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ORIGINAL PAPER

Fruit quality components of balsam pear (*Momordica charantia* L.) and soil respiration in response to soil moisture under two soil conditions

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Abstract

Balsam pear (*Momordica charantia L.*) is an important vegetable reported to have pharmacological properties. It contains abundant bioactive compounds which can be affected by viticulture and environment factors. Identification of the optimal cultivate condition is fundamental to enhance fruit quality components of balsam pear and to decrease carbon dioxide efflux of vegetable garden. The objective of this study was to identify changes of health-promoting bioactive compounds (flavonoids and saponins) and fruit nutritional quality of balsam pear, as well as seasonal variation of soil respiration (Rs) in response to soil moisture under different soil types. A field experiment was conducted using a 3 × 2 factorial involving three levels soil moisture including 50–60% (L), 70–80% (M), and 90–100% (H) of field moisture capacity (FC) under Loessial soil (L) and Cumulic cinnamon soil (C) conditions. The results indicated that moderate soil moisture was benefit for improving quality components, 70–80% FC was benefit for accumulation of health-promoting bioactive compounds on the Cumulic cinnamon soil, and 70–80% FC was benefit for the nutritional quality of fruit on the Loessial soil; soil respiration measured in Loessial soil were always higher than that in Cumulic cinnamon soil. Air temperature, photosynthetic active radiation, soil temperature had positive correlation with Rs to some extent, while air relative humidity had a negative correlation with Rs. This study would be potentially beneficial for efficiently producing functional and high quality balsam pear.

Keywords Flavonoids · Fuzzy membership function · *Momordica charantia* L. · Saponins · Water deficit

Introduction

Water is an absolutely necessary element for plants [1]. Water resources are becoming increasingly limited worldwide [2], and a reliable irrigation method is necessary to improve agricultural production and irrigation efficiency [3, 4]. Thus intellectual water management is vital and undeniable [5, 6]. Soil is the material basis for crops to survive and soil fertility can directly affect the crop yield and fruit quality [7]. Some researches have reported that both soil moisture and soil type play a key role in the products yield, nutritional quality and production efficiency during crops development stage [8–10]. Balsam pear (*Momordica charantia* L.) is commonly known as balsam pear, bitter melon, kugua, or karela, and belongs to the Cucurbitaceae family [11–13]. It is an important horticultural crop in the world, and is often cultivated with irrigation in tropical and subtropical regions [14, 15]. Balsam pear possesses various beneficial effects, including antioxidant, anti-inflammatory [16], anti-cancer [17], anti-obesity [18], anti-viral [19], anti-helminthic activity [20], anti-diabetic [21], anti-osteoporosis [22, 23], reduction of blood glucose level and lipid metabolism, and reduction of cholesterol [24]. It is known as 'the mainstream food of the 21st century' and has been widely used in industrial medicine, cosmetics and food industry [12, 25]. As soil conditions are vital for plant nutrients and secondary metabolites, a suitable cultivation environment is necessary to improve comprehensive quality of balsam pear.

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Therefore, choosing the optimal soil type and moisture may be of great significance for balsam pear production.

Soil respiration (Rs) is an important biological characterizations of soil quality and soil fertility [7]. It is also recognized as the comprehensive reflection of soil biological activity and material metabolism intensity [26]. Soil moisture has been considered as one of the most influential factors controlling Rs based on different carbon models, such as Roth-C and quadratic models [27]. Davidson [28] found that Rs correlated exponentially with soil moisture in forest ecosystem; Lavigne [29] also reported that when the soil water content below field holding capacity, Rs positively correlated with soil moisture in a balsam fir ecosystem. What's more, the changes in the magnitude of Rs could greatly influence the concentration of CO_2 in the atmosphere [30]. Therefore, understanding the changes of soil respiration during growing stage under different soil conditions has important significance on scientific planting balsam pear.

Nowadays, many studies concentrate on soil respiration in different ecosystems, but neglect the roles of some ecological factors, such as soil moisture and soil type, both in the changes of soil respiration. Meanwhile, there has been a lot of researches looking at the pharmacological characteristics of balsam pear, but they focus less on the effects of soil environment and still lack effective and comprehensive methods for evaluating the comprehensive quality of balsam pear. AI (artificial intelligence) models including Auto Regressive Integrated Moving Average (ARIMA), the AR Moving Average (ARMA), the Auto Regressive (AR), and the Moving Average (MA) models of time series in various fields of hydrology. These models have been widely applied in forecasting rainfall in irrigation schedules, evapotranspiration and water crisis issues [31–36]. Valipour [31] successfully forecasted the monthly inflow of Dez dam reservoir using AI model. However, researches about AI models applied in vegetables quality evaluation are less, and it also lack quantitative, comprehensive, systematic and standard evaluation systems in China [37]. Fuzzy membership function value can indicate the relative advantages and disadvantages of comprehensive quality, it is an effective method in evaluation of vegetables quality [38–40]. Therefore, the objectives of the current study are as follows: (1) using fuzzy membership function to evaluate health-promoting bioactive compounds (flavonoids and saponins) and nutritional quality compounds (vitamin C, soluble sugar, soluble protein, total soluble solids) of balsam pear fruit in responses to soil moisture and soil type; (2) to investigate the effects of soil moisture and soil type on the seasonal variation of Rs and the correlations between Rs and some other environment factors. The study results may provide theoretical basis and practical guidance for the scientific planting, efficient management and quality improvement of balsam pear.

