturia pyrina*). For stone fruits (apricot, cherry, peach, plum), *Monilia* twig blight (*Monilia laxa*) and brown rot (*Monilia spp.*) are the most important diseases assessed (Figure 4). Apricot respectively peach rust (*Tranzchelia spp.*) is also widely assessed in apricot and peach. Bacterial canker (*Pseudomonas syringae*) is a key focus in apricot, while peach leaf curl (*Taphrina deformans*) and powdery mildew (*Sphaerotheca pannosa*) is a key focus in peach.

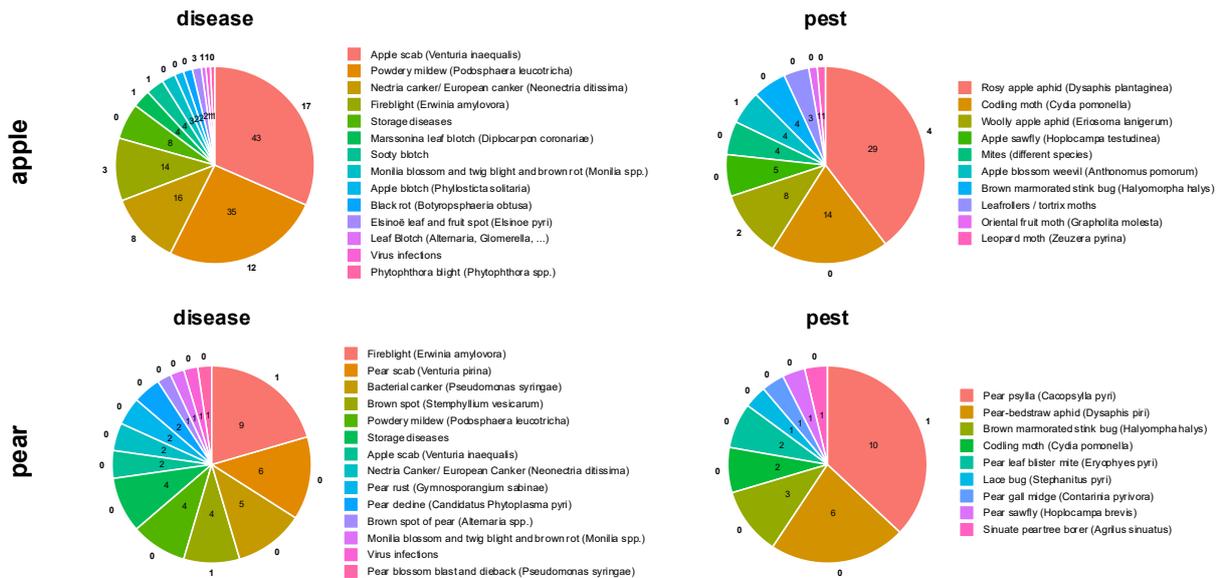


Figure 3: Diseases and pests assessed by variety testers (pie chart) respectively screened for by breeders (number outside the pie chart) in pip fruits. Answers for breeders: apple n=17, pear n=1. Answers for variety testers: apple n=37, pear n=16.

