Research Findings

An open fruit of soft-seed pomegranate. Photo by the authors.

Testing Coherent Fertilizing Approaches in Soft-Seed Pomegranate Production at Heyin, Henan Province, China

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Abstract

The Heyin region of Henan Province is a traditional pomegranate (*Punica granatum* L.) production area in China. In recent decades, soft-seed cultivars have been introduced to the region, which have gained increasing popularity. A survey carried out among Heyin pomegranate growers revealed substantial variability of yields; about 65% of growers obtain yields lower than 22.5 Mg ha^{-1}, compared to 45 Mg ha^{-1} obtained by the top 3% of farmers. The common pomegranate fertilization practice is intuitively focused on nitrogen (N), phosphorus (P), potassium (K), and organic manure, and lacks scientific quantitative basis. Moreover, it ignores other macronutrients essential to crop production, such as calcium (Ca) and magnesium (Mg). The objectives of the present study were to investigate the current motivation of local pomegranate growers to adopt new fertilizer approaches; to examine the contribution of soil testing and formula fertilization (STFF) approach to soft-seed pomegranate fruit yield and quality; and, to examine the effect of polyhalite, a supplementary fertilizer

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(Ca, Mg, K, and S donor), applied in addition to the STFF practice, compared to farmers' common practice (FFP). An experiment was set in selected farmers' orchards, distinguishing between three groups of tree age: 10, 15, and 20 years. The experiment included three treatments: FFP, STFF, and STFF + supplementary polyhalite application. Fruit yield significantly increased by 24.6-59.4% in response to the STFF treatment. Supplementary polyhalite application in addition to STFF brought about a further yield increase, which ranged from 30-82% compared to FFP. The higher yields were obtained despite the drastic reduction in NPK application in the two STFF treatments, compared to FFP, but was dependent on tree age; the younger the tree, the greater the impact of fertilizer treatment. Fruit quality traits, such as fruit size, color, aril sugar and acid contents and ratio, and vitamin C content, were significantly improved under the STFF treatments, while polyhalite further enhanced fruit attractiveness in terms of size and color. Consequently, the STFF treatment plus supplementary polyhalite increased farmers' net income by 48-148%. Nevertheless, additional fine-tuning of the STFF approach, as well as the precise polyhalite dose required, is still needed.

Keywords: Calcium; fruit quality; fruit yield; polyhalite; Polysulphate; *Punica granatum* L.

Introduction

Pomegranate (*Punica granatum* L., Punicaceae) is a domesticated fruit tree; its fruit is highly appreciated due to its nutritional and economic values (Romano *et al*., 2016). The tree species also has significant cultural prestige. Pomegranates originated in Central Asia (Iran and Afghanistan) and spread to China, India, Mediterranean countries, and Africa (Janick, 2005; Stover and Mercure, 2007; Holland *et al*., 2009; Cao *et al*., 2015). Recent growing interest in the health benefits of pomegranate juice has led to growth in both global demand and production area. According to recent estimations, from 2014 to 2025, the area under pomegranate cultivation will increase ten-fold (Venkataramudu *et al*., 2018). China is among the leading countries in pomegranate production, with increasing consumption, output and cultivation area year by year (Wang *et al*., 2010). Heyin area of Henan Province has a long history of pomegranate cultivation. With a cultivated area of about 3,000 ha, Heyin is one of the leading pomegranate growing regions in China (Cao and Hou, 2013).

Until recently, pomegranate varieties cultivated in China belong to the common type, the seed coats of which are rigid and, therefore, are not easy to chew and swallow. Softness, or absence of seeds, is a desirable economic trait that improves the consumptive quality of fruits (Mars, 2000). The 'Tunisia' pomegranate is a soft-seed variety introduced to China in 1986 (Baike.so.com, 2016). After years of careful cultivation, 'Tunisia' has been adapted to China's environment, becoming the best soft-seed pomegranate variety currently available (Xue *et al*., 2017a). The market price of soft-seed pomegranate is 2-4 times that of the common variety, and soft-seed pomegranate growth has obviously increased the income of farmers (Xue *et al*., 2017b). With the increasing market demand for soft-seed pomegranate, planting of 'Tunisia' soft-seed pomegranate has extensively expanded; at present, 67% of pomegranates in Heyin region are soft-seed pomegranates (Chen *et al*., 2005).

