Prospects and Significance of Chinese Jujube (*Ziziphus jujuba*) in New Mexico: A Review

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ABSTRACT

This is a review paper on the jujube plant. The jujube (*Ziziphus jujuba* Mill.) is a medium-sized tree indigenous to northern China. It is cultivated mainly for its nutritious fruits. The tree adapts well to subtropical and temperate climates and can be easily cultivated where peaches and apples grow. Prospects of jujube as a future crop are increasing in the United States, including New Mexico. However, there are only a few studies relating to jujubes reported from New Mexico. The lack of planting materials and research information are a few factors limiting its cultivation. Researchers should focus on improving propagation techniques to ensure proper supply and availability of jujube planting materials. Although New Mexico has a suitable climate for jujube, many farmers are unfamiliar with the crop due to the lack of proper extension and promotion approaches. Therefore, participatory research projects with farmers' involvement are necessary to identify and address several challenges relating to crop establishment, growth, production, post-harvest, and marketing phases. These findings could help establish jujube orchards and industries in New Mexico. Here, we review the characteristics, significance, and potential of jujube in New Mexico, USA.

KEYWORDS: Jujube, Ziziphus, Plant, Cultivation, New Mexico

INTRODUCTION

This is a review paper on the jujube plant, especially its relevance to horticulture in New Mexico. Jujube (*Ziziphus jujuba* Mill., Rhamnaceae) is a versatile deciduous tree primarily planted for edible fruit.[1] It originally grew along the Yellow River of northern China. These trees were moved to almost all parts of China and subsequently to neighboring Asian countries. Today, jujube is dispersed in approximately 50 countries all around the world, mainly in Asia, Europe, Russia, Africa, Australia, and North America.[2] Jujube easily adapts to arid and semi-arid climate at an elevation of 0–2000 m with diverse temperature ranges of 5.5–28 °C.[3,4] Its cultivation ranges from poor marginal land to fertile soil, but it does much better in

sandy loam soil with slightly acidic to alkaline soil (pH 4.5–8.4).[4,5] Jujube could survive annual precipitation of 87–2000 mm.[4] Young jujube trees in Portales, New Mexico (NM) are as shown in Figure 1.

Figure 1. Jujubes as drought-tolerant crops in Portales, NM.

Morphological and Phenomenological Behavior

Jujube is a perennial tree that reaches a height of 5–10 m. Young plants have thorns in branches (straight or curvy) but are usually absent in mature trees.[4] Green leaves are usually alternate, simple, and ovate to lanceolate. The inflorescence type is a cyme having 2–13 number of flowers. Flowers are formed in leaf axils, are short-stalked, 3.5–10 mm in diameter, and greenish-white to yellow.[4,6] Fruit type is a drupe, ellipsoid to elongate to round and bright reddish-brown. Fruit diameter ranges from 14–40 mm and differs among varieties.[4]

The management of the jujube orchard depends on the occurrence of particular growth stages. The growth stages of plants, however, vary with location, climate, and environment.[7] In Portales, NM, Sapkota et al. studied the growth stages of jujube and reported eight principal growth stages (Table 1, Figure 2).[8]

Major growth stages	Months
Bud growth	mid-March to first week of April
Leaf formation and growth	mid-April to mid-May
Shoot formation and growth	May to June
Inflorescence formation	mid-May to late June
Flowering	late-May to July
Fruiting	mid-June to mid-August
Fruit maturation	mid-August to late September
Winter dormancy	mid-October to mid-March

Table 1. Phenological stages of jujubes in Portales, NM.

The phenological knowledge might help farmers to plan and perform management practices such as irrigation scheduling, fertilizer application, timely harvesting, etc. at optimum growth stage.[9] For example, water requirement of the jujube tree is relatively higher at fruit

