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Review

PITAHAYA (*Hylocereus* spp.) A FITOGENETIC RESOURCE WITH AN HISTORY AND FUTURE FOR THE DRY TROPIC OF MEXICO

Revisión bibliográfica
Pitahaya (*Hylocereus* spp.) un recurso fitogenético con historia y futuro para el trópico seco mexicano

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ABSTRACT. Some aspects regarding with cropping of pitahaya in Mexico are described. The review shows mostly the importance of this culture, aspects like crop distribution and perspectives, because its marketing potentiality and adaptation capacity to adverse environments mainly to humidity deficit on the soil. Pitahaya fruits have a high market price at national and international markets. However it is noticeable the scarce number of researches about the optimum period for fruit harvest and the sustainable agro technical management in order to obtain a product with the better organoleptic properties for the commercialization with better prices for the producer.

Key words: acclimatization, marketing, crop

RESUMEN. Se describen algunos aspectos relacionados con el cultivo de la pitahaya en México. La revisión enfatiza en la importancia de este cultivo, así como su distribución y perspectivas, debido a sus potencialidades para la comercialización y capacidad de aclimatación a ambientes adversos, sobre todo al déficit de humedad en el suelo. Los frutos de la pitahaya se comercializan a altos precios, tanto en mercados locales como internacionales; sin embargo, son escasas las investigaciones sobre su manejo agrotécnico sostenible, sobre todo las relacionadas con el momento óptimo para la cosecha, que permita obtener un producto con mejores propiedades organolépticas para su comercialización a precios ventajosos para el productor.

Palabras clave: aclimatación, comercialización, cultivo

INTRODUCTION

Cacti belong to the order *Cariophyllales*, where they share the presence of betalains (1) with other families; they come from the American continent and although its 1500-2000 species are distributed from Canada to Patagonia, there are between 550 and 900 in Mexico, where 79 % are endemic species (2).

There are about 35 species, mainly belonging to the genera *Hylocereus*, *Selenicereus*, *Cereus*, *Leptocereus*, *Escontria*, *Myrtilloactos*, *Stenocereus* and *Opuntia*, with crop potential for fruit, vegetable or fresh fodder production (3). The genus *Hylocereus* with 16 recognized species is the most worldwide distributed creeping cactus (4). It has a great DNA polymorphism, which involves a wide variation of types that probably correspond

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to the same species. It is geographically distributed in places where ecological conditions are limiting, which represents a serious threat for its survival due to several natural and anthropological causes (4). The origin of this genus is attributed to the forest regions of the tropics and subtropics of Mexico, Central and South America (5).

H. undatus, *H. polyrhizus*, *H. costaricensis*, *H. triangularis* and *H. purpusii*, traditionally known as red pitahayas, are mainly grown in Central America and Israel (1), whereas yellow pitahaya *Selenicereus* spp., with 20 species (6), is distributed in Bolivia, Peru, Ecuador, Colombia and Venezuela[A].

The main application of pitahaya is nutritious, especially the fruit, although its flowers are consumed as vegetables whereas young shoots as fresh vegetables (7). Seeds are used as probiotics, since they contain oligosaccharides, which can constitute an important ingredient in functional foods and nutraceutical products (8).

This review reports some characteristics of pitahaya crop (*Hylocereus* spp.), both from the botanic and managing points of view, particularly as related to harvest and postharvest, as well as its industrial potential and prospects for production and marketing, based on the permanent updating of the knowledge got by different researches on this crop.

Therefore, by this way, it is intended to contribute to this crop assessment and conservation, considering the adaptive features of this genus to drought and aridity conditions, and its advantages for the sustainable management of both small and large cropping areas in different productive structures.

CROP IMPORTANCE AND DISTRIBUTION IN MEXICO

Pitahaya is a cactus acclimated to different environments in Mexico and some Central American countries (9). *H. undatus*, *H. purpusii* and *H. ocamponis* are distributed in the states of Quintana Roo, Yucatan, Tabasco, Veracruz, Guerrero, Queretaro, State of Mexico, Puebla, Oaxaca, Michoacan, Jalisco, San Luis Potosi, Colima and Sinaloa (10, 11, 12, 13). Out of the 31 recognized species, only three have been recorded in Mexico (14). *H. undatus* is wildly distributed in all these states.