Most studies on pomegranate have focused on fruit characteristics and the benefits to human nutrition and health. However, the scientifically-based agronomic perspective of pomegranate crop requirements is quite vague, and professional empirical recommendations are limited (Lazare *et al*., 2019). The lack of knowledge is even more significant with regard to the relatively new soft-seed cultivars. Consequently, fruit yield and quality vary greatly among local pomegranate growers in Heyin; inasmuch as the potential for increasing soft-seed pomegranate production in response to agronomic improvements is huge in this region.

The importance of fertilizer application in support of production and quality is very clear to most pomegranate growers. However, lacking concrete, scientifically-based recommendations, many pomegranate growers use fertilizers blindly, or over-use fertilization. This practice not only wastes fertilizer, but also adversely affects tree growth and development, and causes substantial damage to the soil environment (Zhang *et al*., 2012). Soil testing and formula fertilization (STFF) is a method to determine crop fertilizer requirements based on direct examination of the soil's nitrogen (N), phosphorus (P), and potassium (K) availability to plants at a specific time and location. Principal rules of NPK uptake by crops, and comprehensive monitoring of the relationships between crop growth and development and soil nutrient status, can give rise to the appropriate fertilizer dosage required to obtain certain yield levels and to efficient nutrient use, while improving produce quality and saving farmers' inputs (Zhang, 2006). STFF has already been successfully applied to fruit trees such as apples, citrus, pears, and peaches (He, 2009; Ye, 2017; Zhang *et al*., 2017).

Nevertheless, beyond NPK, other macronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S) are essential, ensuring normal crop performance, productivity, and adequate produce quality. Calcium has well-documented roles in plant signaling, water relations and cell wall interactions. The broad influence of Ca on fruit development, physical traits, disease susceptibility, and ripening through facilitating developmental and stress response signaling, stabilizing membranes, influencing water relations and modifying cell wall properties through cross-linking of de-esterified pectin was recently reviewed by Hocking *et al*. (2016). Pomegranate was determined as a 'Ca loving species', which displayed a higher total amount of Ca than all other nutrients throughout the growing season (Maity *et al*.,