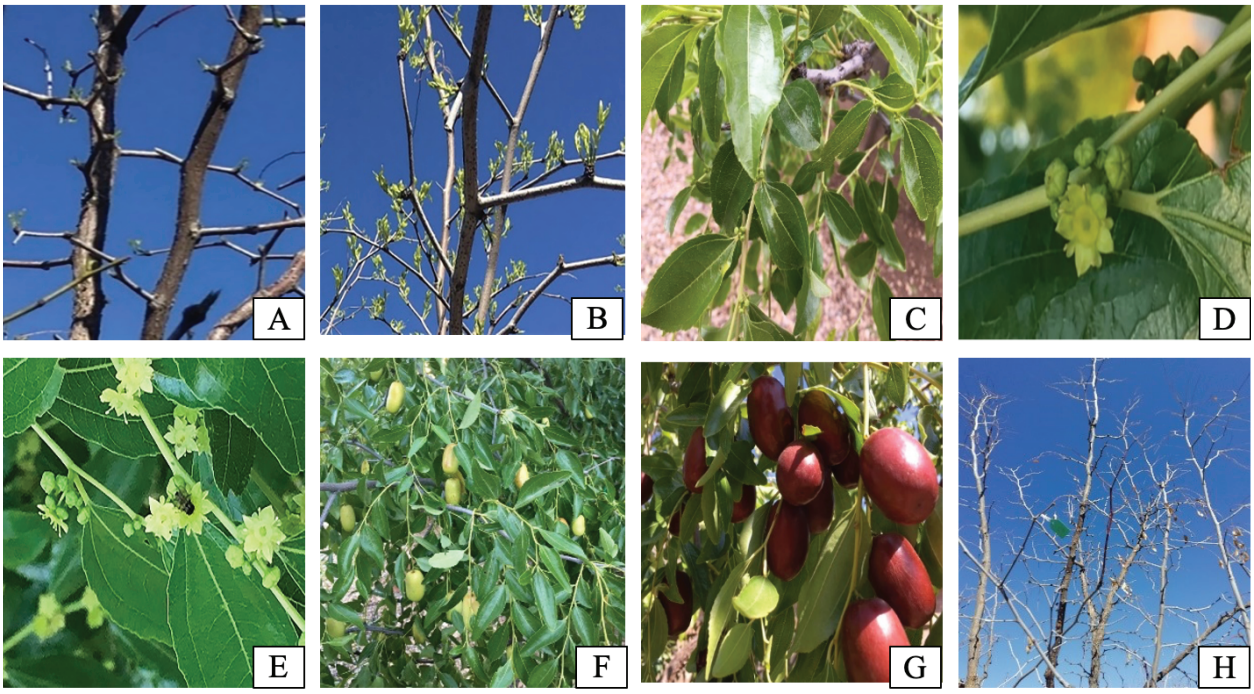

Figure 2. Major growth stages of jujube in Portales, NM: A-H refers to bud growth, leaf formation and growth, shoot growth, inflorescence formation, flowering, fruiting, fruit maturation, and winter dormancy, respectively.

setting and growth,[4] and the stage occurs from mid-June to early August in Portales, NM. Farmers may consider watering the trees during this period to get more production. Jujube phenology differs from other similar crops in NM. For example, peach and apple produce leaves in mid-February to early-March, and flowers in early to mid-April in Alcalde, NM.[10] In case of apricot, the leaf formation, flowering, fruiting, fruit growth and maturation, and harvesting stages occur in mid-Feb to early March, early to mid-March, late June to late July, depending on the cultivars.[10] Thus, the winter frost in this region is more likely to damage similar crops (peach, apple, and apricot), but jujube could skip the damage since the leaf formation and flowering stage occurs late.

Jujube Benefits and Industrial Applications

The jujube tree has several advantages: i) broad environmental adaptability, ii) provision of edible fruits, nectars, and fodder, and iii) landscape benefits.[1,11] Vegetatively propagated tree generally begins to produce fruits two years after transplantation and continues for 50 years.[12] The fruit yield of jujube ranges from 50–250 kg/tree depending on the cultivars and management practices.[12] The yield is higher compared to similar crops grown in semi-arid regions: peach (45–70 kg/tree) in Spain[13] and apricot (20–100 kg/tree) in Turkey.[14] In Alcalde, NM peach yield ranged from 12.1–67.2 kg/tree depending on cultivars.[15]