Materials and methods

Site description, plant materials and experimental design

The experiment was carried out at the Institute of Soil and Water Conservation, Northwest Agriculture and Forestry University in Yangling (34°12′-34°20′N;108°-108°7′E, at an altitude of 560 m), Shaanxi, China, from May to September in 2014. The soil used in this trial were Cumulic cinnamon soil and Loessial soil, which physical and chemical properties were showed in Table 1. Cumulic cinnamon soil was the main types of soil in the Loess Plateau in China, it was obtained from the Ansai county of Shaanxi, China. Loessial soil's parent material was mainly loess sediments, located in the arid and semi-arid areas of the south of warm temperate zone, it was the mainly agricultural soil in Guanzhong Plain of ShaanXi, China.

Balsam pear (*Momordica charantia* L. var '*Lan Shan Da Bai*') as materials in the experiment were pot cultivation of seedling. They were transplanted when developing five true leaves with inter-plants spacing of 0.5 m and inter-rows spacing of 0.6 m on April 28 in 2014. Fertilizers were applied with 5N-4.37P-8.3K for each plot before planting, and add equal portion of urea, potassium sulfate during blossom period.

A field experiment was conducted using a 3 × 2 factorial experiment involving three levels soil moisture of 50–60% (L), 70–80% (M), and 90–100% (H) of field water capacity (FC) under Loessial soil (L) and Cumulic cinnamon soil (C) conditions, there were six treatments including CL, CM, CH and LL, LM, LH. Plot size was 4 m long and 1.5 m wide, 0.6 m water proof board was buried between adjacent plots to prevent water permeability. Water control treatments were established on 9 June. Soil water content 0–0.4 m was measured by Time Domain Reflectometry (TDR) probe every

Table 1 The core physical and chemical properties of Loessial soils and Cumulic cinnamon soils

	Loessial soil	Cumulic cinnamon soil
Topsoil capacity weight/(g cm^{-3})	0.95	1.20
Field capacity/(g kg^{-1})	220	240
Organic matter/(g kg^{-1})	8.73	9.60
Total nitrogen/(g kg^{-1})	0.42	0.52
Available nitrogen/(mg kg^{-1})	9.78	9.57
Total phosphorus/(g kg^{-1})	0.56	0.64
Available phosphorus/(mg kg^{-1})	24.75	26.93
Available potassium/(mg kg^{-1})	91.92	102.37
pH	8.4	7.5

3 days during water control period. The probe was calibrated with oven drying method in each plot every 15 days and the water was expressed as a percentage of volumetric water content. Irrigation were according to the upper limit, the irrigation amount at each time was estimated using the following equation [41]:

$$M = S \times H \times R \times (Wa - Wb) \quad (1)$$

The M stands for irrigation quantity (m^3); S stands for the plot area; H stands for irrigation wetting layer depth; R stands for soil density (g cm^{-3}); Wa stands for the target set moisture content (%); Wb stands for measurement of moisture content (%).

Quality traits measurement

Bioactive compounds determination with dry samples. Randomly selected fruit (the same date of pollination) and leaves (the same leaf age) of the mature period with total six times during the entire mature period (26 June, 9 July, 19 July, 29 July, 8 August, 19 August). Samples were dried under 55℃.The root samples were sampled at the end of growth period. Dried under same temperature as fruit and leaves. All drying samples smashed into powder and passed through the 80 mesh screen, ultrasonic extracted with ethanol for further determination. Flavonoids content was estimated according to the method described by Pang [42], routine used as standard (Sigma company, USA). Total saponins content was estimated according to the method described by Qiu [43], ginsenosides (Rg1, Chinese medicine institute) used as standard.

Fruit nutritional quality determination with fresh samples. Sampled fruit with total three times (9 July, 8 August and 19 August) during the entire mature period. For each treatment, five uniform fruits were sampled, sarcocarp were combined for measurement of vitamin C (Vc), soluble protein (SP), soluble sugar (SS), and total soluble solids (TSS). Content of Vc was measured by molybdenum blue colorimetric method, SP content was measured by ultraviolet spectrophotometry (BIBBY Jenway 6305, Britain), SS content was measured by anthrone colorimetry [38], TSS was determined on juice using a handheld refractometer (ATC-1 Atago, Tokyo, Japan) with automatic temperature compensation.