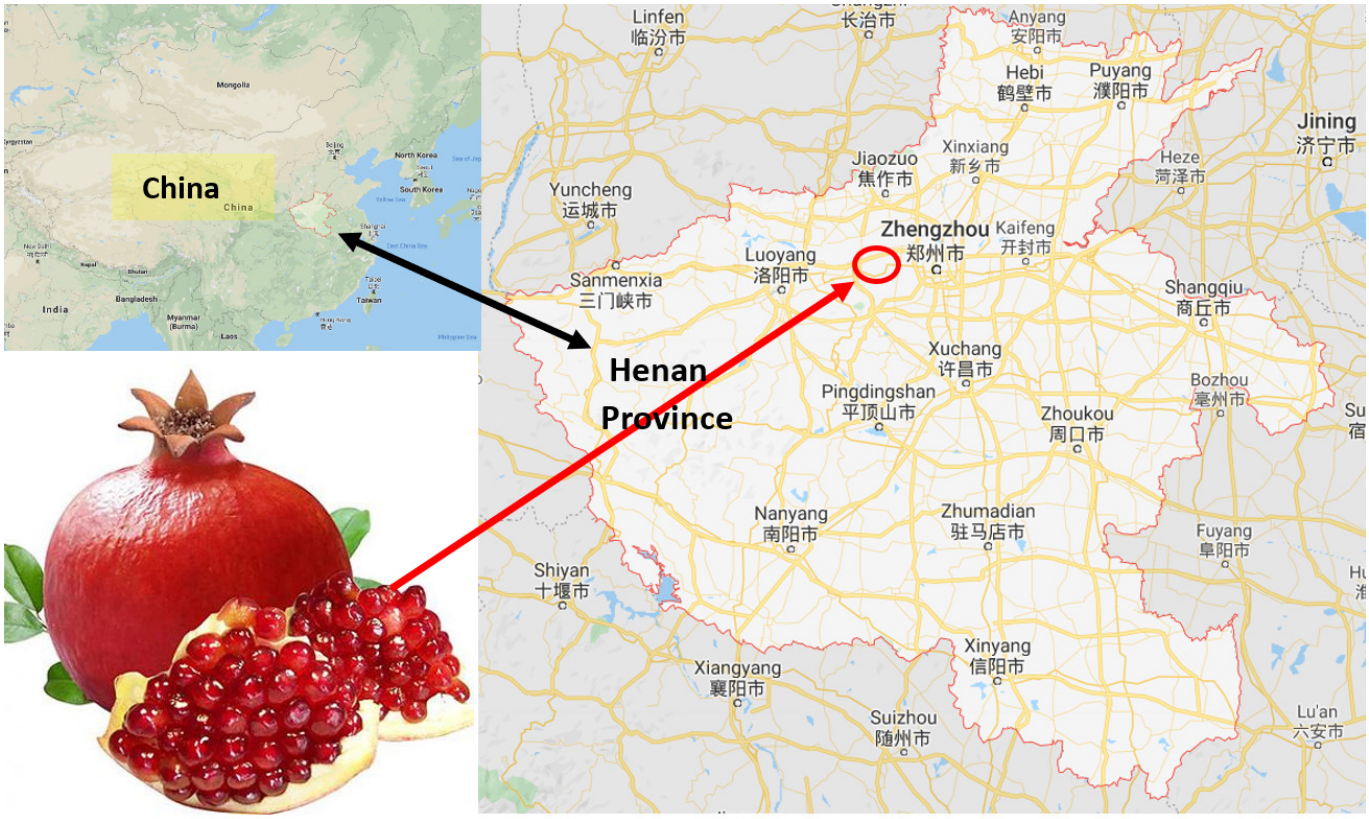

Fig. 1. Heyin pomegranate production area near Xingyang City in Henan Province, China (red circle). *Source:* Maps were extracted from Google Maps, and the image of soft-seed pomegranate was taken from http://eng.fruitkii.com/Product/details/281244.

2019). The authors demonstrated that the macronutrient uptake pattern in pomegranates followed the order of Ca>N>K>Mg>S>P, and that most of the uptake of N, K, Ca, Mg and S from the soil occurred between pre-pruning and bloom. Chater *et al.* (2020) have also recently highlighted the particular significance of Ca to pomegranate cultivation. Davarpanah *et al.* (2018) described the effects of foliar Ca application on reducing fruit cracking damage in pomegranates.

Unequivocally, Heyin fruit farmers have an urgent need for well-founded locally fitted pomegranate-specific fertilizer recommendations in order to achieve high yields from their fruit trees and improve the quality of soft-seed pomegranate. The desired practice should consider local soil properties, yearly precipitation pattern, and crop nutrient requirements during the growing season. A major question, however, is the extent of cognizance, and the consequent willingness to adopt new practices, among local farmers. There were therefore three objectives of the present study to: 1) investigate the current motivation of local pomegranate growers to adopt new fertilizer approaches; 2) examine the contribution of the STFF approach to soft-seed pomegranate fruit yield and quality, compared to the common practice; and, 3) examine the effect of polyhalite, a new supplementary fertilizer (Ca, Mg, K, and S donor), applied in addition to the STFF practice.

Materials and methods

Regional pomegranate cultivation survey

In order to characterize pomegranate production in the Heyin Pomegranate area, Henan Province, China (Fig. 1), a field study was carried out in six administrative villages, including Gaoxiang, Liugou, Guanyu, Zaoshugou, and Niukouyu in Fuyang City. Out of 157 households interviewed during May to December 2016, 112 valid questionnaires were obtained. The survey items included farmers' education, understanding of soil testing and formula fertilization techniques, pomegranate orchard area, planting density, yield, and fertilization practices.

Soil and climate

Subsequent to the survey, a field experiment was carried out in pomegranate orchards exhibiting similar soil fertility. Topsoil samples were taken from each field at five sampling points, at a depth of 0-20 cm. Samples were mixed and air-dried, and the soil pH (soil-water ratio was 1:2.5), total N content (half-micro-Kelvin method), available P_2O_5 ($NaHCO_3$ method), and available K_2O (NH_4OAc extraction method) were determined according