Jujube fruits are sweet and texturally similar to apple. The fruits can be consumed in fresh, dried, and processed form.[3,16] Besides, the fruits can be diversified into various products such as paste, syrup, puree, jam, candy, beverages (juice, wine, tea), powder, and confections for value addition and industrial applications.[1,3,16] Jujube also provides ecological benefits as they cover the land and reduce soil erosion.[17] The commercial uses of jujube are as shown

in Table 2. Jujube fruits are rich sources of vitamin C, minerals, and antioxidants.[22] The 100 g dried fruits contain 192-359 mg vitamin C.[23] Table 3 displays the nutritional composition of jujube fruit.[24]

Plant organ	Use/s	Reference(s)
fruits	food	1,16
wood	furniture, musical materials, cup, plate, handicrafts, agricultural equipment, fuel	1,18
leaves	tea, wine, fodder	1,19
flowers	nectar, honey	20
spiny branches	live fences	21

Table 2. Commercial uses of jujube trees.

Nutrients	Raw fruits	Dried fruits
Water (g/100 g)	77.86	20.19
Energy (kcal/100 g)	79	281
Protein (g/100 g)	1.2	4.72
Total Lipid (g/100 g)	0.2	0.5
Carbohydrates (g/100 g)	20.23	72.52
Sucrose (g/100 g)	-	8.63
Glucose (g/100 g)	-	18.28
Fructose (g/100 g)	-	20.62
Fiber (g/100 g)	-	6
Ash (g/100 g)	0.51	2.08
Calcium (mg/100 g)	21	63
Iron (mg/100 g)	0.48	5.09
Magnesium (mg/100 g)	10	-
Phosphorous (mg/100 g)	23	68
Potassium (mg/100 g)	250	217
Sodium (mg/100 g)	3	5
Zinc (mg/100 g)	0.05	0.39
Copper (mg/100 g)	0.073	-
Manganese (mg/100 g)	0.084	-
Vitamin C (mg/100 g)	69	217.6
Thiamin (mg/100 g)	0.02	0.047
Riboflavin (mg/100 g)	0.04	0.053
Vitamin B-6 (mg/100 g)	0.081	-
Vitamin A (IU/100 g)	40	-
Niacin (mg/100 g)	0.9	-

Table 3. Nutritional composition of Chinese jujube fruit based on information from USDA food and nutrient database.[24]

Jujube has great medicinal values. Almost all plant parts (root, bark, leaf, flower, fruit, and seeds) have been utilized to make drug ingredients in ancient Chinese medicine.[23,25] The fruit extract contains several bioactive compounds such as triterpenic acids (ceanothic, oleanolic,

zizybernalic, ursolic, and betulinic acids), α-tocopherol, and polysaccharides and is useful in the treatment of different types of cancers such as breast, cervical, hepatoma, lung, and ovarian.[26,27] The pharmaceutical components found in jujube and their importance in the medical field are as shown in Table 4.

Plant parts	Compound(s)	Biological activities	Reference(s)
fruits	aqueous extracts	anti-tumor, prevents breast and cervical cancer cells, reduced the growth of C643's cells (human thyroid carcinoma cells), antioxidant activity	28,29,30
	alphitolic acid	act against human cancer cells (PC-3 cells and MAD-MB-231 cells)	31
leaves	flavonoids	antidiabetic, antiaging, cardioprotective, neuroprotective, sedative,	19
	triterpenic acids	anti-inflammatory, antimicrobial, antioxidant	32,33
	polyphenols	antimicrobial, antitumor, antioxidant	34,35
seeds	flavonoids, saponins, oil, and unsaturated fatty acids	sedative and hypnotic	36,37
roots	ceanothane- and lupane-type triterpenoids	anti-cancer, anti-inflammatory, antiviral activity for human immunodeficiency virus	38

Table 4. Pharmaceutical components found in jujube.

Propagation Techniques

The seedlings produced from jujube seeds require a longer period to reach the fruit-bearing stage. Thus, seed germinated seedlings are generally not used to grow fruit trees for commercial orchards directly, but one-year-old seed germinated seedlings are used as a rootstock for grafting propagation.[39,40] Previous study has reported that jujube seeds have a germination rate of 5% at room temperature and 37% at 30 °C.[41] Propagation success has also been achieved with jujube softwood cuttings. Xiang-dong reported wild jujube softwood cuttings had 32% (no hormone treated), 74% (3000 mg/L NAA) and 64% (3000 mg/L IAA) rooting success.[42] Several propagation techniques have been reported for the jujube plant (Table 5).