Soil respiration and environment factors

Rs was measured during the growing season (June–September) using a LICOR-6400 portable photosynthesis system equipped with a LICOR 6400-9 soil respiration chamber (LICOR, Inc., Lincoln, NE, USA) [44]. Polyvinyl chloride soil collars 10.5 cm in diameter and 5 cm in height were used for the measurements. To minimize the soil surface disturbance-induced CO_2 efflux, the collars were installed at least 24 h prior to each measurement. Collars were inserted in the soil to a depth of 4 cm, and three replicate measurements were made on each collar on the observation days. The litter in the collars was removed before the measurements began. All the measurements were performed between 9:00 and 11:00 a.m. on 16 June, 1 July, 17 July, 2 August and 20 August. Monthly average air temperature and air relative humidity (Fig. 1) were recorded automatically by HOBO (CO-UX100-011) from 1 June to 30 August, which was located in the middle of the plot area at a height of 1.5 m, once per hour. Photosynthetic active radiation were measured by using a LICOR-6400 portable photosynthesis system equipped in different growth period.

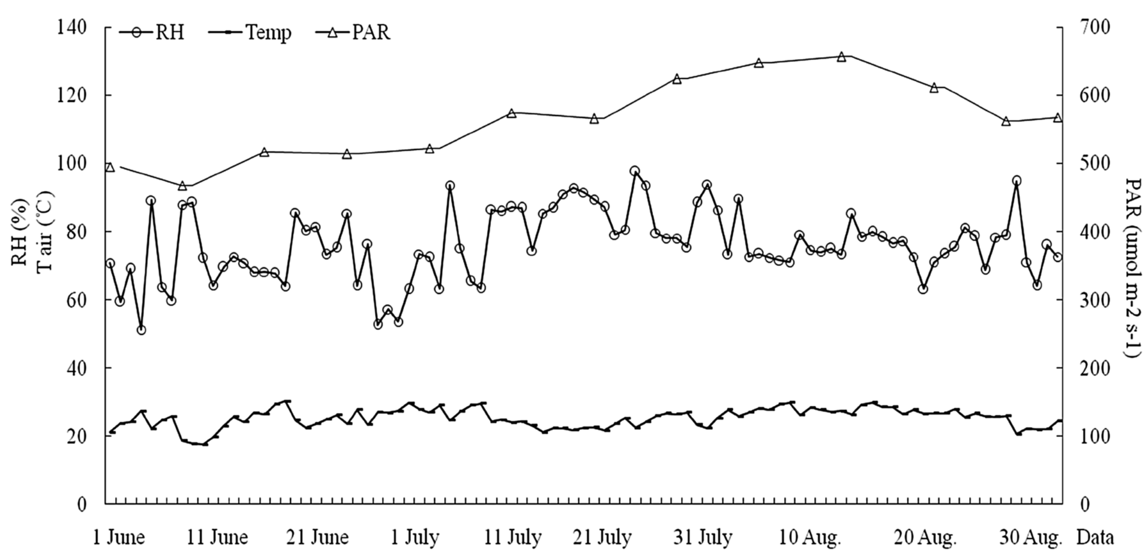

Fig. 1 Variation of environmental factors at the study site

Thermo Recorder TB-52 records 5–10 cm soil temperature of different treatment.

Statistical analysis

The experimental data were analyzed with SPSS 20.0. A one-way analysis of variance was performed to evaluate the effect of different soil types and soil moisture levels on fruit quality, subsequently, a Duncan multiple range test was used to identify statistically significant differences ($p < 0.05$) between the mean values of membership function values within each treatments.

Fuzzy membership function (artificial intelligence) was used to comprehensively evaluate each fruit quality index, the membership function values U(xi) was calculated from Eq. 1 [45]:

$$U(xi) = (xi - Xmin)/(Xmax - Xmin) \tag{2}$$

If an index and comprehensive evaluation results showed a negative correlation, the anti-membership function values was calculated using the following expression:

$$U(xi) = 1 - (xi - Xmin)/(Xmax - Xmin) \tag{3}$$

U(xi) was the membership function value, xi was measured value of an index, Xmax and Xmin were maximum and minimum values in an index of all the treatments.

Results

Changes of bioactive compounds in balsam pear during growing stage

As shown in Fig. 2. Flavonoids and saponins content in fruits and leaves were increase first and then decreased during growing stage under two soil conditions, except for a