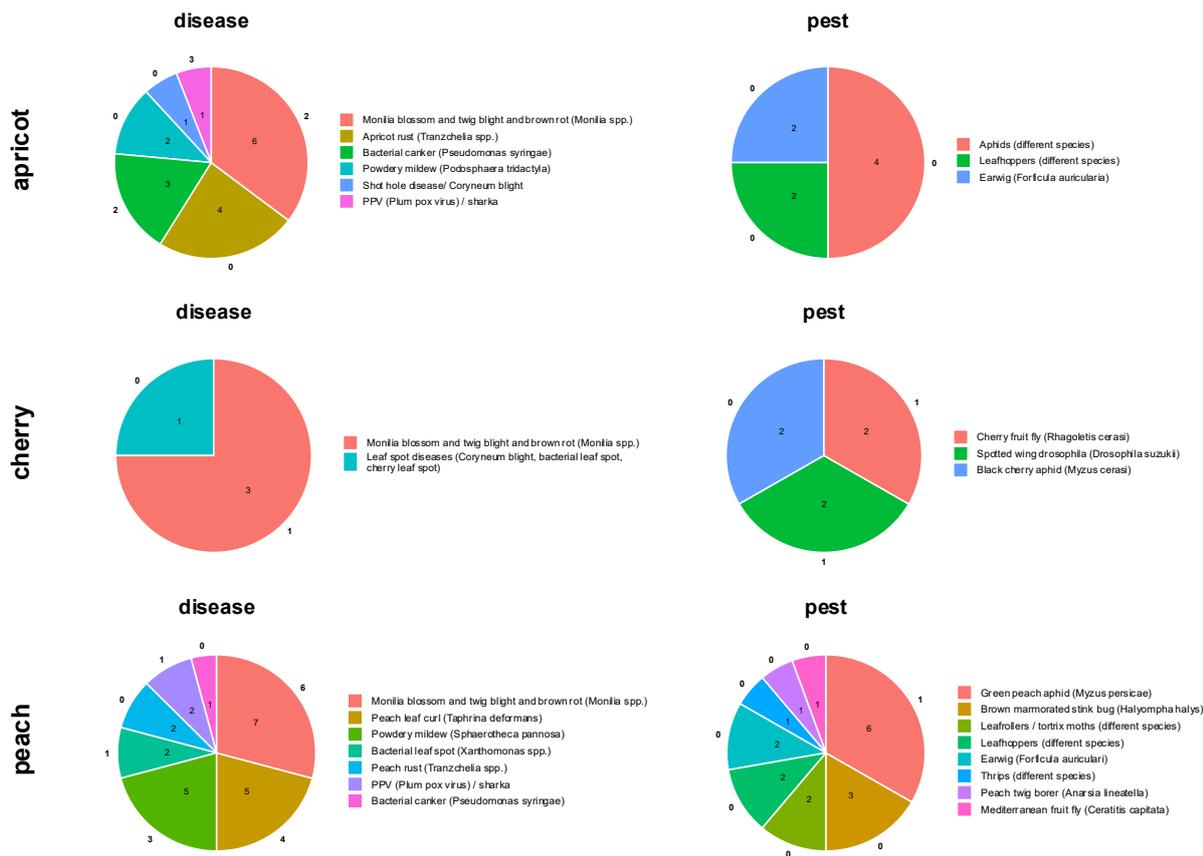


Figure 4: Diseases and pests assessed by variety testers (pie chart) respectively screened for by breeders (number outside the pie chart) in stone fruits. Answers for breeders: apricot n=4, cherry n=1, peach n=9. Answers for variety testers: apricot n=6, cherry n=3, peach n=8.

Steps of breeding and testing and areas of needs

Along the breeding process, breeders reported their main area of needs to be right at the beginning within pre-breeding, and second during the selection of candidate lines (Figure 5). The main areas of challenges within pre-breeding reported were the maintenance of genetic resources, the access to genetic resources material, the access and sharing of data on genetic resources, and the integration of traits fitting with climate change. For the selection of candidate lines, the main challenge is the establishment of efficient screening methods. And for the step of testing the candidate lines, the challenge is the data collection and testing them under organic and/or low input conditions.

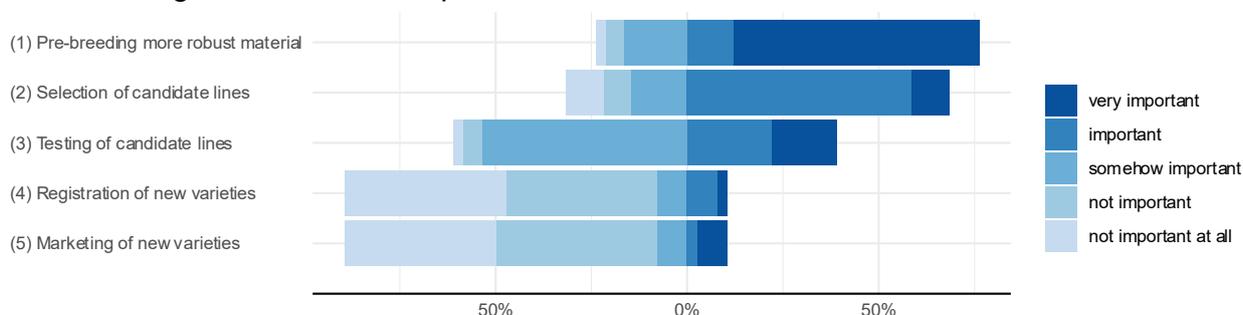


Figure 5: The breeding process of a new variety has been divided into five main steps: (1) pre-breeding, (2) selection of candidate lines, (3) testing of candidate line, (4) registration of a new variety, and (5) marketing of a new variety. The breeders were asked to rank them according to their area of needs (1= most important, 5= least important).