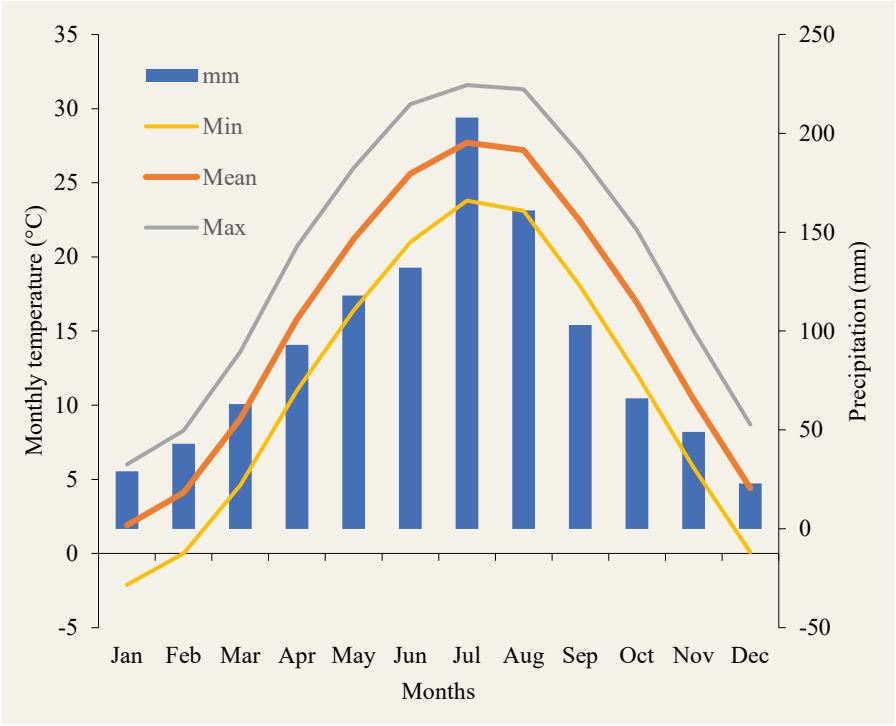

Fig. 2. Climatic profile of Xingyang City, China, including monthly precipitation, and minimum, mean, and maximum monthly temperature. *Source:* Data were taken from https://en.climate-data.org/asia/china/henan/xinyang-2679/.

Table 1. Basic chemical soil properties at the soft-seed pomegranate experiment at Heyin, Henan Province, China.

Tree age	pH	Total N	Available P	Available K
Years		*g k^{-1}*	*mg k^{-1}*	
10	7.56	0.91	15.74	151.3
15	7.54	0.87	14.76	152.5
20	7.54	1.03	16.25	162.2

Table 2. Seasonal doses of N, P_2O_5, K_2O, CaO, MgO, and SO_3, as applied according to the three fertilizer treatments included in the soft-seed pomegranate experiment in Heyin, Henan Province, China.

Treatment code	Organic fertilizer	N	P_2O_5	K_2O	Polyhalite			
					K_2O	CaO	MgO	SO_3
	kg ha^{-1}							
FFP	7,500	500	500	500	-	-	-	-
STFF	-	373.5	223.5	327	-	-	-	-
STFF+PH	-	373.5	223.5	327	+ 52.5	63.75	2.25	180

to Bao (2005). The basic soil chemical properties of the experiment sites are shown in Table 1. The regional climate conditions (Fig. 2) are characterized by a warm wet summer, cold winter, and mild intermediate seasons. The main rainy season is during the summer, but precipitation, averaging 1,088 mm year^{-1}, may occur all year round.

Fertilization treatments

The experiment focused on Tunisian soft-seed pomegranate. Trees were categorized according to three age groups: 10, 15, and 20 years, the planting density of which was 1,482; 1,739; and 1,184 trees ha^{-1}, respectively. In the experiment, three fertilization approaches were tested within each tree-age group, as shown in Table 2.

The farmers' fertilization practice (FFP), which served as the control, included organic fertilizer application in the autumn, and NPK application at the spring bloom stage. In the second treatment, soil test and formula fertilization (STFF), NPK doses were reduced according to the predetermined soil chemical properties (Table 1) and divided into four applications in autumn (following harvest, November), early spring (before shoot burst, late March), late spring (bloom, late May), and summer (fruit expansion, late August). The third treatment, STFF+PH, polyhalite (Polysulphate®, ICL Fertilizers, Cleveland, UK) was added in addition to the NPK fertilization practice of STFF, contributing Ca, Mg, S, and some additional K (Table 2). Each treatment was repeated three times, and the test plot area was 200 m^2.

Yield and quality assessments

On September 25, 10 pomegranate trees were randomly selected for harvest in each plot. The number of fruits per tree was recorded and the total weight was determined. Ten representative pomegranate fruits from each plot were selected for quality determination. Juice total sugar concentration was determined using a DBR45 digital refractometer (Delta Acque, Italy). Total acid content was determined by NaOH titration. To determine levels of reduced vitamin C, the 2, 6-dichlorophenol method (Li, 2000) was employed.