Mexico is the center of origin of some cacti species, which are widely used as ornamental plant, but also as an important food source and for other uses such as medicinal, living fences, etc. Its cultivation is a profitable economic activity in rural regions where climatic and edaphic conditions are not favorable for other crops, due to water shortage, stony soil and low nutritional capacity. The genus *Hylocereus* is among the cacti with great productive and economic potentials, which gathers various species with different growth habits and having fruits that are commonly known as Pitahayas.

H. undatus has a great economic importance in Mexico, its fruits are highly estimated for the appearance and taste; also, they are easily sold in local and regional markets and trade increases in the domestic and overseas markets (15). This plant can be fully exploited, and while it is highlighted by the economic importance of fruits (16), young stems are also used as food. Yucatan is the main fruit producing state reaching moderate yields (17).

BOTANICAL FEATURES

Pitahaya is a perennial, creeping, epiphytic that commonly grows on trees and/or rocks, because it cannot sustain itself (18).

Within the genus *Hylocereus*, *H. undatus* is the most deeply studied species for its wide morphological, physiological and genetic variation (19). Several researches have been conducted with *H. undatus*, *H. ocamponis* and *H. purpusii*, showing that the three species have vessel elements with simple perforation plates and alternate pits, tissue fibers, low paratracheal parenchyma, heterogeneous radios. Wood is mesomorphic, with variations only in the length of glass element and the width of radios. At present, there are not enough anatomical descriptions that allow supporting species recognition at the genus *Hylocereus* present in Mexico and its distribution (20).

Stems or cladodes are succulent, green and photosynthetic; they are characterized by thick ridges or ribs that longitudinally run through them. Typical leaves become aculea (2 to 4 mm) arranged at the edges forming fascicles called areolas (small pads similar to buds which give rise to shoots and inflorescences)[B].

[A] Caetano, C. Identificación de los recursos genéticos y fitoquímicos de pitahaya amarilla en Colombia, [117-2]. Ministerio de Agricultura y Desarrollo Rural MADR, Asofrocol y UNAL Palmira, Colombia, 2010, 51 p.

Flowers are hermaphrodite and actinomorphic; they are directly inserted on stems having tubular shape; they are large (20-40 cm long and up to 25 cm diameter), very showy and attractive to pollinators (21), mainly bats in the case of red pitahayas (22); they open only once at night, generally appear lonely and have a heteroclamideous perianth. The male sexual verticil is composed by numerous spirally arranged stamens producing tricolpate pollen grains. Gynocieum ovary is inferior with many joined carpels and unilocular (covered by aculea in the case of *Selenicereus*) extending in a unique style with completely green bracts or green with red edges and white, yellow or pink petals, which contains numerous crasinucelar and bigtegmic seminal primordia with long funicles arranged in a basal or parietal placentation. The flower has a nectarial chamber (23).

The fruit is a globose or subglobose berry (dehiscent in *Hylocereus* and indehiscent in *Selenicereus*) measuring an average from 8 to 15 cm long and from 6 to 10 cm diameter, its pericarpel is red or yellow[B].

GERMINATION

The period for the onset of germination is different between pitahaya species. Studying this parameter, statistically significant differences were observed for two species, indicating that germination started on the second day and ends on the ninth day at *S. megalanthus* and from the fourth to seventh day at *H. polyrhizus*; the largest number of germinated seeds occurs on the fourth and fifth days, with the highest values for the red species[B].

Seeds with longer fruit extraction have lower germination percentages and in those with one-day fruit extraction, this value can decrease from 75,7 to 7,2 % for a lot stored during 30 days. The difference between lots of 30 and 90 days may be of 0,7 %[C].

Under different temperature conditions, pitahaya seed germination gradually decreases and varies with species; in *H. undatus* and *H. polyrhizus* from 92 to 67 % and from 96 to 99 %, respectively; in *Hylocereus* sp it decreases 20 % at the sixth month and no germination occurs at the seventh month[B].

GENETIC VARIABILITY

Regarding studies of genetic variability with RAPD markers (Randomly Amplified DNA polymorphisms) in 50 collections of pitahaya (*Hylocereus undatus* Haworth, Britton and Rose) from nine states of Mexico and one collection from Colombia, which was included as a check, a high variability (polymorphism of 92,5 % between collections) was detected in populations of this species and a group of materials from three states that differ from the other collections in their RAPD genotype, suggesting that there is endemic genetic variability in Mexico, which can be considered one of several diversity centers of *H. undatus* (4).