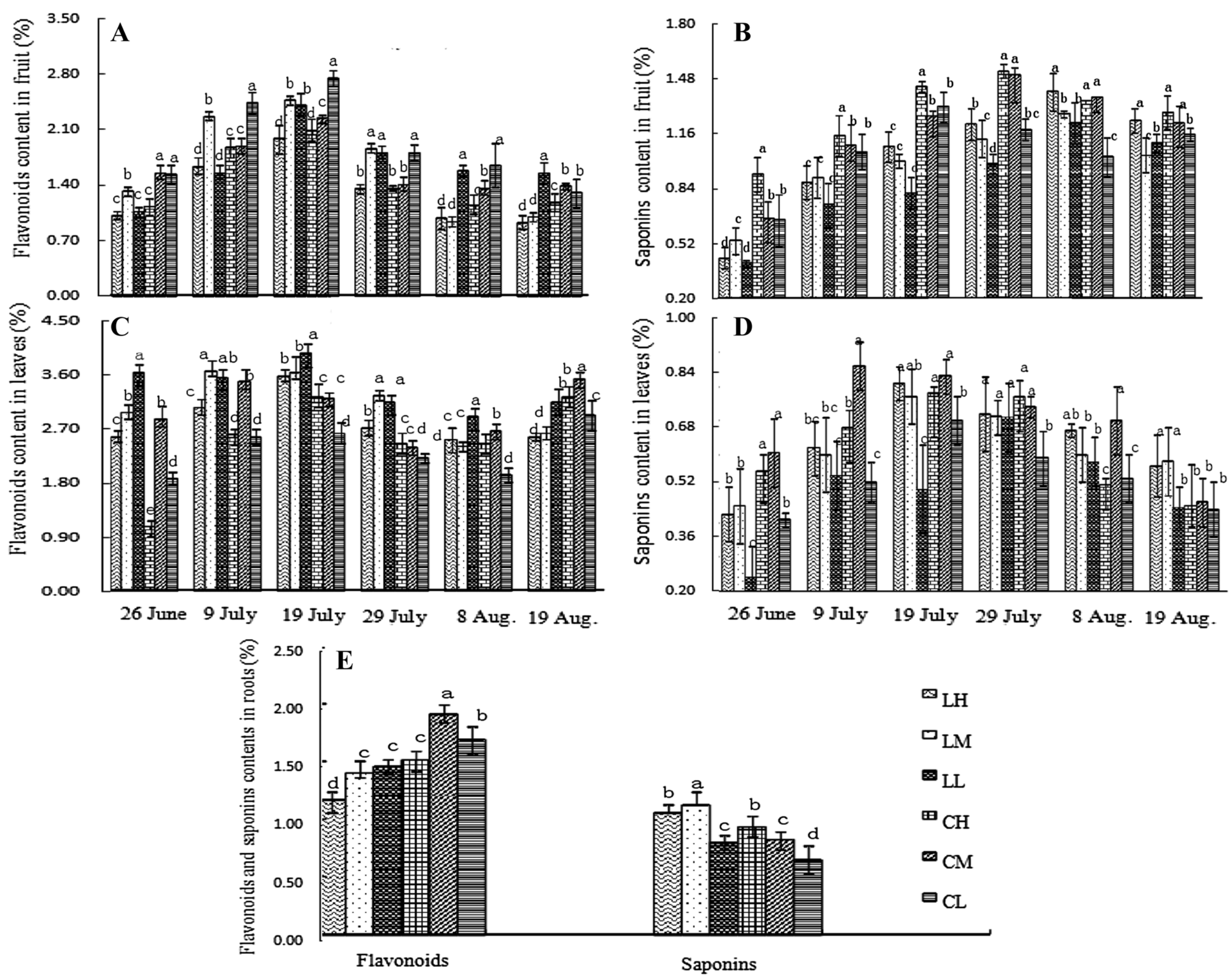

Fig. 2 Accumulation of flavonoids and saponins in balsam pear fruit (**a, b**), leaves (**c, d**) and root (**e**) during growing stage

slightly increased of flavonoids content in leaves during late fruit stage (19 August).

The average flavonoids content in balsam pear organs showed leaves > fruits > roots. Response of flavonoids in fruits, leaves and roots (Fig. 2a, c, e) to soil type performance higher in Cumulic cinnamon than that in Loessial soil, except for leaves flavonoids content is higher in Loessial soil than that in Cumulic cinnamon soil during early and full fruit stage (From 26 June to 29 July). With respect to Cumulic cinnamon soil, CL is suitable for fruits, leaves flavonoids accumulation during development period, except for CH is suitable for leaves flavonoids production at the full fruit stage (29 July). Root flavonoids content was CM > CL > CH. In regards to Loessial soil, LM and LL is suitable for fruit flavonoids accumulation at the early fruit stage (26 June, 9 July and 19 July) and late fruit stage (8 August and 19 August), respectively. Root flavonoids content was LL > LM > LH.

The average saponins content in balsam pear organs showed fruits > leaves > roots. Response of saponins in fruits, leaves (Fig. 2b, d, e) to soil type performance higher in Cumulic cinnamon than that in Loessial soil during early fruit stage (From 26 June to 29 July). Two peaks for saponins accumulation in fruits and leaves were 29 July and 9 July in CH and CM, respectively. With respect to Cumulic cinnamon soil, CH is suitable for fruits and leaves saponins accumulation during early fruit stage (26 June, 9 July, 19 July). Root saponins content was CH > CM > CL. As regards Loessial soil, LH and LM is suitable for fruits and leaves saponins accumulation at the early fruit stage (26 June, 9 July and 19 July). Root saponins content was LM > LH > LL.

