Defence Life Science Journal, Vol. 5, No. 1, January 2020, pp. 18-24, DOI : 10.14429/dlsj.5.14656

Effect of Altitude on the Phenology and Fruit Quality Attributes of Apricot (*Prunus armeniaca* L.) Fruits

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ABSTRACT

Consumer concern about poor taste of fresh apricots is increasing and knowledge about the more suitable production requirement is essential. Genetic component influencing apricots quality is well known. However, there is limited information on environmental effect on fruit quality. This study aims to evaluate influence of altitude on phenological and fruit quality characters of apricot genotypes. Fruits from 162 genotype were collected from nine locations from 3006-3346 m asl in trans-Himalaya. The altitude had a marked influence on date of flowering, fruit weight, moisture and TSS content. For every 100 m increase in altitude, flowering and fruit ripening delayed by 3.3 and 7.1 day, respectively. Inverse relationship between altitude and fruit weight (R^2=0.310) was observed. For every 100 m increase in altitude the fruit weight decrease by 0.5 g. Fruit moisture content decreased significantly with increase in elevation (R^2=0.585). Decrease in moisture content was 1.9% for every 100 m increase in elevation. Altitude showed linear relationship with fruit TSS content (R^2=0.726). For every 100 m increase in altitude, the fruit TSS increased by 1.2ºBrix. Knowledge from the present study on the impact of altitude on fruit quality characters provides a useful guide for selecting orchard location towards improving fruit quality.

Keywords: Elevation; Flowering; Ladakh; Quality improvement; Sweetness

1. INTRODUCTION

Apricot (*Prunus armeniaca* L.) is an important temperate fruit tree species. While consumers cherish the aromatic flavor and beauty of high-quality apricot fruits, there are often complaints about the suboptimal fruit quality in the marketplace[1]. A lack of sweetness or sugar in purchased apricot fruit is among the most common of the consumer complaints[2]. Growing concern of the consumers for poor quality apricots needs serious consideration. Accordingly, breeding programs based on up-to-date scientific approaches are being taken to develop cultivars with high level of product quality[3]. However, fruit quality depends on two main components, genotype and environment. A great deal of research is carried out on the genetic component influencing apricots quality character[4-8]. However, there is limited information on environmental effect on fruit quality.

Genetic component determining the apricot fruit quality characters is well established. However, little is known about the influence of environmental factor on fruit quality. Few studies on limited number of cultivars are available on the variation of fruit quality characters with reference to environmental factors. Güleryüz[9], *et al*. found that when Hasenbey and Şekerpare cultivars were grown at two different altitudes (850-1200; 1150-1600 m asl), the fruit TSS increases and fruit size decreases at higher elevation. Olmez[10], *et al*. evaluated three apricot cultivars at 731, 855 and 1115 m asl. No linear relation was observed between increasing altitude and fruit quality traits such as TSS and fruit weight. Recently we have demonstrated the importance of environmental factors for determining sugar content and sugar profile in dried apricots[11]. The geographical elevation had no influence on kernel amygdalin content[12]. In view of the contrasting results from limited studies, it is felt that more studies involving larger number of samples across different altitudes are needed to better understand the altitude effects on apricot fruit quality characters. While most of the studied were conducted below 1500 m asl, there is little information from regions above 3000 m asl. The knowledge on altitudinal effect on fruit quality is vital since it guide us in selecting orchard location towards improving fruit quality.

Altitudinal gradients are among the most powerful ‘natural environments’ for testing effect of environmental factors on fruit quality characters. Steep changes in temperature, moisture, atmospheric pressure, ultraviolet radiation, hours of sunshine, wind, season length and geology occurs along altitudinal gradient[13]. Accordingly, to obtain a better understanding of the effect of climatic variables, this study was conducted to study the effect of growing locations with different altitudes on fruit quality characters of fresh apricots. In particular, great attention was given to phenology, sugar content and fruit size on account of large variation in date of flowering (25-114

Received : 12 June 2019, Revised : 14 January 2020
Accepted : 04 February 2020, Online published : 19 February 2020

Julian days), total soluble solids (TSS) content (9.3-37.9ºBrix) and fruit weight (5.6-105.3 g) reported from different apricot growing regions around the world.

