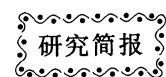


DOI: 10.3724/SP.J.1006.2012.00181



## 不同绿豆品种的叶片解剖结构

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**摘 要:** 选取开花结荚期间光合性能及活性氧代谢存在明显差异的不同绿豆品种, 以石蜡切片研究其主茎节位各功能叶片解剖结构特征, 探讨其植株衰老过程中叶片解剖结构的动态变化。结果表明, 绿豆植株开花后, 随生育进程, 主茎开花节位叶片自下向上逐渐衰老, 叶肉细胞逐渐解体, 栅栏组织排列趋向紊乱, 叶片厚度、栅栏组织厚度以及栅栏组织厚度与叶片厚度的比值均趋于减小; 不同绿豆品种叶片解剖结构的动态变化存在着显著差异, 高产品种叶片相对较厚, 栅栏组织较发达, 结构较紧密, 生育后期叶肉细胞解体较慢。综合分析表明, 绿豆叶片解剖结构的变化与其产量水平是密切相关的, 功能叶片较厚、栅栏组织较发达的绿豆品种具有相对较高的产量潜力。

**关键词:** 绿豆品种; 叶片; 解剖结构

## Anatomical Structure of Leaf in Different Mung Bean Varieties

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**Abstract:** The morphological structure is the basis of physiological function of plants, leaf is the main organ of photosynthesis that gives seed yield in mung bean [*Vigna radiata* (L.) Wilczek], so it is necessary to analyze anatomical structure of leaf in different genotypes of mung bean. The objective of this experiment was mainly to study the anatomical structure in the leaves of mung bean genotypes with different photosynthetic capabilities and reactive oxygen metabolisms in the flowering and podding stage, and explore the anatomical structure changes of mung bean during the whole aging process. The results showed that after the plants flowered, their functional leaves aged gradually from bottom to top. In the aging process, leaf structures gradually senesced, mesophyll cells gradually disintegrated, palisade tissue arrangement tended to disorder, thickness of leaf and palisade tissue, ratio of palisade tissue thickness to leaf thickness tended to decrease. There were significant differences in dynamic changes of leaf structure of mung beans. Compared with low-yield varieties, the leaf structures of the high-yield varieties aged slower and thickness of leaf was thicker, palisade tissue more developed and the structure of organism was closer, and mesophyll cells disintegrated slowly at the late growth stage. The above results indicated that the change in anatomical structure of leaf was closely correlated with the yield, and the genotypes of mung bean with high yield potential had thicker functional leaves and more developed palisade tissue.

**Keywords:** Mung bean varieties; Leaf; Anatomical structure

绿豆 [*Vigna radiata* (L.) Wilczek] 是我国重要的食用豆类作物之一, 目前生产上绿豆产量水平普遍较低, 在一定程度上限制了其产业的发展。光合作用是植物生长发育和产量形成的基础, 叶片是植物光合作用的主要器官, 很多研究者对植物叶片的解剖学结构及其与光合生理、抗性的关系等进行了研究<sup>[1-11]</sup>, 认为植物体的形态、结构与生理功能是统一的, 光合作用的差异也必然与叶的光合器官解剖学特征紧密相关。近年来, 个别研究者对绿豆叶片的解剖结构进行了初步探讨, 发现冠层温度较低品种

在结荚后期叶片结构衰老缓慢, 叶肉细胞中含有较多的叶绿体<sup>[12]</sup>; 绿豆叶片的超微结构研究发现绿豆植株开花后, 叶片开始衰老, 叶绿体基粒片层、基质片层解体, 线粒体嵴数减少<sup>[13]</sup>。目前有关绿豆生育期间叶片解剖结构的动态变化特性尚不十分清楚, 因此, 本研究选取开花结荚期间光合性能及活性氧代谢存在明显差异的不同绿豆品种, 采用石蜡切片研究其叶片在开花结荚期间的解剖学特征, 探讨不同绿豆品种植株衰老过程中功能叶片解剖结构的动态变化, 为绿豆高产育种和栽培研究提供理论依据。

本研究由农业部“公益性行业(农业)科研专项”(200903007)和陕西省小杂粮产业技术体系项目资助。

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Received(收稿日期): 2011-07-03; Accepted(接受日期): 2011-09-17; Published online(网络出版日期): 2011-11-07.