Propagation	Location	Methods	Key research finding(s)	Ref
grafting	Korea	Compared 7 techniques (chip budding, whip and tongue graft, bark graft, splice graft, standard ono graft, modified rootstock ono graft, and modified scion ono graft) without hormonal treatments	Bark graft resulted 100% propagation success (~5 weeks) followed by modified scion ono (58.33%). Similarly, bark, modified, splice, and modified scion ono graft had produced comparatively higher emergence of vegetative shoots (100, 47.6, and 33.3%), respectively	43
Branch cuttings	China	Stem cuttings (15 cm long, taken from secondary shoots) were treated with water (control) and IBA (500, 1000, 1500 mg/L) for 5 seconds, and inserted in sand	Cuttings dipped in 1500 mg/L IBA yielded best rooting after 20 days of treatment (rooting = 93.3%, average number of roots = 4.35, average root length = 17.64 mm)	44
Micro propagation	Turkey	Used two types of jujube genotypes (20-C-52 and 20-c-51) and different combinations of plant growth hormones	All the jujube shoots explants (100%) cultured in Murashige and Skoog medium containing 0.1 mg /L thidiazuron (TDZ) + 0.5 mg /L BAP + 0.1 mg /L indole butyric acid (IBA) + 0.3 mg /L gibberellic acid nutrients produced shoots (M = 5.5)	45
Seed propagation	Turkey	Jujube seeds were subjected to seven treatments (control, hot water (45 °C for 30 min), water (for 24 hour), scarification, sulfuric acid (30 min) plus water treatments (24 hour), dehulled damaged membrane, and dehulled seeds)	Dehulled seeds had the greatest germination rate (63.3%) followed by scarification treatment (50%) whereas control (no treatment) had lowest germination (3.3%)	46

Table 5. Propagation techniques for jujube.

Jujubes in New Mexico

The published statistics on detailed crop information such as cultivated area, production, import/export, and market in NM are not yet available. Interestingly, the demand for jujube fruits has been growing, probably due to an increasing number of Asian people, changing consumer preferences, and growing education on the taste, nutritional, and medicinal values of the fruit; however, the supply is short. Many regions of the US, including NM, have great potential to produce jujubes at a volume high enough to meet domestic demand,[6,8,47] but the lack of research facilities and extension services has restricted its commercial cultivation.

To our knowledge, at present, New Mexico has jujube orchards in four different locations: Alcalde, Los Lunas, Leyendecker, and Portales (establishing phase); and all of them are oriented for research activities. Additionally, scattered jujube trees are found in Las Cruces and Tucumcari. Information on farmer-owned jujube orchards is unavailable. Limited plant cultivars, difficulties in plant propagation likely due to the hard seed coat,[46,48] and poor marketing/extension are few factors for the infrequent cultivation of jujube in the United States.[8,47] Grafting (bark and whip)[6] and root suckers[47] are currently being used in the United States for jujube propagation. To our understanding, tissue culture technique has a great potentiality to address the shortage of jujube saplings, but it requires sophisticated technology, skilled manpower and is relatively expensive.

THE MOST RECENT RESEARCH ACTIVITIES ON JUJUBE IN NEW MEXICO

Considering the multiple benefits of jujube, two universities, New Mexico State University (NMSU) and Eastern New Mexico University, have initiated jujube research projects. The past and current research in NM have focused on cultivar trials, fruit nutrient dynamics, and plant propagation. For example, Yao et al. conducted trials taking nineteen drying and multipurpose jujube cultivars (including 'Kongfucui', 'Sihong', 'Jinkuiwang', 'Lang', and 'Xiangzao') at three different locations in NM (Alcalde, Leyendecker, and Los Lunas),[49] found jujube performance varied with location, and reported the most suited cultivar to particular locations in terms of higher fruit yield: 'Kongfucui' (13.3 kg/tree) for Alcalde, Jinkuiwang (12.31 kg/tree) for Leyendecker, and Jinsi-2 (8.37 kg/tree) for Los Lunas.[49] The authors further mentioned that all experimented cultivars did better in terms of fruit yield and nutrients contents (total soluble solids) at Leyendecker than Alcalde and Los Lunas. Based on their studies, the researchers suggested not to cultivate drying cultivars at Alcalde that are best suited to Los Lunas and Leyendecker.