Pre-breeding challenges

Access to genetic resources remains a significant challenge for breeders. While many rely on their own collections (40%), others source material from research institutes (20%), other breeders (17%), gene banks (15%), and farmers (9%). However, one-third of respondents reported difficulties accessing public collections or noted the absence of such collections in their region. Maintaining and evaluating genetic resources is equally problematic due to high costs and insufficient public funding for facilities and trained staff. Additionally, ensuring the sanitary status of plant material is critical to avoid introducing diseases such as Sharka/Plum Pox Virus or Peach Mosaic Virus during the breeding process. Complementary solutions to in-field preservation of genetic material are cryopreservation and centralized germplasm collections, though they require coordination at European level, substantial investment and infrastructure.

To successfully develop new cultivars, knowledge on traits of potential parents is essential. However, breeders reported a lack of data on genetic material in general, and in particular of potential parents tested under organic or low-input conditions. Another challenge regarding the access of data on genetic material is due to inconsistent scoring methods, data protection restrictions, and the high cost of obtaining research results through non-open-access journal articles. Harmonized scoring systems and affordable access to data are essential for improving pre-breeding processes.

Integrating traits that address climate change, such as frost tolerance, heat resistance, sunburn, and drought tolerance, into breeding programs is particularly complex. These traits are difficult to assess due to their dependence on specific climatic conditions, phenological stages, and the lack of reliable screening methods. Furthermore, the effects of climatic stressors on trees are influenced not only by the variety but also by the rootstock, which affects water and nutrient transport. The mismatch between the rapid pace of climate change and the long timelines required for fruit tree breeding further complicates the integration of climate-resilient traits.

Selection Challenges

Efficient screening methods are critical for identifying promising candidate lines, yet many pests and diseases lack established protocols, and new methods need to be developed. Controlled-condition screenings are often technically complex, time-consuming, or hindered by the plasticity of certain traits, such as fire blight resistance in apples. Correlating results from controlled screenings with field performance is challenging, and defining appropriate thresholds for selection is essential. Early field screenings are necessary to validate indoor results. Alternatives to complex and time-consuming methods, are multi-traits analysis screening methods with molecular markers. However, markers are currently only available for a few diseases and pests. Another approach involves in-field screening under no-spray conditions for three years, relying on "survival of the fittest." However, climatic conditions during specific phenological stages can limit the effectiveness of this method.

Testing challenges

Testing candidate lines under organic and low-input conditions is resource-intensive and presents several challenges. Testing perennial fruit crops requires long-term data collection across multiple locations to account for varying microclimates. However, breeders are often confronted with a lack of funding and personnel. Faster and simpler methods, such as digital tools for image analysis and automated post-harvest assessments, could help streamline data collection. Harmonization of data collection methods is also necessary to facilitate

collaboration and data sharing among breeders and testers. While most testers use EUFRIN (48%) or ECPGR (22%) descriptors, others rely on UPOV or custom descriptors, leading to inconsistencies in collected data.

Testing under low input organic conditions is particularly challenging due to high pest and disease pressure, which can complicate trait assessments. Minimal plant protection is often required after initial no-spray testing to maintain tree health. Scoring scales used in conventional testing may need adaptation for organic conditions to account for the higher pest and disease pressure. Participatory testing with farmers, research centers, and contractual partners offers a cost-effective and collaborative solution, but farmers require training or specialized personnel must collect data to ensure reliability. Around two-thirds of testers conduct on-farm evaluations, highlighting the importance of collaboration with farmers in organic variety testing.