2. MATERIALS AND METHODS

2.1 Study Sites and Materials

Apricot fruits were collected from nine villages spread across trans-Himalayan Ladakh region. Apricots are being grown in the region either as individual trees or small groups of trees in traditional way without the use of chemical fertilizer and pesticides. Majority of the apricots in Ladakh are raised from seedlings. The altitude of collection sites ranged from 3006 to 3346 m above sea level (asl) (Table 1). The mean minimum and maximum temperature of the region recorded daily during cropping season (April-October) in 2015 at an experimental orchard (elevation 3340 m) was 5.8±5.2 ºC and 18.8±5.4 ºC, respectively, while the mean minimum and maximum relative humidity was 22.1±2.0% and 28.3±2.7%, respectively. The light intensity at noon in open field was 131194±43574 lux[8]. The annual precipitation of the region is less than 200 mm of which more than 70% is in the form of snowfall[14]. From each site equal numbers of genotypes differing in seed stone colour (i.e brown and white) and kernel taste (i.e sweet and bitter) were selected as previously described[8]. From each site six samples each with brown stone with a bitter kernel, brown stone with a sweet kernel, and white stone with a sweet kernel were selected.

2.2 Phenological, Pomological and Quality Traits

Flowering date was evaluated when 50% of the floral buds reached the full bloom stage and expressed in Julian days (JD) (natural days from 1st January). Date of fruit harvesting from each genotype was determined by a panel of four assessors who identified the best ripening stage for fresh consumption based on colour, taste and fruit firmness. Fruit samples (50 fruits per tree) were randomly handpicked at eating maturity stage. Harvested fruits were immediately transported to the laboratory and pomological traits and standard fruit quality parameters (Table 2) were determined on the day of harvest. Stone and fruit weight were measured with an electronic balance to an accuracy of 0.001 g. Dimensional properties were measured with a digimatic calliper (CD-6"CS, Mitutoyo, Japan) to an accuracy of 0.01 mm. TSS were measured with the refractometer (ATAGO, Tokyo, Japan) and values were corrected at 20ºC. Fruit moisture content was determined using oven drying method at 50°C till constant weight and expressed as percentage of fresh weight. The perimeter of the blush area was drawn on a tracing paper and used to determine fruit blush area using graph paper[15].

2.3 Statistical Analysis

Pomological and quality traits were performed in triplicate. Each replicate consisted of three fruits. The experimental results were expressed as the mean ± standard deviation (SD) using statistical analysis with SPSS 16 (Statistical Program for Social Sciences, SPSS Corporation, Chicago, Illinois, USA) and MS Excel 2007. One way analysis of variance (ANOVA) and post hoc analysis with 2-sided Tukey's HSD at $p \leq 0.05$ level were performed. Pearson's correlation analysis was performed to find correlation between the variables.

3. RESULTS AND DISCUSSION

3.1 Altitude Effects on Flowering Phenology and Fruit Ripening Date

The altitude of growing location had a marked influence on the flowering phenology (Table 2). Linear relationship between date of flowering and increasing elevation was observed (R^2=0.914, $p \leq 0.001$) (Fig. 1(a)). For every 100 m increase in geographical elevation, flowering delayed by 3.3 days. Flowering dates showed marked variability and ranged from averaged 104.0 at 3006 m to 116 JD at 3346 m elevation (Fig. 2). Delay in flowering in higher altitude regions may be associated with decreasing temperature. Significant differences in flowering dates in apricot have been reported from different regions. Blooming dates of apricots in Italy and Spain ranged from 25-80 JD[16], 79.9-88.7 JD in Serbia[17] and 111-114 JD in Ladakh[8]. Results of the present study suggested that differences in date of flowering are largely due to environmental factors associated with altitude. Late blossoming is an important factor in high altitude regions experiencing spring frost. It protects the flowers from damage caused by spring frost. Similarly, linear relationship between harvest date and increasing elevation was observed (R^2=0.820, $p \leq 0.001$). For every 100 m increase in elevation, fruit ripening delayed by 7.1 days. Apricots from different regions are known for marked differences in date