URL: <http://www.cnki.net/kcms/detail/11.1809.S.20111107.1554.024.html>

## 1 材料与方法

试验在西北农林科技大学农作一站进行。选用夏播区生育期基本一致,直立型绿豆品种 Lü1 (冀绿 2 号)、Lü2 (安 9910)、Lü3 (泰来绿豆)、Lü4 (赤峰绿豆)为材料,其中 Lü1 (冀绿 2 号)和 Lü2 (安 9910)是夏播区高产品种,其抑制活性氧代谢能力和光合性能较强<sup>[14-15]</sup>, Lü3 (泰来绿豆)和 Lü4 (赤峰绿豆)是夏播区低产品种,其光合性能较弱<sup>[14-15]</sup>。于 6 月中旬播种,苗齐后每穴留单株定苗,生育期间田间管理同大田生产。

于始花期选同一天开花且生长一致的绿豆植株,挂牌标记主茎开花节位,自开花到成熟期每隔 7~8 d 选取有代表性的标记植株,每品种 3 株,分叶位摘取主茎开花节位(第 6~9 节)三出复叶的中间小叶,及时带回实验室,按品种分节位将叶片洗净,用吸水纸吸干表面水分,分别在叶片中部,距离中脉 0.5 cm 处切取面积约 1 cm<sup>2</sup> 见方的组织,用 FAA 固定液固定。用常规石蜡切片法,经酒精和二甲基苯系列脱水、透明、浸蜡、石蜡包埋,制成叶片横切片,切片厚度 10 μm 左右,番红-固绿双重染色,中性树脂胶封

片。然后在 OLYMPUS BH2 型植物显微成像分析系统下观察,选择有代表性的石蜡切片拍照,用测微尺测量叶片厚度、栅栏组织厚度,每个节位叶片测定 5 个位点,共 30 个数值,取其平均值。采用 SAS V6.12 软件统计分析相关数据<sup>[16]</sup>。

## 2 结果与分析

### 2.1 叶片的组织结构特征及其动态变化

绿豆叶片均由上下表皮和叶肉组成,上下表皮均由一层细胞构成,位于上下表皮之间的叶肉组织上部分化为栅栏组织,下部分化为海绵组织。不同绿豆品种叶片结构上存在着一定的差异,以第 9 节位叶片为例,由图 1 可以看出,高产品种冀绿 2 号和安 9910 叶片的栅栏组织较发达,排列比较紧密;低产品种泰来绿豆和赤峰绿豆叶肉组织相对松散,细胞间隙较大。花荚盛期后,随着植株的衰老,各品种主茎开花节位叶片的叶肉细胞开始解体,栅栏组织排列趋向紊乱,细胞数量减少。从叶肉细胞的整个解体过程看,低产品种泰来绿豆和赤峰绿豆解体较快,而高产品种冀绿 2 号和安 9910 解体相对较慢(图 1)。