The growing demand of pitahaya has led to a rapid loss of diversity, due to the excessive collection of wild material. This practice requires setting a balance between profitability and preservation, which implies defining strategies involving specific ecological, technological and socio-economic aspects for each region, particularly in the absence of selected genetic material and well-established management practices among producers[A], enabling them to get crop income, consequently, to improve their life quality.

On the other hand, it is remarkable to point out that pitahaya growers from Tianguistengo, state of Oaxaca, Mexico, have a deep morphological knowledge, which is observed when developing their own classification and nomenclature, according to traditional and diverse selection criteria, mainly based on fruit and stem characters from more than 25 cultivars (24).

ADAPTABILITY TO ADVERSE FACTORS

Pitahaya (*Hylocereus undatus* Haw.) is a native cactus of America, whose adaptability to different environmental conditions favored its introduction to countries with marked differences in climate and soil (25).

As a xerophyte species -adapted to dry and arid environments-, it has developed some mechanisms to encourage water uptake (very big radical apparatus with large horizontal development), to prevent loss through transpiration (aerial organs with reduced or thick cuticles; low number of stomata per unit area

[B] Suárez, R. R. S. Evaluación de métodos de propagación en pitahaya amarilla *Selenicereus megalanthus* (Haw.) Britt and Rose y pitahaya roja *Hylocereus polyrhizus* (Haw.) Britt and Rose [en línea] [Tesis de Maestría]. Universidad Nacional de Colombia Sede Palmira, Colombia, 2011, 280 p., [Consultado: 9 de noviembre de 2015], Disponible en: <http://www.bdigital.unal.edu.co/4471/>.

[C] Manzano, E. Efecto de la luz y el agua en la germinación y fotosíntesis del cacto epífito *Rhipsalis baccifera* (J. S. Miller) Stearn del bosque nublado [Tesis de Maestría], Instituto de Geología, Xalapa, Veracruz, México, 2008.

present in the stem) or to promote its accumulation by developing aquifer parenchyma, which is plastically manifested in the almost universal fleshy consistence of aerial organs[C].

The study of pitahaya (*Hylocereus undatus*) plants having white and red pulps collected in the valley of Tehuacan, Puebla, and submitted to sulphatic-chloridric salinity values of 2.5, 5 and 10 dS m^{-1} demonstrated that there are no direct effects on plant root and shoot production due to salinity, which makes evident the tolerance of this plant species to sulphatic-chloridric salinity (26).

LIMITATIONS

Despite the worldwide expansion of pitahaya growing areas, little has been studied about its development limitations. At present, Nicaragua holds the world leader in terms of a cultivated area of 560 hectares (27). Yucatan peninsula is the Mexican region with the largest cultivated area; more than 300 producing hectares are estimated (27). Since then, the state of Yucatan excels as pitahaya producer[D]. Concerning *H. undatus* adaptability, it is grown in different countries of America, Asia and Middle East, tropical and subtropical countries of the world[E].

In Mexico, some etiological studies on fish eye disease caused by *Botryosphaeria dothidea* have identified in time both the symptoms and control method[F].

Soft rot of pitahaya (*Hylocereus undatus*) stems is another disease that is present in the municipalities of Halachó, Santo Domingo Maxcanú, Sinanché, Kinchil, Dzidzantún, at the state of Yucatan, highlands producing *H. undatus* and *H. purpusii* species. In these areas, the disease has been associated with two bacteria inducing rot after 15 days of its presence in the crop. *H. undatus* is the most sensitive species, due to Ca and N deficiency, favoring pathogen development. In general, this disease severity in pitahaya plants is associated with nutritional deficiencies (28).

Anthracnose (*Colletotrichum gloesporoides*) with an incidence of 16,6 %, basal rot (*Fusarium oxysporum*) with 29,3 %, black mold damage (*Cladosporium*) with 34,2 %, wilt (*F. oxysporum*) with 36,6 %, leaf rot (*F. oxysporum*) with 47,5 % and fruit scab with 48 % were reported as the most important diseases in some areas of the country[G].