Table 1. Geographical locations and sampling sites of apricots in trans-Himalaya

Sampling localities	Population ID	Latitude (N)	Longitude (E)	Altitude (m) (asl)	Sample size
Takmachik	TAK	34° 23.522"	76° 45.981"	3006	18
Domkhar	DOM	34° 23.522"	76° 45.984"	3008	18
Khalsi	KLS	34° 19.166"	76° 52.564"	3011	18
Nurla	NUR	34° 17.941'	76° 59.490"	3046	18
Saspol	SPL	34° 14.251"	77° 10.194"	3116	18
Nimmu	NMU	34° 11.357"	77° 20.437"	3190	18
Tamisgam	TSG	34° 19.444"	76° 59.463"	3241	18
Tia Khaling	TIA	34° 19.979"	76° 58.685"	3311	18
Leh	LEH	34° 08.267"	77° 34.378"	3346	18

of fruit ripening. Apricots are harvested in May to June in Greece and America[18] while cultivars and selections grown in Spain attain maturity in mid-May and late June[19]. Fruits attain maturity in late June and early July in Anatolia, Turkey[20] while those from Lake Van Region, Turkey are harvested in late July to early August[21]. In trans-Himalayan Ladakh fruits are harvested between August and early September[8]. Results of the present study highlighted that difference in fruit harvesting dates from different apricot growing regions is primarily due to environmental effects.

3.2 Altitude Effects on Pomological Traits

Table 2 presents pomological attributes of 162 apricot genotypes collected from nine locations. Fruit weight ranged from 5.3-52.5 g. In comparison, fruit weight among the promising genotypes of the Lake Van region ranged from 24.2-48.3 g[21]. Drogoudi[18], *et al*. reported 36.5-105.3 g fruit in 29 cultivars/hybrids of Greek and American origin. Milošević[22], *et al*. reported fruit weight of 49.1-81.5 g in promising apricot resources in Central Serbia. The fruit weight of 21 apricot cultivars collected from Canada, Czech Republic, Ukraine and USA ranged between 28.1-77.7 g with mean weight of 42.44 g[4]. We observed inverse relationship between altitude and fruit weight (R^2=0.310, $p\leq0.1$) (Fig. 1(b)). For every 100 m increase in elevation the fruit weight decrease by 0.5 gm. Small fruit size may also be due to genotypic effect. Ledbetter[1], *et al*. observed that when Central Asian apricot germplasm were grown in California conditions the fruit remained small (9.4 g), which underline importance of genotypic effect on fruit size. Wide variability in fruit weight (5.6-105.3 g) among cultivated apricot is therefore the result of both genotypic and environmental factors.

Our data partially agree with the observations made by Olmez[10], *et al*. who reported that only one out of three apricot cultivars studied showed decreasing fruit size with increasing elevation. However, in the two other cultivars, fruit size increases with increasing from 731 to 855 m asl and then showed declining trend when grown at 1115 m asl. Our data is in contrast with studied on other fruits such as fig[23] and chestnut[24] where increase in fruit size was observed with increasing elevation. In sweet cherry and mandarin, no relation was found between fruit weight and altitude[25,26]. Contrasting results in the previous studies could be due to difference in altitude of studied areas. While most of the studied were conducted below 1500 m asl, our study focus of high altitude regions above 3000 m asl.

Fruit moisture content decreased significantly with increase in elevation (R^2=0.585, $p\leq0.05$) (Fig. 1(c)). Decrease in moisture content was 1.9% for every 100 m increase in elevation. Fruits of trans-Himalaya, therefore, have lower moisture content as compared to previous reports[27,28], which may be because of drier climatic conditions in higher elevations. Fruit moisture content is an important factor at commercial maturity stage. Apricots with high moisture content are sensitive to transportation and handling. High moisture contents cause fruit to spoil earlier[27]. Blush area and seed dimensional properties showed inverse relationship with altitude, however, the values are not highly significant ($p\leq0.05$).