Changes of nutritional quality in balsam pear during growing stage

Changes of Vitamin C (Vc), soluble protein (SP), soluble sugar (SS) and total soluble solids (TTS) of balsam pear fruits during growing stage in all treatments are listed in Table 2. Variation in soil moisture had significant effect on nutrient of fruit.

Vitamin C (Vc) is one of the indispensable components of nutrition in fruits. Vc content were sustained increasing under two soil condition regardless of soil water content, and reach the maximin value at late fruit stage (19 August). In

Table 2 Changes of nutrition quality of balsam pear fruit during growing stage

	Treatments	9 July	8 August	19 August
Vitamin C (mg 100 g^{-1})	LH	34.10 ± 0.22b	37.40 ± 0.64b	41.27 ± 0.71b
	LM	34.97 ± 0.79b	42.83 ± 0.97a	46.34 ± 0.85a
	LL	35.64 ± 0.56a	38.70 ± 0.82b	43.20 ± 0.23b
	CH	32.65 ± 0.26c	38.45 ± 0.73b	41.04 ± 0.92b
	CM	34.72 ± 0.81b	36.78 ± 1.03c	37.41 ± 1.06c
	CL	36.18 ± 0.55a	39.01 ± 0.43b	42.29 ± 0.99b
Soluble protein (mg g^{-1})	LH	6.46 ± 0.32c	7.30 ± 0.62e	9.82 ± 0.50b
	LM	7.50 ± 0.45a	12.97 ± 0.51a	11.67 ± 0.30a
	LL	6.88 ± 0.62b	11.54 ± 0.28b	7.67 ± 0.31c
	CH	6.71 ± 0.34c	7.74 ± 0.54e	9.57 ± 0.21b
	CM	7.33 ± 0.31a	9.37 ± 0.72d	10.04 ± 0.71b
	CL	6.81 ± 0.27b	10.27 ± 0.36c	9.32 ± 0.56b
Soluble sugar (mg g^{-1})	LH	10.39 ± 0.75b	7.62 ± 0.37b	11.17 ± 0.24b
	LM	10.42 ± 0.59b	10.09 ± 0.46b	12.42 ± 0.31a
	LL	13.10 ± 0.39a	11.14 ± 0.37a	9.56 ± 0.43c
	CH	10.59 ± 0.59b	8.50 ± 0.21c	7.51 ± 0.44d
	CM	8.23 ± 0.45c	8.71 ± 0.40c	7.09 ± 0.85d
	CL	10.00 ± 0.87b	9.78 ± 0.32b	10.20 ± 0.94c
Total soluble solid (%)	LH	3.60 ± 0.10c	4.93 ± 0.15b	4.37 ± 0.06c
	LM	3.83 ± 0.15b	4.87 ± 0.15b	5.03 ± 0.06a
	LL	4.03 ± 0.06a	4.83 ± 0.06b	4.70 ± 0.00b
	CH	3.67 ± 0.06c	5.13 ± 0.31a	4.77 ± 0.06b
	CM	3.93 ± 0.06a	4.07 ± 0.12c	4.23 ± 0.06
	CL	3.80 ± 0.00a	4.93 ± 0.06b	4.43 ± 0.06c

L Loessial soil, *C* Cumulic cinnamon soil, L—50–60% of field moisture capacity (FC), M—70–80% FC, H—90–100%FC; a–f Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$

regard to soil type, Vc content were higher under Loessial soil than Cumulic cinnamon soil condition. With respect to soil moisture, CL and LM treatments accumulated higher Vc content than other treatments, the results also showed that if the water stress was too severe in Loessial soil, it would be adverse for cumulative of Vc content.

SP content increased first and then decreased under Loessial soil, however, it sustained increasing, and reach the maximin value at late fruit stage (19 August) under Cumulic cinnamon soil. The values of SP decreased at low soil moisture while increased at higher soil moisture at late stage under two soil condition, this may be water apply effect plant normal growth, LM treatment accumulated more soluble protein than CM treatment.

SS content were higher under Loessial soil than Cumulic cinnamon soil. SS content was LL > LM > LH at early stage and LM > LL > LH at late stage, there were no difference between LL and LM treatments, however, they were remarkably higher than that in LH treatment. Fruit accumulated more soluble sugar in CM and LM treatments. Changes in SS with soil moisture may probably be due to fulfillment of crop water demand and better utilization of nutrition under optimum soil water availability, either with relative higher soil moisture or too low soil moisture had disadvantage on SS accumulation.

TSS were increased with the development stage in CM and LM treatments, while it increased and then decreased in other treatments. There were no difference between CH and LH treatments. However, low and moderate soil moisture condition, higher TSS was accumulated in Loessial soil.