Regarding the main problems caused by insect-pests, literature recognizes the following as the most frequent ones: leaf leg bugs, known as “x’kisay” in Yucatan (*Leptoglossus phyllopus*, *L. zonatus* and *L. gonagra*), stem and fruit borer (*Lepidoptera*, *Pyralidae*), stem miner (*Lepidoptera*, *Gracilaridae*), *Ceratitiscapitata* and *Anastrephaludens*; cutting ants (*Acromyrmexocto espinosus*) and fire ants (*Solenopsis geminata*), which are mainly fought with chemicals. The presence of these agents is scare in yellow pitahaya plants of Colombia[B].

PROPAGATION

The main propagating form of pitahaya is vegetative from stems, cuttings or cladodes, in nature by removing stems and, in the case of crop plants, through direct transplantation to the land or by putting them into bags with substrate until new stem formation. Grafts are used in selected stocks and shoots (5, 29, 30).

Pitahaya is also reproduced by seeds scattered by birds and other animals, mainly bats in the case of red pitahaya (31); however, sexual propagation is not recommended for crop purpose, since plants require too much care when transplanted and they take four to six years to reach their reproductive stage (5), but it is widely used in scientific research (30).

Propagation by cuttings of *H. undatus* using nutrient solutions with three types of substrates (sand, coconut fiber and vermicompost) showed no effect on root length or its number, but it did in the number of shoots formed. The substrate based on coconut fiber increased the number of roots and shoots[H].

[D] Secretaría de Agricultura y Ganadería, Desarrollo Rural, Pesca y Alimentación. Anuario estadístico dela producción agrícola [en línea]. 2010, [Consultado: 9 de noviembre de 2015], Disponible en: <http://infosiap.siap.gob.mx/aagricola_siap/icultivo/index.jsp>.

[E] Meraz, A.; Gómez, C. y Schwentesius, R. ‘‘Pitahaya de México, producción y comercialización en el contexto internacional’’. En: Pitayas y Pitahayas, edit. Universidad Autónoma Chapingo, Chapingo, México, 2003, pp. 99-116.

[F] Valencia, B. A. J. Etiología de la enfermedad ojo de pescado en pitahaya (Hylocereus undatus H.) [Tesis de Maestría]. Colegio de Postgraduados de Montecillo, Montecillo, México, 2002, 110 p.

[G] Araujo, L. y Medina, O. Reconocimiento de patógenos asociados al cultivo de pitahaya amarilla (Selenicereus megalanthus Haw.) en el departamento del Valle del Cauca [Tesis de Grado]. Universidad Popular del Cesár, Valledupar, 2008, 148 p.

Stake growth is highly influenced by water availability and light intensity; thus, the effect of shade on *H. undatus* during the rainy and dry seasons causes higher stem elongation with intermediate light intensities (36 and 48 % photosynthetic photon flow); the rate of stem elongation also increased with more soil water (32).

At present, *in vitro* propagation of some pitahaya species like *H. purpusii*, which is in danger of extinction, has been successful up to 90 % germination (33), so that this propagating method has become a choice to ensure the existence of some species at risk of disappearing.

MATURITY AND HARVEST

During fruit growth of *Hylocereus undatus* species, maturity occurs between 25 and 31 days after anthesis, as indicated by a peel color change from light green with incipient red parts to purple red, reducing progressively fruit firmness. At the same time, Brix degrees and reducing sugars increase. On the other hand, malic and ascorbic acids decrease with maturity. All these factors make that the organoleptic fruit properties are generally more accepted at different markets after 29-31 days of maturity (34).

Studies in Israel (35) and Vietnam (36) showed that fruits of *Hylocereus undatus* are harvested when they become red between 28 and 30 days after anthesis. Similar results were obtained in a sensory study, where the most accepted fruits were harvested between 25 and 31 days after anthesis (34). In California, USA, pitahaya matures between 40 and 45 days after flowering, when fruits have reached its maximum level of total soluble solids (13-16 °Brix) (37). In general, it is noted that fruit color development is related to its total soluble solid content.