Discussion

The results of this study highlight several critical challenges and opportunities in organic fruit breeding, emphasizing the importance of collaboration, participatory approaches, and innovative strategies to address current and future needs. To overcome the identified obstacles, fostering strong networks, testing cultivars under organic and/or low input conditions, implementing multi-site and on-farm testing, and utilizing predictive modelling are essential steps forward.

Collaboration among genebank curators, breeders, and scientific institutes is vital for advancing organic fruit breeding. Strong networks facilitate the exchange of knowledge, genetic material, and screening methods, which are critical for overcoming barriers in organic systems (Kellerhals & Bühlmann-Schütz, 2022; Koustis et al., 2018). Platforms such as conferences, field trips, shared databases, and open-access tools can enhance communication and data sharing among stakeholders. Additionally, the maintenance of genetic resources, including old local varieties and wild species, is crucial for resistance breeding and preserving long-term genetic diversity. These resources provide valuable traits for pest and disease resistance, as well as adaptability to diverse environmental conditions (Buscaroli, 2022; Dumont et al., 2025; Kellerhals et al., 2004; Lateur et al., 1998; Lateur & Populer, 1994; Mukan et al., 2024; Ruess et al., 2018).

Organic breeding programs should prioritize broader tolerance, focusing on polygenic or quantitative resistance rather than single-gene traits. This approach integrated resilience to pests, diseases, and environmental stressors, which are increasingly important in organic systems. The integration of new breeding techniques, such as molecular markers, can accelerate the identification and incorporation of these traits into breeding programs (Ahmad et al., 2021; Bastiaanse et al., 2013; Bolliger, 2024; Kellerhals & Bühlmann-Schütz, 2022).

Participatory approaches, including participatory breeding and on-farm variety testing (Colley et al., 2021; Korsgaard & Toldam-Andersen, 2024; Linhard Pedersen et al., 2022; Ristel et al., 2016; Warlop et al., 2010; Wolter et al., 2018), are vital for developing varieties that are well-adapted to diverse growing conditions. Involving farmers, research centers, and contractual partners in the testing process ensures that selected varieties meet the practical needs of growers while reducing costs. However, participatory testing requires reliable data collection to ensure consistency and accuracy. Training farmers or deploying specialized personnel can address this challenge, enabling robust and actionable results. These approaches also foster stronger relationships between breeders and growers, creating a feedback loop that informs breeding priorities.

Testing varieties under organic and/or low-input conditions is essential for identifying varieties with better resistance or tolerance to pests and diseases (Bertelsen & Lindhard

Pedersen, 2022; Rondia et al., 2024). Organic systems impose unique challenges, such as limited use of synthetic inputs, which necessitate the development of varieties specifically adapted to these conditions. Screening methods tailored to organic systems can help breeders identify traits that enhance resilience and productivity, particularly robustness towards the main pests and diseases.

Multi-site testing is critical for evaluating varieties under diverse climatic conditions, particularly in the context of climate change. Different regions face distinct challenges, such as hardiness of dormant buds in northern zones or low-chill requirements in warmer climates. Establishing dedicated testing networks tailored to specific climatic regions would enable breeders to assess candidate lines under varied conditions, ensuring the development of resilient varieties. Predictive modelling of future climatic scenarios is another essential tool for adapting breeding programs to integrate traits relevant to climate change. Traits such as chilling requirements, blooming time, frost susceptibility, and heat tolerance are often interrelated, making their integration into breeding programs complex. For example, while low chilling requirements are necessary to ensure blooming, they must be balanced with low frost susceptibility and high heat requirements to delay blooming and avoid damage from late frosts. Predictive modelling can help breeders anticipate these interactions and develop varieties better suited to future climatic conditions.

Furthermore, the resilience of fruit trees is influenced not only by the variety but also by the rootstock. Rootstocks determine the root system and overall growth of the tree, affecting water and nutrient transport as well as tolerance to environmental stressors. Testing cultivar-rootstock combinations under organic and/or low input farming system conditions and in varying environmental conditions is essential to optimize performance and ensure adaptability to diverse growing systems. This underscores the need for variety testing programs to include rootstock evaluations alongside variety trials (Pfeiffer, 2022; Spornberger & Schüller, 2016).

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