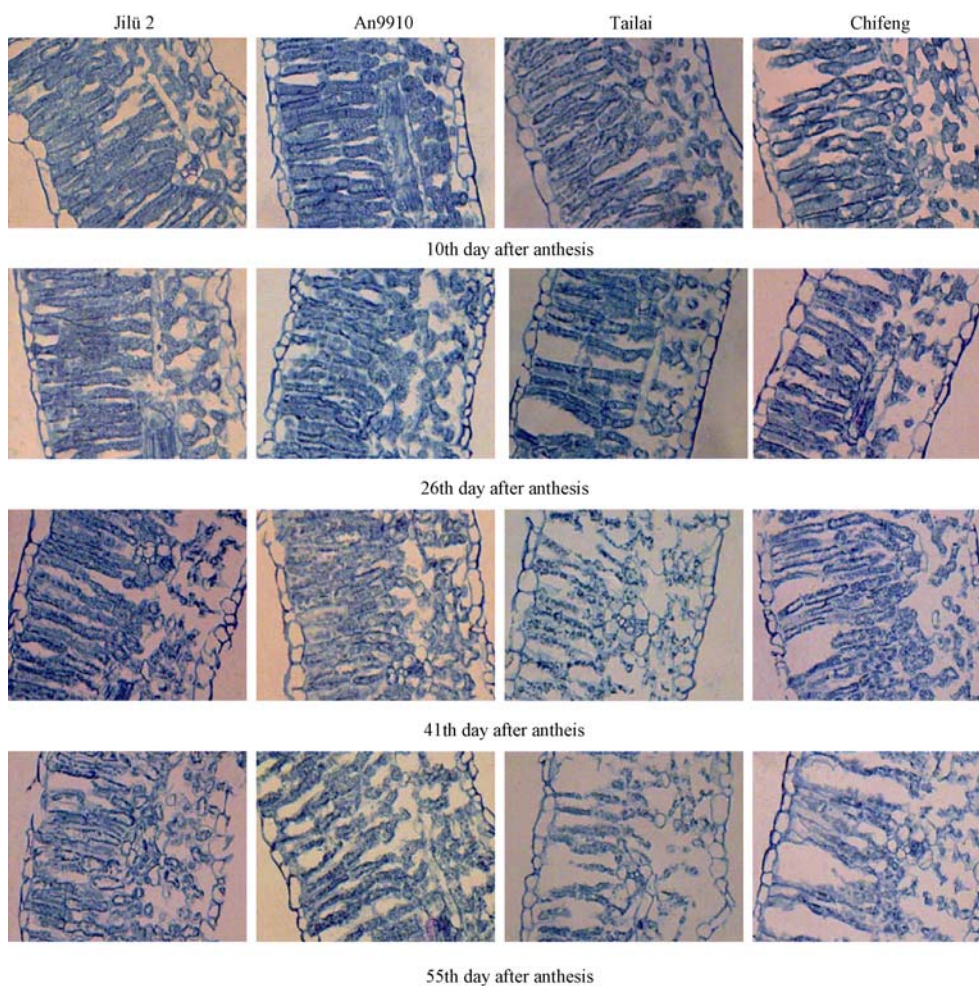


图 1 不同绿豆品种开花结荚期第 9 叶显微结构的变化(×400)

Fig. 1 Micro-structure changes in the ninth leaf of different mung bean varieties at flowering and podding stages (×400)

2.2 不同绿豆品种叶片厚度的动态变化

通过对 4 个品种主茎开花节位叶片结构的显微测量表明(表 1), 随花后生育进程, 各品种主茎开花节位叶片厚度均趋于减小。不同品种间叶片厚度在花荚盛期后存在显著差异, 高产品种冀绿 2 号和安 9910 显著高于同期低产品种

泰来绿豆和赤峰绿豆的同节位叶片。同品种叶片厚度随节位的上升而增大, 即第 9 叶>第 8 叶>第 7 叶>第 6 叶, 但变化幅度不大, 差异不显著。

2.3 不同绿豆品种叶片栅栏组织厚度的动态变化

由表 2 可以看出, 绿豆开花后, 主茎开花节位叶片

表 1 不同绿豆品种叶片厚度的变化  
Table 1 Changes of leaf thickness of different mung bean varieties (μm)

叶位 Leaf position	品种 Variety	开花后天数 Days after anthesis							平均 Average
		10 d	18 d	26 d	34 d	41 d	48 d	55 d	
第 6 叶 6th leaf	Lü1	233.2±7.9 a	227.7±7.3 a	228.8±6.7 a	227.5±6.3 a	218.1±5.4 a	218.2±5.7 a	216.2±5.6 a	224.2
	Lü2	231.5±6.2 a	229.0±6.4 a	225.9±6.8 a	225.0±6.0 a	224.2±4.9 a	222.0±5.3 a	217.8±5.2 a	225.1
	Lü3	219.0±5.4 b	217.4±6.1 a	215.7±5.5 b	209.8±5.4 b	208.8±4.8 b	206.7±4.6 b	205.4±4.6 b	211.8
	Lü4	220.6±5.6 b	218.7±5.9 a	213.4±5.4 b	210.6±5.0 b	208.9±4.3 b	206.2±4.3 b	205.7±4.2 b	212.0
第 7 叶 7th leaf	Lü1	225.7±6.3 b	235.3±5.8 a	230.7±6.1 a	226.4±6.1 a	223.5±5.7 a	221.3±5.3 a	222.3±4.6 a	226.5
	Lü2	235.9±5.6 a	230.3±5.2 a	227.6±5.8 a	225.4±5.6 a	225.3±4.9 a	224.7±4.9 a	220.7±4.7 a	227.1
	Lü3	221.4±4.8 b	221.3±4.8 b	219.9±5.5 b	206.7±5.1 b	210.2±4.3 b	208.7±4.3 b	206.7±4.2 b	213.6
	Lü4	222.7±4.6 b	222.5±4.6 b	218.7±5.2 b	214.6±4.7 b	210.0±4.1 b	208.4±4.2 b	207.1±4.3 b	214.9
第 8 叶 8th leaf	Lü1	227.3±5.9 b	239.2±5.5 a	234.1±5.5 a	232.8±6.0 a	229.5±5.8 a	225.2±5.1 a	223.3±5.5 a	230.2
	Lü2	236.4±5.7 a	231.4±6.1 b	231.1±5.7 a	227.9±5.5 ab	227.7±5.5 a	225.0±4.7 a	224.2±4.9 a	229.1
	Lü3	225.2±4.7 b	223.5±4.5 c	223.8±4.6 b	222.5±4.7 b	219.2±4.7 b	216.2±4.9 b	215.0±4.2 b	220.8
	Lü4	224.9±5.1 b	222.7±4.3 c	221.5±4.8 b	221.2±4.3 b	220.9±4.4 b	218.7±4.6 b	217.0±4.4 b	221.0
第 9 叶 9th leaf	Lü1	—	246.5±5.9 a	238.1±5.2 a	235.3±5.5 a	234.9±4.7 a	231.1±5.6 a	225.6±5.0 a	235.3
	Lü2	—	233.3±5.2 b	233.2±4.9 a	230.9±4.7 a	229.5±6.3 a	228.1±4.8 a	227.2±4.5 a	230.4
	Lü3	—	227.5±4.6 c	226.3±4.4 b	223.6±4.2 b	221.5±4.1 b	220.4±4.3 b	218.8±4.4 b	223.0
	Lü4	—	223.3±4.9 c	223.1±4.6 b	222.3±4.5 b	221.7±3.8 b	221.4±3.9 b	219.4±4.3 b	221.9