3.3 Altitude Effects on Fruit TSS Content

Altitude showed linear relationship with fruit TSS content (R^2=0.726, $p\leq0.01$) (Fig.1(d)). For every 100 m increase in elevation, the fruit TSS increased by 1.2ºBrix. Our result is in agreement with reports on mandarin[26], where high TSS

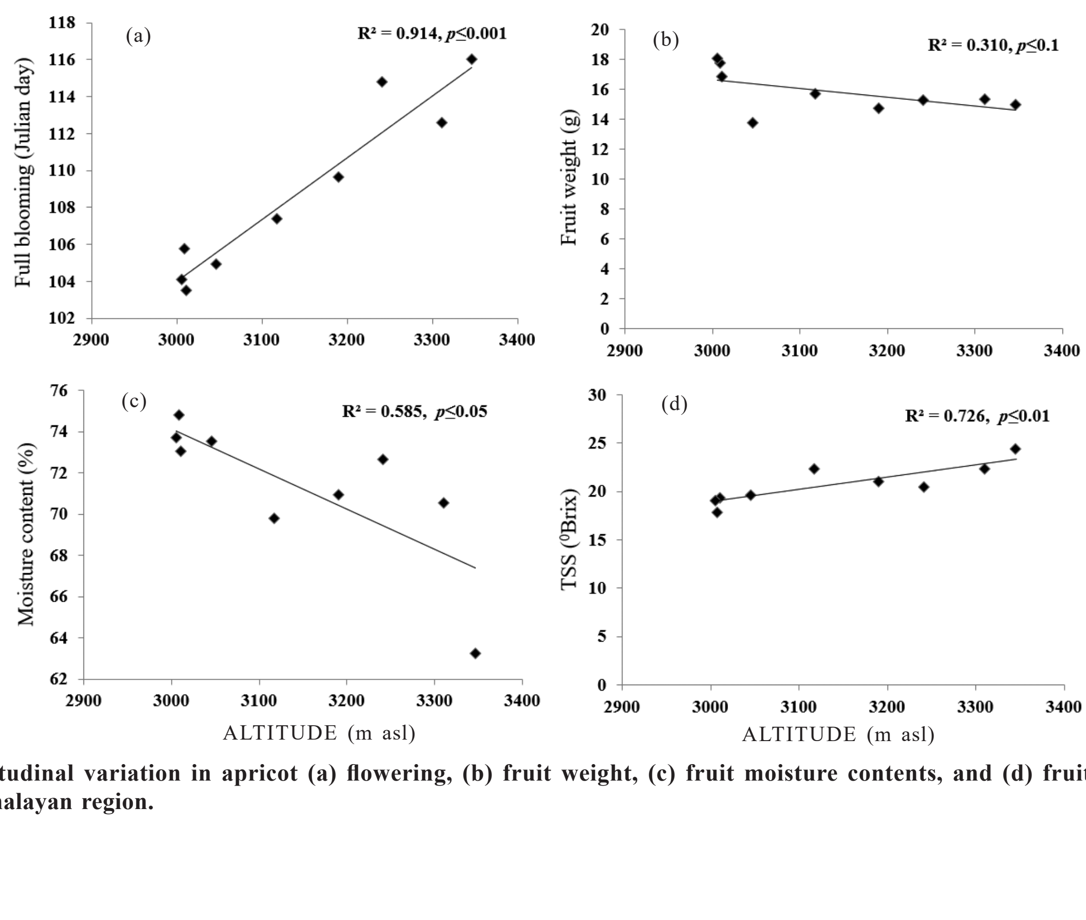

Figure 1. Altitudinal variation in apricot (a) flowering, (b) fruit weight, (c) fruit moisture contents, and (d) fruit TSS in trans-Himalayan region.

was found at higher altitude. However, inverse relation was observed when 'Wonderful' pomegranate cultivar was harvested at commercial harvest stage at 222, 662 and 898 m asl[29]. Similarly, low altitude (229 m asl) persimmon fruits have higher TSS content than those from a high elevation (770 m asl) region[30]. Altitude has no influence on fruit TSS content in sweet cherry[23] and blueberry fruits[31].

The evaluated genotypes showed marked variability in TSS content ranging from 10.7-37.6ºBrix with average value of 20.7±5.1 (Fig. 3). In comparison, the value ranged from 11-27ºBrix among 128 apricot cultivars and types in Turkey[20], 15.7-18.9ºBrix in 14 genotypes grown in Central Serbia[22], 10.6-16.3ºBrix in 43 selections and cultivars grown in Spain[19], 9.3-