Data processing and statistical analyses

Microsoft Excel 2010, SPSS 21.0, and Origin 8.1 programs were employed for data processing and analyses. The Duncan method was used to determine the significance of variance between the treatments.

Results

Survey of current production of soft-seed pomegranate in Heyin

A random survey, which included 112 fruit growers and about 71 ha in Heyin area, revealed that the yield levels of soft-seed pomegranate varied greatly, ranging from 7.5-45 Mg ha^{-1} (Table 3). Most farmers (about 65%), using about 52% of the planted area, obtained relatively low yield levels that ranged from 7.5-22.5 Mg ha^{-1} and were responsible for only 36% of production. In contrast, high-yield pomegranate orchards (37.5 Mg ha^{-1} or more) were associated with less than 12% of the growers, 11% of the surveyed area, and 19% of pomegranate production. The majority of pomegranate growers, more than 82%, were aware of the potential to improve yield and quality through modification of their fertilizer practice and showed willingness to adopt soil test-based formula fertilization, whenever it proved successful.

Effects of fertilizer treatments on fruit yield parameters

The modified fertilizer treatments, STFF and STFF+PH, had significant positive influence on fruit size, number of fruits per tree, and consequently, on the yield of soft-seed pomegranate, compared to the common FFP control (Fig. 3). This was observed on top of a tendency of fruit weight to decline, and a significant increase in the number of fruits with aging trees. Compensating for these two opposite effects in tree age, the mean total yield was hardly affected, with 28.5, 31.6, and 27.2 Mg ha^{-1}, for 10, 15, and 20 years of tree age, respectively.

Fruit size significantly increased in young trees (10 years) in response to both STFF and STFF+PH treatments; however, this effect gradually declined with tree age, remaining significant for STFF+PH compared to FFP among 15-year-old trees, and almost completely diminished among older trees (Fig. 3A). The number of fruits per tree significantly increased in both STFF and STFF+PH compared to FFP throughout tree ages, with a slight but significant advantage for STFF+PH compared to STFF (Fig. 3B).

Consequently, when compared to FFP, total fruit yields significantly increased among younger trees by 59.4 and 82.4%

Table 3. Results of the orchard yield survey carried out among 112 pomegranate growers at Heyin region, Henan Province, China, in 2018.

Yield level	Growers		Area		Production	
Mg ha^{-1}	*number*	*%*	*ha*	*%*	*Mg*	*%*
7.5-15	4	2.9	4.00	5.7	48	2.8
15-22.5	68	61.8	32.53	46.0	586	33.7
22.5-30	20	17.7	15.73	22.3	409	23.6
30-37.5	8	5.9	10.67	15.1	363	20.9
37.5-45	8	8.8	6.40	9.1	269	15.5
>45	4	2.9	1.33	1.9	61	3.5
	112	100	70.66	100	1,735	100