With regard to the red fruit color of *Hylocereus*, this is due to betalaines (38). Moreover, there is a significant negative correlation between values of °Hue (hue angle) (39) and the total betacyanin content of *H. polyrhizus* nut and fruit, which provides red hues by condensing a cycle-DOPA (dihydroxyphenylalanine) structure with betalamic acid, reaching a dramatic increase of 90 and 65 %, respectively, between 25 and 30 days after anthesis (40), meanwhile values equal to or less than 30 ºHue are required to marketable pitahayas (36).

The relationship between some damage symptoms and the activity of enzymes associated either with fruit browning (brown color is related to polyphenol oxidase action) or pitahaya fruit antioxidant system shows a direct relationship to POD (peroxidase) and PFO (polyphenol oxidase) activities. The maximum CAT (catalase) activity observed during climacteric period responds to the right balance with the expected high production of H_2O_2 at that time (41).

POSTHARVEST

Peel color varies during storage and between maturity states (early, half and full), so that hue angle values gradually decrease from orange red, red to purple red (41).

Harvested fruits during half and full maturity keep better peel color features at the level of total soluble solids for 12 days of storage (20 ± 2 °C) than fruits harvested in early maturity. However, the rapid acidity reduction affects their quality. Moreover, fruits harvested in early maturity retain the highest levels of firmness, acidity and vitamin C, and better °Brix/acidity relationship until the 10th day of storage (39).

Fruits harvested with 70-100 % color can be kept at room temperature between six and eight days of useful life with the required quality parameters (TA, 0,24 %; less than or equal to 30 ^{0}Hue; Brix/AT relationship lower than 40; weight loss less than 5 %) and between 10 and 12 days under air conditioning at 20 + -2 °C. Even under these conditions, inner fruit quality deteriorates at longer permanence, affecting its consistency, due to pulp softening related to the increased activity of pectinmethylesterase during maturity and to the mid sheet dissolution of their tissues, although its outward appearance is kept (42) and it is generally accepted for the market.

[H] Cerqueda, R. H. Propagación sexual y asexual de la pitahaya (Hylocereus spp.) [Tesis de Maestría]. Instituto Politécnico Nacional. Centro interdisciplinario de investigación y desarrollo integral regional. Unidad-Oaxaca, Oaxaca, México, 2010, 62 p.

Concerning fruit firmness, titratable acidity (TA), total soluble solids (TSS) and vitamin C decreases are reported during storage. Fruit firmness remained higher in early maturity fruits. TA decreased about 80 % at the three stages of fruit maturity, but it was higher when early maturity fruits were harvested. TSS had a significant decrease (P≤0,05) with higher °Brix values in half and full maturity fruits than in those with early maturity (39). There was a close relationship between fruit color development and TSS increase, since fruits with 20 days of development recorded 4,6 °Brix whereas those with 31 days reached 12,6 °Brix (34).

Vitamin C content is related to fruit quality and decreases during storage. It is higher in early maturity fruits harvested and there are differences between half and full maturity fruits harvested. Vitamin C declines are recorded during *H. undatus* fruit maturity; when they are harvested 20 days after flowering, values are of 14,7 mg 100 g^{-1} and of 9,6 mg 100 g^{-1} at 31 days (24).

Storage potential and viability also depend on seed tolerance variation to desiccation, which can be attributed to intrinsic plant characteristics and environmental conditions (43). Moisture contents between 6 and 15 % allow visualizing seed potential to subject them to drying tests for storage purposes (34).

The minimum preservation process of pitahaya (*Hylocereus undatus*) fruits coated by polypropylene plastic film and stored at 4 °C, keep their quality and slice acceptability up to 28 days (44). It is also important to note that immature stems are used for human consumption (45).

During the postharvest handling of fruits stored at 20 °C, there is a weight loss and color variation, also TA percentage decreases; under such conditions, postharvest life lasts 6-8 days in half and full maturity fruits and up to 10 days in initial maturity fruits harvested (39).

Some quality features (weight loss, titratable acidity, peel anthocyanins, outer peel color and breathing) of pitahaya (*H. undatus*) fruits may be affected by atmospheric composition (CA) (5-5: 5 % O_2 + 5 % CO_2 + 90 % N_2, 5-10: 5 % O_2 + 85 % CO_2 + 90 % N_2), cold storage time at 4 ^{0}C and their exposure to room temperature. In the case of AC, weight loss is reduced whereas AT and the outer peel color are not affected under these conditions (51). It is generally concluded that AC levels, depending on storage time, influence the cold storing when pitahayas are transferred to room temperature, compared to those with temperature and without it (26 ± 2 °C) (46).