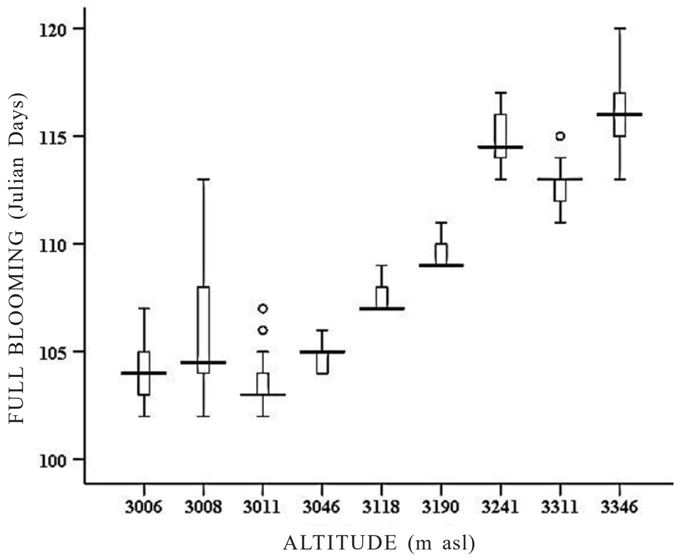

Figure 2. Box plot distribution of date of apricot full bloom along altitudinal gradient in trans-Himalayan region. The plot represents the minimum and maximum value (whiskers), the first and third quartile (box), the median (midline).

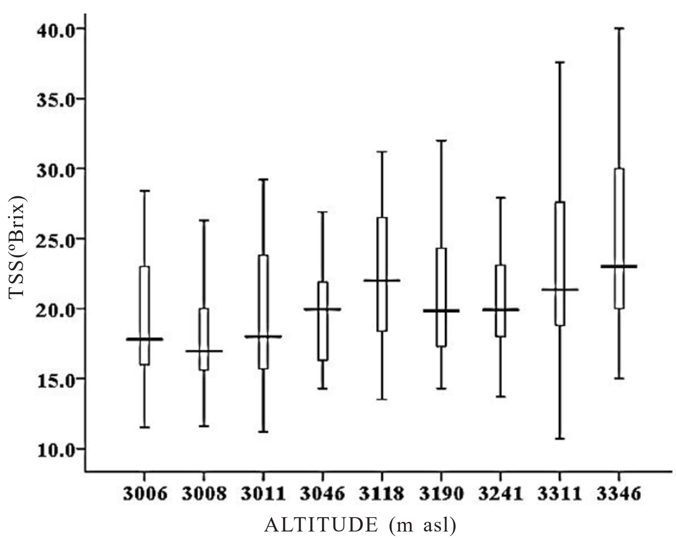

Figure 3. Box plot distribution of apricot fruit TSS along altitudinal gradient in trans-Himalayan region. The plot represents the minimum and maximum value (whiskers), the first and third quartile (box), the median (midline).

Table 2. Morphometric and pomological characteristics of apricot fruits of trans-Himalaya