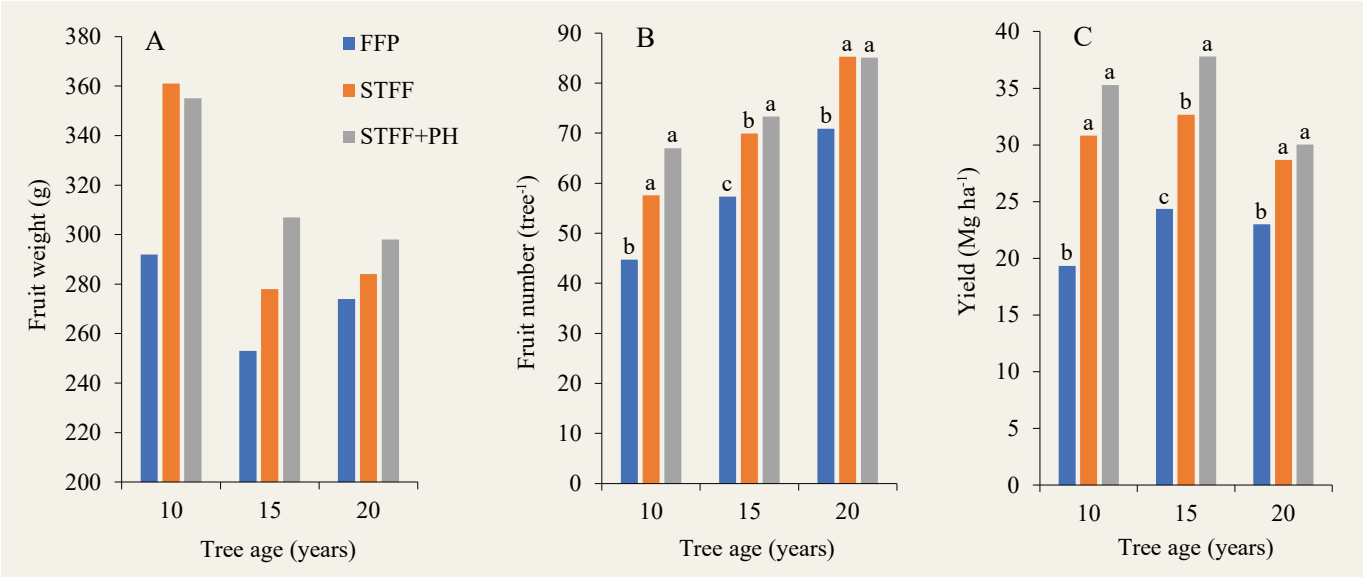

Fig. 3. Effects of fertilizer treatment on fruit weight (A), number of fruit (B), and fruit yield as a function of tree age in soft-seed pomegranate experiment in Heyin, Henan Province, China. Different letters indicate significant differences ($P < 0.05$) within each tree age.

Fig. 4. Effects of the modified fertilizer practices on appearance of soft-seed pomegranate fruit harvested from 15-year-old tree. Photo by the authors.

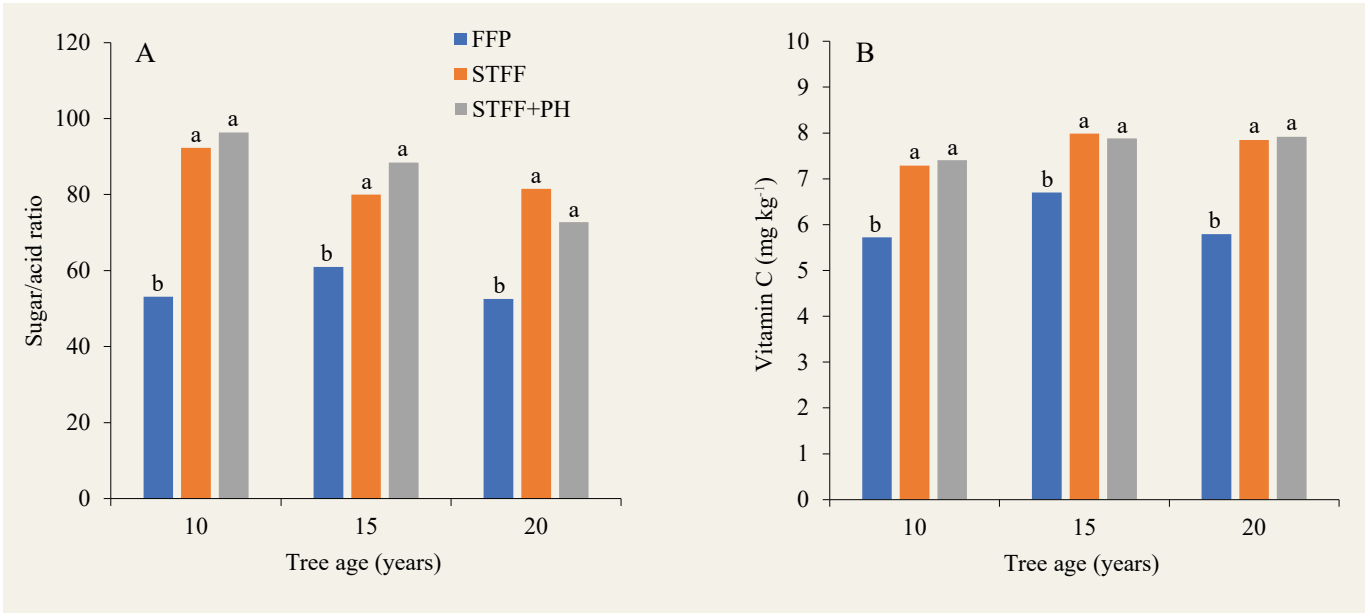

Fig. 5. Effects of tree age and fertilizer treatments on sugar/acid ratio (A) and vitamin C concentration (B) in the aril juice of soft-seed pomegranates. *Note*: different letters indicate significant differences ($P < 0.05$) within each tree-age group.

in response to STFF and STFF+PH, respectively. Among the 15-year-old trees, yield increase rates were smaller, 34.1 and 55.2% more than FFP, for STFF and STFF+PH, respectively. The increase in total fruit yield further declined in older trees but remained significant, with 24.6 and 30.5% more than FFP for STFF and STFF+PH, respectively, with no significant difference between the two modified fertilizer practices (Fig. 3C).