A similar experiment with 4 ornamental jujube cultivars (3 years old) at Alcalde and Los Lunas reported relatively higher fruit yield for 'Teapot' (4.536 kg/tree) followed by 'Mushroom' (3.629 kg/tree), 'So' (1.724 kg/tree), and 'Dragon' (0.091 kg/tree).[50] Despite lower yield, 'Dragon' produced comparatively larger flowers than others.[50] Among tested cultivars, 'Teapot' had higher soluble sugar content (31.7% at Alcalde and 32.2% at Los Lunas) and vitamin C (313 mg/100 g fresh weight in Alcalde). According to Yao and Heyduck, 'So' and 'Dragon' cultivars can serve as year-round ornamentation whereas 'Mushroom' and 'Teapot' provide ornamentation for three seasons.[50] We think more multilocation cultivar research trials should be carried out in NM to recommend region-specific cultivars for farmers.

Huang et al. evaluated the nutrient dynamics (46 jujube cultivars) and vitamin C content (10 cultivars) of jujube fruits at Alcalde and Los Lunas and found a relatively higher vitamin C content for 'Youzao' cultivar with a value of 820 mg/100 g fresh jujube.[51] According to the authors, the soluble solid contents and titratable acidity of evaluated fruits were in the range of 27.2–33.7% and 0.27–0.46%, respectively. Furthermore, Sapkota et al. performed jujube propagation experiments in 2019 at Portales, NM using four different categories of jujube root suckers (height and diameter: <50 cm and 0.15–0.35 cm, 50–100 cm and 0.36–0.75 cm, 100–150 cm and 0.76–1.25 cm, and >150 cm and 1.26–2.45 cm, respectively).[47] The authors found that the sucker (height of 50-100 cm and diameter of 0.36–0.75 cm) had the greatest field survivability (84%) followed by the sucker category (height of 100–150 and diameter of 0.76–1.25 cm) (67%). Their work emphasized that the size of the planting material is one of the major factors determining crop establishment in field conditions.

To date, no economic pest damage was reported for jujube in NM with the exception of Yao observation of peach moth incidence to sour jujube fruits (but not significant loss) at Las Cruces.[6] However, a few insect and disease damaging jujube were reported from other countries: peach moth in China[52] and Korea[53] and witches' broom in China[54] and Korea.[55]

Because the jujube crop is relatively new to most New Mexican farmers, we think research related to propagation, crop physiology, cultivation, and orchard establishment, simulated with extension services, might encourage them to start planting jujubes. Furthermore, such studies might provide growers with information useful for planting and to deal with the challenges that may be encountered in the process of crop cultivation. Additionally, research studies on jujube genetics, breeding, and pests should be considered to develop better cultivars and minimize the potential cultivation problems in the future.

SIGNIFICANCE AND POTENTIAL OF JUJUBE IN NEW MEXICO

New Mexico generally experiences semi-arid climate (hot summer, mild winter) and most of the land in this region is dry. The past 10 years (2010-2019) climate data (https://www.ncdc.noaa.gov/cdo-web)[56] show that Portales, NM experiences an annual average temperature of 15.85 °C, an average minimum temperature of 4.25 °C (January), an average maximum temperature of 26.86 °C (July), and the total average annual precipitation of 520.65 mm. Interestingly, New Mexico has a very similar climate to the Shaanxi area of China (average annual temperature: 12.5 °C, precipitation: 632 mm)[57] where jujube has been widely cultivated. As such, it is possible to cultivate jujube in NM's environment with good production. Even though New Mexico's elevation permits the growth of many other temperate crops (such as apple, peach, and pear), late winter frost/snow is the major threat to these crops. Late spring cold fronts in NM often damage flowers, block pollination, and cause heavy losses to fruit growers.[58] Yao and Welser reported that the winter frost in 2011 heavily damaged the flower buds of peaches in Alcalde, NM; leaving a varying percentage of live flower buds ranged from 11% ('Blazingstar' cultivar) to 85% ('Encore' cultivar).[15] Moreover, Yao et al. shared their experience of not harvesting any apricot fruits for years (2001-2014) due to frost damage in Alcalde, NM.[58] Notably, jujube remains physiologically dormant during winter, produces leaves 1–2 months later than similar fruit trees (e.g., peach), and could easily skip the frost damage and injury.