Location	FB	FrW	SW	FW	TSS	MC	BA	FrL	FrWd	SL	SWd	ST	SCT
TAK	104.1±1.6^{b}	18.1±8.5^{d}	2.0±0.5^{d}	16.0±8.2^{c}	19.1±4.7^{ab}	73.7±5.8^{de}	163.4±294.8^{ab}	30.1±5.7^{cd}	32.1±5.0^{c}	21.1±2.3^{cd}	18.0±2.2^{c}	12.2±2.1^{b}	1.5±0.3^{a}
DOM	105.8±3.1^{d}	17.8±5.4^{cd}	1.9±0.4^{bcd}	15.9±5.1^{c}	17.8±3.7^{a}	74.8±4.2^{e}	225.7±218.7^{ab}	28.0±4.0^{abc}	30.2±4.0^{abc}	19.5±2.0^{ab}	16.5±1.9^{ab}	11.5±1.7^{ab}	1.5±0.3^{a}
KLS	103.5±1.4^{a}	16.8±3.6^{bcd}	1.9±0.4^{cd}	14.9±3.3^{bc}	19.4±5.0^{ab}	73.0±3.8^{cde}	265.6±236.2^{b}	30.5±3.8^{d}	30.9±3.1^{bc}	21.7±3.5^{d}	17.2±2.8^{abc}	11.9±2.6^{ab}	1.4±0.3^{a}
NUR	104.9±0.7^{c}	13.8±2.0^{a}	1.6±0.3^{a}	12.1±1.9^{a}	19.6±3.5^{abc}	73.6±3.2^{cde}	238.8±217.1^{ab}	27.3±1.9^{a}	29.2±1.7^{ab}	19.0±1.6^{a}	16.9±1.4^{abc}	11.6±1.6^{ab}	1.4±0.3^{a}
SPL	107.4±0.6^{e}	15.7±3.5^{abcd}	1.8±0.4^{abcd}	13.9±3.2^{abc}	22.3±5.2^{cd}	69.8±4.8^{b}	182.3±192.9^{ab}	27.9±2.7^{ab}	30.4±2.4^{bc}	19.8±1.4^{ab}	17.1±1.3^{abc}	11.6±1.6^{ab}	1.4±0.3^{a}
NMU	109.6±0.7^{f}	14.7±4.7^{ab}	1.7±0.3^{ab}	13.1±4.5^{ab}	21.1±4.4^{bc}	71.0±3.5^{bcd}	223.5±200.9^{ab}	28.1±2.8^{abc}	29.3±3.1^{ab}	19.6±1.4^{ab}	16.6±1.6^{ab}	11.1±1.5^{ab}	1.5±0.3^{a}
TSG	114.9±1.5^{h}	15.3±3.9^{abcd}	1.8±0.5^{abc}	13.5±3.5^{abc}	20.5±3.4^{abc}	72.7±3.5^{bcde}	230.8±237.1^{ab}	28.0±2.7^{abc}	29.3±2.2^{ab}	20.2±2.4^{abc}	16.8±1.6^{ab}	11.1±1.3^{ab}	1.5±0.4^{a}
TIA	112.7±1.0^{g}	15.3±5.1^{abcd}	1.7±0.5^{abc}	13.6±4.7^{abc}	22.3±6.0^{cd}	70.5±4.0^{bc}	154.6±220.8^{ab}	27.7±3.5^{a}	28.3±3.8^{a}	19.6±2.0^{ab}	16.3±1.9^{a}	11.1±1.7^{a}	1.3±0.2^{a}
LEH	116.0±1.5^{i}	14.9±3.5^{abc}	1.8±0.4^{abc}	13.2±3.3^{ab}	24.3±6.2^{d}	63.3±10.6^{a}	128.7±182.0^{a}	30.0±3.6^{bcd}	30.1±3.5^{ab}	20.6±2.2^{bcd}	17.5±2.4^{bc}	11.7±1.8^{ab}	1.4±0.2^{a}
Average	108.8±4.7	15.8±4.9	1.8±0.4	14.0±4.6	20.7±5.1	71.4±6.2	201.5±226.7	28.6±3.7	30.0±3.5	20.1±2.3	17.0±2.0	11.5±1.8	1.4±0.3

Values represented mean ± SD; for each column different lowercase letters indicate significantly differ ($P \leq 0.05$)

FB: date of full bloom (JD); FrW: fruit weight (g); SW: Seed weight (g); FW: flesh weight (g); TSS: total soluble solids (ºBrix); MC: Moisture content (%); BA: blush area (mm^2); FrL: fruit length (mm); FrWd: fruit width (mm); SL: seed length (mm); SWd: seed width (mm); ST: seed thickness (mm); SCT: seed coat thickness (mm).

18.7ºBrix in 55 cultivars at germplasm collection in Spain[32], 8.7-22.4ºBrix in 51 genotypes from germplasm collection in France[33], 12.3-15.8ºBrix in 18 genotypes belonging to the Italian and international germplasm[6], and 12.7-20.0ºBrix in six cultivars in Pakistan[27]. The present study showed that high altitudes are favourable for production of apricot fruit with high TSS content. Besides environmental factors, the genotypic factor of Central Asian apricots may also be responsible for higher sugar content. Higher fruit sugar content was observed when apricot germplasm from northern Pakistan were grown in California[1] suggesting that Central Asian apricot germplasm have inherent higher sugar content.