Effects of fertilizer treatments on fruit quality parameters

The modified fertilizer treatments had obvious positive effects on pomegranate fruit appearance and attractiveness (Fig. 4). Fruit were larger, well-shaped and colorful compared to the yellowish-green look of the FFP control fruit.

Pomegranate fruit diameter was significantly larger in response to STFF treatment, compared to the FFP control, without any influence of tree age. The supplementary polyhalite did not have any additive consistent effect on fruit diameter (Table 4). In contrast, the supplementary polyhalite brought about significant increase in the aril sugar concentration (Brix), while STFF alone showed a similar tendency, which was not significant. These effects on aril sugar concentration were limited, however, to the two younger tree groups, whereas the 20-year-old trees remained unaffected (Table 4). STFF, with and without supplementary polyhalite, significantly reduced aril juice acidity, compared to FFP, across tree-age groups (Table 4).

Both modified fertilizer treatments gave rise to significant and equal increases in the sugar/acid ratio and in vitamin C content of pomegranate aril juice, compared to FFP fruit across tree-age groups (Fig. 5).

Effects of fertilizer treatments on the economic benefit to pomegranate farmers

In spite of the significant reduction in amount of fertilizer applied, fertilizer

Table 4. Effects of fertilizer treatment and tree age on fruit diameter, and on aril Brix and acidity in the soft-seed pomegranate experiment at Heyin, Henan Province, China.

Tree age	Treatment code	Fruit diameter	Brix	Acidity
Years		*cm*	----------*%*----------	
	FFP	8.40 b	14.91 b	0.28 a
10	STFF	8.84 a	15.10 ab	0.16 b
	STFF+PH	8.70 a	15.77 a	0.16 b
	FFP	8.11 b	14.26 b	0.23 a
15	STFF	8.34 ab	14.97 ab	0.19 ab
	STFF+PH	8.57 a	15.03 a	0.17 b
	FFP	8.35 b	14.73	0.28 a
20	STFF	8.67 a	14.66	0.18 b
	STFF+PH	8.58 ab	15.09	0.21 b

Note: different letters indicate significant differences ($P < 0.05$) within each tree-age group.

Table 5. Effects of tree age and fertilizer treatment on farmers' revenue, fertilizer cost, and farmers' net income, calculated from the results of the soft-seed pomegranate experiment at Heyin, Henan Province, China.

Tree age	Treatment code	Revenue	Fertilizer cost	Net income	Net income rise
Years		----------*Yuan 10^4 ha^{-1}*----------			*%*
	FFP	19.34	0.57	10.52	-
10	STFF	30.83	0.63	21.95	109
	STFF+PH	35.27	0.90	26.12	148
	FFP	24.35	0.57	15.53	-
15	STFF	32.65	0.63	23.77	53
	STFF+PH	37.79	0.90	28.64	84
	FFP	23.01	0.57	14.15	-
20	STFF	28.68	0.63	19.80	40
	STFF+PH	30.03	0.90	20.88	48

costs for the STFF treatment and for the STFF+PH treatment are higher than for the common FFP (Table 5). Nevertheless, the obvious rise in revenue and, subsequently, in the net income to the grower, more than compensates for the higher fertilizer cost. The rate of the net income rise varied between treatments and among tree-age groups; STFF gave rise to 109, 53, and 40% higher net income in 10, 15, and 20-year-old trees, respectively, while supplementary polyhalite in addition to STFF brought about even greater increases of 148, 84, and 48%, respectively (Table 5).

Discussion

Heyin pomegranates were already highly appreciated in ancient times and were mentioned in the "Farmers' Almanac" written by Wang Zhen of the Yuan Dynasty as "the best pomegranates in China" (Li, 2009). Today, Heyin pomegranates continue to exhibit numerous advantages including large size, thin skin, juiciness, sweetness, attractive appearance, soft seeds, and long postharvest storage life. Nevertheless, a huge gap exists between the rising demand for quality pomegranates and the growers' capacity to meet this demand. Therefore, increasing the yield and improving the quality of soft-seed pomegranate in Heyin is of great importance to the development of the pomegranate industry in China (Lu and La, 2015).