Comprehensive fuzzy membership function evaluation

Health-promoting bioactive compounds were evaluated based mainly on fruit, leaf and root of balsam pear, respectively (Table 3). In order to select the optimal soil types and soil moisture, adopt the fuzzy membership function to evaluate by adding membership function value of flavonoids and saponins in various organs, then membership function value in all organs were added to comprehensively evaluate health-promoting bioactive compounds of balsam pear. Among them, in terms of fruit of balsam pear, choose three optimal treatments, they were CH (1.246), CM (1.310) and CL (1.462), respectively. In terms of leaves, selected CM (1.641), as an optimal treatment; In terms of root system, select LM (1.307) and CM (1.354) as optimal treatments, because the screened treatments of health-promoting bioactive compounds in three organs is the CM treatment, therefore, considering CM (Cumulic cinnamon soil controlled 70%-80% FC) as the most suitable combination treatment for improving health-promoting bioactive compounds of balsam pear.

Selected the vitamin C, soluble protein, soluble sugar and the total soluble solid four nutritional indexes of the balsam pear fruit as nutritional quality (Table 4), adopt the fuzzy membership function to evaluate the comprehensive nutritional quality by adding membership function value of each index, on average, the comprehensive membership function value of nutritional quality in Loessial soil treatments (LH, LM and LL) were higher than that of the Cumulic cinnamon soil (CH, CM, CL), among all treatments, the comprehensive membership function value of LM treatment was 3.911, significantly higher than other treatments, it indicated that LM treatment (70–80% FC in Loessial soil) was advantage to improving comprehensive nutritional quality of balsam pear.

Variations of soil respiration during growing stage

Soil respiration (Rs) increased from early fruit stage (16 June) afterwards with the growth of balsam pear, reached a maximum in full fruit stage (1 July and 7 July) and then began to decrease, reaching its lowest value in late fruit stage (20 August) in all treatments (Fig. 3a). On average, the date of highest Rs value obtained in the Cumulic cinnamon soil

Table 3 Evaluation of the health-promoting bioactive compounds by fuzzy membership function

Treatments	Fruit			Leaf			Root		
	Flavonoids	Saponins	U(Xi)	Flavonoids	Saponins	U(Xi)	Flavonoids	Saponins	U(Xi)
LH	0.000	0.410	0.410 e	0.456	0.700	1.156c	0.000	0.854	0.854c
LM	0.557	0.231	0.788c	0.718	0.600	1.318b	0.307	1.000	*1.307a*
LL	0.590	0.000	0.590d	1.000	0.000	1.000c	0.387	0.313	0.699d
CH	0.246	1.000	*1.246b*	0.136	0.600	0.736d	0.453	0.604	1.058b
CM	0.541	0.769	*1.310b*	0.641	1.000	*1.641a*	1.000	0.354	*1.354a*
CL	1.000	0.462	*1.462a*	0.000	0.150	0.150e	0.693	0.000	0.693d

Italic numbers indicate higher membership function value; Capital letters in italic indicates the most suitable combination treatment

L loessial soil, *C* cumulic cinnamon soil, L—50–60% of field moisture capacity (FC), M—70–80% FC, H—90–100%FC; a–f Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$

Table 4 Evaluation of the nutritional quality by fuzzy membership function

Treatments	Vitamin C	Soluble protein	Soluble sugar	Total soluble solid	U(Xi)
LH	0.254	0.000	0.528	0.440	1.222e
LM	1.000	1.000	0.911	1.000	*3.911a*
LL	0.567	0.295	1.000	0.880	2.742b
CH	0.213	0.053	0.264	0.880	1.409d
CM	0.000	0.368	0.000	0.000	0.368f
CL	0.563	0.330	0.607	0.620	2.120c

Italic numbers indicate higher membership function value; Capital letters in italic indicates the most suitable combination treatment

L loessial soil, *C* cumulic cinnamon soil, *L* 50–60% of field moisture capacity (FC), M—70–80% FC, H—90–100%FC; a–f Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$