In trans-Himalayan Ladakh region apricot trees are cultivated in irrigated plantation. Irrigation water requirements are high due to high evaporative demand and scarcity of rainfall. Therefore, deficit irrigation is not uncommon in Ladakh, which may be a favourable factor for high TSS content of apricots. Studies have shown that deficit irrigation results in apricots with higher TSS[34]. Dry climatic conditions with low rainfall in high altitude regions appeared to be favourable factor for fruits with high sugar content. Previous research has reported that fruit TSS is associated with a dry climate in cactus pear[35]. Fruits from dry locations are often sweeter than those from humid or irrigated land[36]. Therefore, dry climatic conditions seem to be one of the important factors responsible for high TSS content of apricots of high altitude regions.

3.4 Correlation among Variables

Table 3 present correlations among variables. Seed stone colour showed significant correlation with kernel taste (r = 0.506), fruit weight (r = 0.530) and TSS (r = 0.451). Therefore, apricots with white stone are associated with sweet kernel, larger fruit and high TSS content. Sweet kernel taste is significantly correlated with fruit weight (r = 0.426) and TSS (r = 0.463). Date of flowering is significantly correlated with harvest date (r = 0.690). Fruit harvest date is positively correlated with TSS (r = 0.324). The result suggested that late maturing apricot genotypes have higher TSS content. Fruit weight showed correlations with TSS (r = 0.177). However, Caliskan[7], *et al*. did not find correlations between fruit weight and TSS.

4. CONCLUSIONS

The knowledge on altitudinal effect on apricot fruit quality is vital since it guide us in selecting orchard location towards improving fruit quality. The geographic elevation had a marked influence on flowering, fruit weight, moisture and TSS content. At higher elevation delayed flowering and fruit ripening occurs, and fruit remains smaller with low moisture content. Apricots from higher altitude regions are sweeter with high sugar content as compared to those grown at lower elevation. Dry climatic conditions with low rainfall appear to be favourable factor for fruits with high sugar content in high altitude regions.

Table 3. Pearson's correlation coefficients of fruit quality characteristics

	SC	KT	FB	HD	FrW	SW	FW	FW/SW	TSS	MC	BA	FrL	FrWd	SL	SWd	ST	SCT
SC	1	.506**	-.098*	.035	.531**	.375**	.530**	.327**	.451**	-.203**	.312**	.309**	.366**	-.044	.257**	.274**	-.208**
KT		1	-.015	.057	.421**	.228**	.426**	.356**	.463**	-.148**	.371**	.190**	.224**	.001	.046	.067	.136**
FB			1	.690**	-.154**	-.103*	-.154**	-.093*	.218**	-.335**	-.085	-.046	-.175**	-.014	-.063	-.121**	-.010
HD				1	-.120**	-.142**	-.115*	-.006	.324**	-.322**	-.032	-.059	-.210**	-.095*	-.123**	-.114*	-.121**
FrW					1	.694**	.998**	.609**	.177**	.098*	.284**	.673**	.726**	.332**	.426**	.274**	.075
SW						1	.644**	-.123**	.083	-.051	.016	.562**	.561**	.492**	.586**	.379**	.261**
FW							1	.659**	.180**	.109*	.300**	.663**	.719**	.307**	.398**	.256**	.055
FW/SW								1	.194**	.177**	.362**	.321**	.397**	-.076	-.040	-.032	-.161**
TSS									1	-.559**	.132**	.111*	.119**	-.070	.058	.102*	-.113*
MC										1	-.035	-.023	.053	-.031	-.082	-.100*	.059
BA											1	.239**	.268**	.061	.067	.181**	-.176**
FrL												1	.759**	.679**	.574**	.325**	.195**
FrWd													1	.454**	.648**	.416**	.169**
SL														1	.621**	.315**	.334**
SWd															1	.582**	.281**
ST																1	.091*
SCT																	1

* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$;
SC: Stone colour; KT: kernel taste; FB: date of full bloom; HD: date of harvest; FrW: fruit weight; SW: Seed weight; FW: flesh weight; FW/SW: flesh and seed weight ratio; TSS: total soluble solids; MC: moisture content; BA: blush area; FrL: fruit length; FrWd: fruit width: SL: seed length; SWd: seed width; ST: seed thickness; SCT: seed coat thickness.

Conflict of Interest: None

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ACKNOWLEDGEMENTS

The study was supported by the Defence Research and Development Organisation (DRDO), Ministry of Defence, Government of India. AN, DD, and AKB are grateful to DRDO for providing a research fellowship.

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