同一叶位栏中同列标明不同字母的值在 1%水平上差异显著。Lü1: 冀绿 2 号; Lü2: 安 9910; Lü3: 泰来绿豆; Lü4: 赤峰绿豆。  
Values followed by a different letter within each column for same leaf position are significantly different at the 1% probability level.  
Lü1: Jilü 2; Lü2: An9910; Lü3: Tailai; Lü4: Chifeng.

表 2 不同绿豆品种叶片栅栏组织厚度的变化  
Table 2 Changes of palisade tissue thickness of different mung bean varieties (μm)

叶位 Leaf position	品种 Variety	开花后天数 Days after anthesis							平均 Average
		10 d	18 d	26 d	34 d	41 d	48 d	55 d	
第 6 叶 6th leaf	Lü1	126.7±5.6 a	125.2±5.1 a	124.8±4.8 a	122.5±4.5 a	118.6±3.6 a	113.2±3.2 a	108.9±3.9 a	120.0
	Lü2	125.2±5.1 a	124.6±4.6 a	122.0±3.8 a	119.9±3.1 a	115.2±4.0 a	113.8±3.8 a	109.3±3.3 a	118.6
	Lü3	107.8±3.6 b	107.4±4.7 b	106.7±4.2 b	104.1±4.1 b	102.5±2.5 b	97.1±3.1 b	92.2±2.2 b	102.6
	Lü4	108.7±4.6 b	107.6±6.2 b	105.9±4.3 b	102.6±2.6 b	99.3±3.3 b	96.5±3.3 b	92.4±2.6 b	101.8
第 7 叶 7th leaf	Lü1	127.8±3.4 a	126.4±4.1 a	125.2±4.8 a	123.7±3.7 a	120.5±3.5 a	116.6±3.6 a	112.7±2.7 a	121.8
	Lü2	126.8±4.4 a	125.1±5.1 a	124.6±4.6 a	122.2±4.2 a	117.1±4.1 a	114.4±3.4 a	110.8±4.8 a	120.1
	Lü3	108.2±4.2 b	107.8±3.6 b	107.3±3.6 b	104.6±4.6 b	104.7±4.7 b	98.3±3.3 b	93.5±3.5 b	103.5
	Lü4	110.7±4.9 b	109.7±4.0 b	108.6±3.6 b	106.9±3.9 b	104.8±3.5 b	101.7±3.7 b	95.6±3.6 b	105.4
第 8 叶 8th leaf	Lü1	128.2±4.8 a	129.4±5.4 a	128.5±4.0 a	127.8±4.9 a	123.9±3.9 a	120.9±3.6 a	115.2±3.2 a	124.8
	Lü2	126.5±5.2 a	125.9±5.9 ab	125.8±4.9 a	123.4±3.4 a	119.6±4.1 a	116.9±3.9 a	114.4±4.4 a	121.8
	Lü3	111.3±5.6 b	113.3±5.4 b	112.7±4.2 b	111.1±4.6 b	109.5±3.5 b	107.9±3.8 b	104.3±3.3 b	110.2
	Lü4	112.1±3.8 b	112.7±3.9 b	111.6±3.5 b	110.8±3.8 b	108.5±3.0 b	105.4±3.4 b	102.3±3.3 b	109.1
第 9 叶 9th leaf	Lü1	—	134.7±5.3 a	133.0±3.0 a	131.3±3.2 a	128.4±3.4 a	125.5±2.5 a	120.2±3.5 a	128.9
	Lü2	—	131.0±7.0 ab	129.2±5.4 a	128.4±3.3 a	127.9±3.8 a	124.8±3.8 a	119.8±4.2 a	126.9
	Lü3	—	114.8±3.8 b	113.7±3.2 b	112.5±2.2 b	111.1±3.6 b	109.4±3.4 b	107.3±3.3 b	111.5
	Lü4	—	113.1±5.0 b	112.6±4.6 b	111.4±3.9 b	110.5±2.5 b	107.9±4.8 b	106.5±3.5 b	110.3