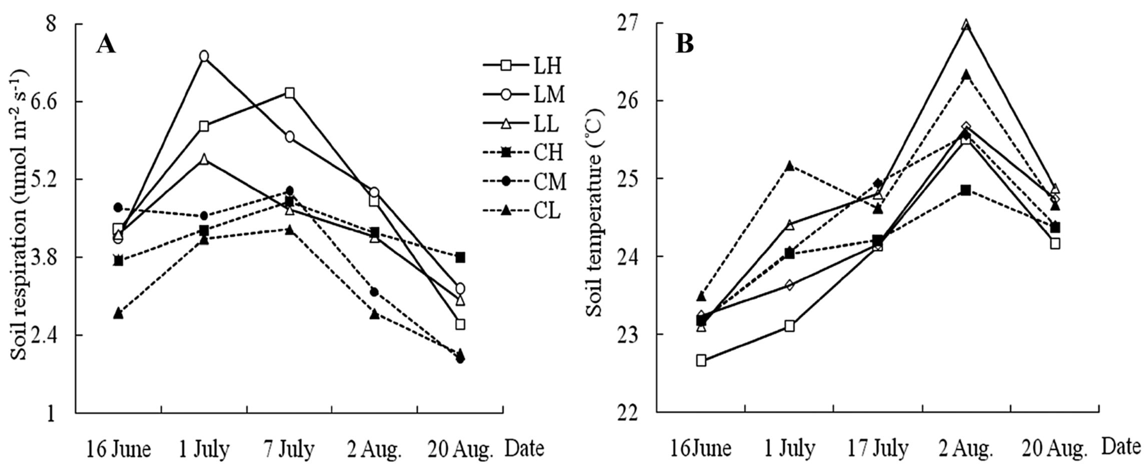

Fig. 3 Variation of soil respiration and soil temperature during growing stage

were in full fruit stage (17 July), it appeared later than that of the Loessial soil in early fruit stage (1 July), the reason may be the overall fertility of Cumulic cinnamon soil was higher than that of Loessial soil (Table 1), led to make the entire exuberant development period of balsam pear last longer. But at the same time, Rs measured in Loessial soil were always higher than that in Cumulic cinnamon soil over the entire growing season, probably because the field holding capacity of Loessial soil was lower, and soil porosity was bigger, more benefit for root growth and led to stronger soil respiration. Rs also varied among the different soil moisture, on the average, low soil moisture caused rapid declines in Rs rate from early fruit stage to late fruit stage. However, high and moderate soil moisture showed different influence on Rs in different periods.

As showed in Fig. 3b, soil temperature were increase first and then decreased during growing stage under two soil conditions, the trend of its were similar as soil respiration. However, the maximum value of soil temperature were reach in August. There were no obvious difference when considering soil types. In regard as soil moisture, soil temperature increased with the soil water content decreased.

Correlation analysis between soil respiration and environment factors

Table 5 showed that cultivation environment factors including soil moisture, soil temperature, air temperature, air humidity, and photosynthetic active radiation all had effect on the Rs, at the same time; they were also relationship between each of them. 'Thermal' contribution factors for environment, such as photosynthetic active radiation, air temperature and soil temperature which were significantly positive correlation with the Rs. However, the correlation coefficient of soil temperature ($r = 0.86$) is higher than that of soil moisture ($r = 0.79$), and Rs was more sensitive to soil temperature than soil moisture. For its reason, on the one hand, the water will help promote material transportation which the respiratory metabolism needed, on the other hand, soil temperature can activate related enzymes which

Table 5 Correlation analysis between Rs and cultivation environment factors (n = 15)

	Soil respiration (μmol m^{-2} s^{-1})	Soil moisture (%)	PAR (μmol m^{-2} s^{-1})	T soil (℃)	T air (℃)	RH (%)
Soil respiration	1					
Soil moisture	0.79*	1				
PAR	0.86*	0.50	1			
T soil	0.86*	0.39	0.98*	1		
T air	0.64	0.23	0.87*	0.83*	1	
RH	−0.90*	−0.49	−0.93*	−0.91*	−0.86*	1

Rs soil respiration, *PAR* photosynthetic active radiation, *T soil* soil temperature, *T air* air temperature, *RH* relative humidity

*Significance at $0.01 < p < 0.05$

the respiratory metabolism needed. Therefore, soil temperature and soil moisture become the main impact factors of Rs. On the contrary, air relative humidity was significantly negative correlation with the Rs (r = 0.90).

Discussion

Changes of bioactive compounds and nutritional quality

Flavonoids and saponins, as secondary metabolites, which are more susceptible to the ecological environment than genetic characteristics [46, 47]. Soil as an important substrate environment which directly effect the crops growth and development [30]. In this study, flavonoids and saponins accumulation in Cumulic cinnamon soil is higher than that in Loessial soil, for Cumulic cinnamon soil texture and fertility is beneficial for the plants root growth [48]. Water stress stimulates the accumulation and release of secondary metabolites in plants, and further leads to oxygen stress [10]. Plants can deal with water stress through the accumulation of flavonoids for it has strong antioxidant activity [21]. In this study, in terms of the flavonoids content of balsam pear organs, CL, LL and LM treatments were beneficial to the accumulation of flavonoids in fruit, leaves and roots, respectively. These results are in accordance with the study that low soil moisture could increase flavonoids content in fruit and leaves [47]. But for saponins content, CM treatment is most beneficial to the saponins accumulation in fruit, leaves and roots. This result is according with Jaafar [10], which indicated that sufficient water supply can induce the secondary metabolites production.