NUTRITIONAL VALUE

Pitahaya species (*Hylocereus spp*) have nutritional qualities. *H. undatus* contains 14,84 g of crude protein, 21,50 g of crude fiber and 39,94 g of essential minerals (47).

Immature, soft consistent stems are used in Mexican cuisine; however, there is little information about their nutritional content. When studying the composition of tender stems collected from an experimental pitahaya plantation in Tepoztlan, Morelos state, Mexico, crude protein contents of 11,08 to 24,49 g and crude fiber contents of 7,86 to 14,79 g were recorded, with lower ash contents (10,80 to 14,90 g) and ethereal extract (0,64 to 1,46 g) obtained through a proximate analysis and expressed on dry basis (g/100 g dry matter). As for minerals, *H. undatus* has significant contents of K (4,82 mg kg^{-1}) and Zn (34,02 mg kg^{-1}) (48).

INDUSTRIAL POTENTIAL

Pitahaya fruit has great industrial potential due to its high betalains content, which are pigments having antioxidant properties and are considered as an alternative to the use of artificial colors in foods. These advantages for agro-industry have increased the international interest in this crop, both for marketing and to find other processing choices (49). The red species is valued by betalains production, so that its extraction and use has been extensively studied (50).

In recent years, studies on betalains and its properties have proliferated in several species of the genera *Opuntia* (17, 51) and *Hylocereus* (50). Besides providing color to fruits and having antioxidant activity, betalains are recognized for other important biological activities, such as induction of quinone reductase, a potent detoxifying enzyme in the chemoprevention of cancer (52), and its cell-antiproliferative activity of malignant melanoma (53).

Betalains content is different according to the groups of species, depending on fruit color. Since

betalains were found in greater proportion than phenols, they are considered as the most contributing compounds to the antioxidant activity observed (53).

Besides, its high content of soluble solids (up to 18 °Brix) provides them a great marketable and agro-industrial potential. Every pitahaya pulp can be processed (freezing, concentration, dehydration, fermentation, thermal processing and chemical preservation) to extract dyes and pectins contained in the peel or pulp through a domestic, handicraft or industrial technology (1); it is also used in the production of juices, sorbets, jelly, ice cream, yogurt, jam, syrup, candy and pastries (5).

The possibility of advancing flowering up to 83 %, under irrigation, and increasing the number of flowers with respect to those developed under dry conditions favors a better yield and enhances its potentialities for industrial production[1].

PITAHAYA CROP PROSPECTS

As an agricultural choice in regions with scarce water resources, pitahaya crop becomes an economically and socially important activity for rural communities in Mexico and several American countries, as it is a resistant plant to different limiting weather conditions and its management requirement is minimal. Another advantage for the region is that pitahaya fruit reaches a good price in local, regional, national and international markets as it is an exotic fruit (27). On the other hand, it can develop in home gardens and cash crops in the short and medium terms (27).

In recent years, the interest in commercially growing pitahaya at different parts of the world has been increased. The main producing countries are: Nicaragua, Colombia, Mexico, Guatemala and Israel, where breeding researches on this crop are conducted. As with other crops, seasonal production significantly reduces fruit price; thus, techniques consisting of using irrigation and nitrogen fertilizers applied after harvest are used to increase production (1).

However, the international market prospects demand researches leading to a better fruit quality and especially to supply elite genotypes for seeding and managing the productive chain as well as an added value (transformation) (54).

The use of agro-ecological practices for an optimal crop development is one of the trends that should be encouraged. In this sense, future researches must focus on improving cultural practices to achieve greater compatibility with the environment and to search for the optimum harvesting time, so as to obtain a product with improved organoleptic properties.

The identification of species from the genus *Hylocereus*, which may be established in association with cash crops and develop different fruiting periods, will promote a higher production throughout plant growing cycle. This is another research line to be enhanced with the physiological, structural, anatomical, agronomic studies, etc.

The establishment of marketable pitahaya plantations, not only in domesticating regions but also at different states of Mexico having fruit production potential, without any traditional managing experience, will require to rely on specialized crop research results to develop the necessary experience.

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