The present survey among Heyin pomegranate growers revealed a substantial variation in yields, ranging from 7.5-45 Mg ha^{-1}. Furthermore, about 65% of pomegranate growers produce less than 22.5 Mg ha^{-1}, which leaves a lot of room for yield enhancement (Table 3). So far, the STFF approach has demonstrated outstanding results in many crops and fruit trees (Jin, 2005). Subsequently, and thanks to government promotion, scientific research and the media, more than 70% of the region's fruit farmers have some understanding of the technology. Among the farmers that took part in the present survey, more than 80% were willing to adopt the STFF approach for pomegranate even before any practical assessments.

In the practical experiment, the application of the STFF approach brought about significant fruit yield increases that ranged from 24.6-59.4%, depending on the tree age; the younger the tree, the greater the yield increase (Fig. 3). In addition to yield, STFF significantly enhanced fruit quality traits such as fruit diameter, color, sugar/acid ratio, and vitamin C content (Table 4, and Fig. 5). These results clearly demonstrate that the common fertilization practice (FFP) is utterly wrong and that pomegranate performance can be drastically enhanced through significant reduction of NPK inputs. A recent study of young fruiting pomegranate trees grown on perlite under fertigation showed that net N requirement for obtaining a reasonable fruit yield was about 750 g $tree^{-1}$, which is equivalent to 110 kg N ha^{-1} at a planting density of 148 trees ha^{-1} (Lazare *et al.*, 2020). Even with more conventional fertilizer application techniques, and when soil-water-nutrient interactions are considered, this study suggests that further decreasing fertilizer dosage should be considered and tested in order to reduce production costs and minimize environmental consequences.

The efforts of the Ministry of Agriculture to maintain soil fertility, reduce nutrient losses, and obtain high yield and quality simultaneously through examination and dissemination of STFF, included secondary macronutrients such as Ca, Mg, and S, in

addition to organic and inorganic sources of NPK (Jin, 2005). Supplementary Ca and Mg fertilizers are not always accessible to farmers, while pomegranate requirements of these nutrients are high (Holland *et al*., 2009; Maity *et al*., 2019; Chater *et al*., 2020). Polyhalite, comprising 48% SO_3, 14% K_2O, 6% MgO, and 17% CaO, is less water soluble than more conventional sources (Barbarick, 1991; Yermiyahu *et al*., 2017; Yermiyahu *et al*., 2019) and is, therefore, a suitable fertilizer to supply these four nutrients during the rainy growing season at Heyin (Fig. 2). In the present study, the addition of polyhalite on top of the STFF treatment further increased soft-seed pomegranate fruit yields (Fig. 3). Still, the yield increase largely depended on tree age, with significant advantage in the younger trees. However, this phenomenon is probably associated with general aging symptoms, such as increasing number of thinner twigs and consequently a larger number of flowers and fruit (Fig. 3B) that lead to smaller fruit size, rather than to the tree's nutritional status. Aging problems in fruit trees can often be solved by implementing suitable pruning and fruit thinning practices (Wünsche and Ferguson, 2005). The contribution of polyhalite to various fruit quality traits was less significant (Table 4 and Fig. 5), but it certainly enhanced the red color of the fruit (Fig. 4) and, thereby, attractiveness to consumers. Consequently, this substantially enhanced the benefit for growers (Table 5).

Direct demonstrative experiments in growers' orchards are powerful tools for disseminating beneficial ideas and technologies. Since the STFF approach has *a priori* gained much cognizance among Heyin fruit growers, the remarkable enhancement of fruit yield and quality of soft-seed pomegranate has only helped to strengthen growers' positive opinion. However, the idea of supplementary application of Ca and Mg fertilizers was rather new. The contribution of polyhalite, supplementary to STFF, in enhancing fruit appearance and attractiveness and, thereby, increasing farmers' net income, was very significant in the present study and, presumably, will persuade more growers to further balance pomegranate fertilization. Additional fine-tuning of the STFF approach, as well as the precise polyhalite dose required, is still needed.

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The paper "Testing Coherent Fertilizing Approaches in Soft-Seed Pomegranate Production at Heyin, Henan Province, China" also appears on the IPI website.