Both soil moisture and soil type are able to affect the fruit quality. In this study, Loessial soil is suitable for vitamin C and soluble sugar accumulation, especially in the late stage. Compared with Cumulic cinnamon soil, Loessial soil has better water permeability, lower water retention, and lager soil water and heat variation characteristics, which makes the primary metabolites (vitamin C, soluble sugar, protein and other nutrients) easier to accumulate [48]. The different physical and chemical properties of two soil types distinctly influence the water and fertilizer supply [48], which may indirectly impact root activity and physiological metabolic status of balsam pear [47]. This reason may explain why soil type could influence fruit quality of balsam pear. Under Loessial soil, the highest contents of soluble protein, vitamin C and soluble solids were detected in LH treatment, while the highest accumulation of soluble sugar appeared at LL treatment. Under Cumulic cinnamon soil vitamin C and soluble sugar showed the highest contents at CL treatment. The increace of soluble sugar under low moisture condition is consistent with the conclusion that the osmotic pressure of the cell fluid rises could lead to the percentage of sugary increase under water stress.

Evaluation of bioactive compounds and nutritional quality

Utilization of plant organs can reflect the direction of the modern agricultural production [37]. In terms of balsam pear, health-promoting bioactive compounds mainly concentrated in the roots, fruit and leaves, while nutritional quality mainly reflects in fruit [7]. So nowadays many researches focus on the variation of those quality indexs but neglected quality evaluation [6, 22, 38]. Vegetable quality is of great significance to human health, but the quality composition, vegetable cultivar and the variation of impact factors have increased the difficulty of evaluation for vegetables quality [28]. AI models of time series in various fields have been widely applied [22–27]. The fuzzy membership function (AI models) can reflect integrated level of multiple compounds traits in comprehensive characters, the higher fuzzy membership function value and the better comprehensive quality. Cumulic cinnamon soil is more suitable to promote the accumulation of health-promoting bioactive compounds in balsam pear fruit, leaves and roots. While Loessial soil is more beneficial for improving the nutritional quality of balsam pear fruit. Whether under Cumulic cinnamon soil or Loessial soil condition, the moisture level of 70–80% FC achieved the optimal comprehensive quality of balsam pear. Cheng [40] and Tang [45] evaluated the vegetable quality in garlic and Sweetpotato using fuzzy membership function, but their studies focused on the screen of varieties. Thus, average membership function value evaluation showed that the evaluation results were different with according to different requirements of target. Especially, simply using the fuzzy membership function for more outstanding objects in a certain nutrient sometimes may be biased [22, 43]. For example, if this study only concerns the evaluation of flavonoids content in fruit, the optimal treatment was CL, but in terms of evaluating soluble sugar content in fruit, then the optimal treatment was LL. This is because that the contents of soluble flavonoids and sugar in fruit are easier to accumulate at the level of low soil moisture [47]. Therefore, only considering the single or partial organs of vegetables, this method may lead to the distortion for the evaluation of quality indexes.

Variations of soil respiration during growing stage

The value of Rs is a biological characteristic of soil quality and soil fertility [45]. The process of Rs mainly include soil microbial respiration, plant root respiration, soil animals and minerals containing carbon oxidation and decomposition release [24]. Soil itself and all the processes which affect soil environment can lead to the change of Rs [45]. In this study, the values of Rs under Loessial soil were almost stronger than that under Cumulic cinnamon soil at the same stage. This is because that these two soil types exist great difference in soil fertility and soil structure (Table 1). Plant roots are important components for Rs, because the activity of soil microbes mainly depends on plant roots and the organic matter imported by root systems [46, 47]. The development of plants can enhance the activity of microorganisms, which further increase the content of carbon dioxide in soil, and ultimately improve the release of soil carbon dioxide. In addition, the importance of ground vegetation and litter on Rs has been confirmed. With the growth of balsam pear, Rs showed the trend of increasing first and then decreasing. These results are in accordance with other findings reported in several hot pepper researches [44]. Lavigne found that when the soil water content was under field holding capacity [29], Rs increased with soil moisture increasing, which is consistent with our study that the low water treatment significantly reduced the Rs. Other studies [49, 50] have indicated that the effects of soil water content on Rs were relatively complex, mainly depend on the temperature distribution conditions. In this study, the positive contribution of soil temperature ($r = 0.86$) is higher than that of soil moisture ($r = 0.79$). It showed that the sensitivity of Rs to soil temperature increased in vegetable garden. This may be because that soil temperature affected the viscosity of soil moisture, at the same time, it could promote the enzymes of substances metabolism around balsam pear root system.

Conclusions

From the results of the present experiments it may be concluded that both soil types and soil moisture effect the fruit quality component and soil respiration. Flavonoids and saponins in fruits, leaves and roots of balsam pear accumulated higher in Cumulic cinnamon than that in Loessial soil. On the contrary, Vitamin C, soluble protein, soluble sugar and total soluble solid in balsam pear fruits accumulated higher in Loessial soil than that in Cumulic cinnamon. Moderate soil moisture (70–80% FC) not only can increase the bioactive compounds content and nutrition quality of balsam pear, also decrease soil respiration rate under two soil condition. Furthermore, fuzzy membership function evaluation method (AI) should be flexible application in practice according to the practical purpose. Our results suggest that different vegetables comprehensive quality evaluation models should been proposed in the future, in order to more object and highly effective service for the analysis and evaluation of vegetables quality.

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