Reports indicated that the water table of New Mexico is very low,[59,60] and well-designed irrigation facilities have yet to be constructed in different regions. Jujube, after field establishment, can tolerate very high temperatures and requires much less water supply as it has deeper vertical roots (as deep as 13 m).[4] Water requirements for jujube is variable depending on location. Liu mentioned that jujube can survive and produce a satisfactory yield in arid to semi-arid regions of northeast China with under 200 mm annual rainfall.[4] Similarly, in Shanxi, China, an application of an annual volume of 33.33 mm water resulted in the desirable root traits of jujube trees (12-years).[61] For rainfed areas in western Australia, jujube has been growing well with a yearly rainfall of 200-1000 mm.[5] We were unable to find the information relating to water requirements of similar crops in NM, but researchers from other regions have reported such information. According to Zambrano et al., the daily water demand of young (3-years) peach trees from August to October in 2018 was 23.7 L per tree and total cumulative water consumption was 731 mm (January to October) in Florida.[62] In drier regions of California, peach requires annual irrigation of 1034 mm.[63]

Jujube does not demand intensive care.[4] Timely irrigation, fertilization, pruning, mulching, and weeding are suggested to get maximum potential yield from trees. The nature of the jujube plant to perform satisfactorily even in dry and alkaline soil makes it most suited for cultivation in the southwestern US.[3] Additionally, expanding desertification and decreasing water sources in the future may increase jujube's importance as a fruit product.

There have been raising concerns about plant species becoming invasive to the new area. Azam-Ali et al. mentioned that uncontrolled propagation may convert jujube to weedy species for a particular region.[39] Jujube can spread through seeds (via birds and animals)[64] and root suckers.[65] To date, no reports are available for Chinese jujube acting as invasive species and harming other plant/animal species in NM. But, literature indicated that Indian jujube is becoming weedy species in Florida, USA[66] and Queensland, Australia.[64]

Short-term and long-term strategies should be made to assess the potential risk status of jujube (for example, no risk at all, low risk, moderate risk, high risk, etc.) for becoming invasive to a particular ecological range, and proper preventative as well as control measures may be required to tackle the potential problems. Additionally, the growers, researchers, and other authorized bodies should be made aware of the above-mentioned potential challenges. We think with proper planning, the cultivation of jujube would help cover hectares of fallow lands in NM along with economic and ecological benefits (for example, soil cover, erosion control, etc.). In short, jujube could be a great prospective future crop in NM.

CONCLUSION

Jujube is a versatile fruit tree rich in nutritional and medicinal properties. The crop's physiology and agronomic requirements suggest that it could be a well-adapted fruit tree in semi-arid regions throughout the United States, including NM. Aside from its use as a raw fruit, jujube has high industrial value for processing and diversification. With respect to commercial cultivation, participatory research trials should be carried out to encourage farmers and small enterprises. On the other hand, crop breeders could help extend jujube cultivation by creating jujube varieties with better yield, quality, stress-resistance, and broad environmental

adaptation. At present, in the United States, improved propagation strategies are needed to ensure the adequate supply of planting materials.

We think jujubes could contribute to farmers' income and food security as the trees grow and produce good yields even with drought and poor marginal lands that, in most cases, are unsuitable for other crops. To achieve such benefits, jujube research programs that involve farmers from the initial phase are needed to identify and tackle different challenges during crop establishment, growth, and production. Better extension and promotional techniques could encourage both farmers and other professionals to plant at least a few jujube trees (maybe one or two or many) in their yard and get multiple benefits (fruits, shade, landscape, etc.). With adequate research and marketing facilities, the NM environment guarantees sustainable jujube production in the near future.

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