同一叶位栏中同列标明不同字母的值在 1%水平上差异显著。Lü1: 冀绿 2 号; Lü2: 安 9910; Lü3: 泰来绿豆; Lü4: 赤峰绿豆。  
Values followed by a different letter within each column for same leaf position are significantly different at the 1% probability level.  
Lü1: Jilü 2; Lü2: An9910; Lü3: Tailai; Lü4: Chifeng.

栅栏组织厚度的变化与叶片厚度变化趋势基本一致, 即随花后生育进程, 叶片栅栏组织厚度均趋于减小。方差分析和多重比较表明, 不同品种间叶片栅栏组织厚度存在着显著差异, 高产品种冀绿 2 号和安 9910 显著高于同期低产品种泰来绿豆和赤峰绿豆的同节位叶片。同品种不同节位叶片比较, 栅栏组织厚度表现为第 9 叶>第 8 叶>第 7 叶>第 6 叶。

#### 2.4 叶片栅栏组织厚度与叶片厚度比值的动态变化

叶片栅栏组织厚度与叶片厚度的比值在一定程度上可作为衡量叶片组织结构紧密度的指标<sup>[17]</sup>。由表 3 可以看出, 从开花到成熟过程中, 主茎开花节位叶片栅栏组织厚度与叶片厚度的比值存在着显著的差异, 高产品种冀绿 2 号和安 9910 显著高于同期低产品种泰来绿豆和赤峰绿豆, 表明高产品种冀绿 2 号和安 9910 叶片栅栏组织较发达, 叶片组织结构较紧密。同品种不同节位叶片比较, 栅栏组织厚度与叶片厚度的比值表现为第 9 叶>第 8 叶>第 7 叶>第 6 叶。

### 3 讨论

叶片结构在一定程度上影响其光合作用能力, 许多研究证明植物叶片光合速率取决于叶片叶肉组织和栅栏

组织的厚度<sup>[1,18-20]</sup>。Araus 等<sup>[21]</sup>和 Gamier 等<sup>[22]</sup>研究指出叶片厚度增加使单位叶面积内含有更多的光合细胞。Nestero 等<sup>[23]</sup>研究表明成龄叶片越厚, 栅栏组织越发达, 叶绿体密度大, 叶绿素含量高, 光合活性也越高。黄卫东等<sup>[24]</sup>研究认为叶片栅栏组织的相对变厚有利于叶绿体的向阳排列, 叶片能充分利用光能, 有利于光合效率的提高。梅秀英等<sup>[25]</sup>研究认为叶片栅栏组织与叶肉组织比值越大, 植物的光合效率越高, 生产速度和产量相应越大。Giles 等<sup>[26]</sup>指出衰老叶片光合能力的下降, 与生育后期叶绿体结构的紊乱有着内在的联系, 是造成光合作用下降的重要原因。本研究表明, 绿豆开花结荚期间随着叶片的衰老, 叶片变薄, 栅栏组织排列趋向紊乱, 叶肉细胞逐渐解体, 相比较而言, 清除活性氧代谢能力和光合性能较强的高产品种冀绿 2 号和安 9910 叶片厚度、栅栏组织厚度以及栅栏组织厚度占叶片厚度的比值均较同期低产品种泰来绿豆和赤峰绿豆大, 生育后期叶肉细胞解体较慢, 使其生育后期仍能保持相对较高的叶绿素含量和净光合速率<sup>[14]</sup>, 光合生产力较高, 最终获得了较高的产量, 说明绿豆叶片厚度、栅栏组织厚度以及叶片组织结构紧密度在一定程度上反映了叶片的光能捕获能力和光合生产效率。这与冯乃杰等<sup>[7]</sup>在大豆上的研究结果基本一致。

表 3 不同绿豆品种叶片栅栏组织厚度与叶片厚度比值的变化

Table 3 Changes in ratio of palisade tissue thickness to leaf thickness of different mung bean varieties (%)

叶位 Leaf position	品种 Variety	开花后天数 Days after anthesis							平均 Average
		10 d	18 d	26 d	34 d	41 d	48 d	55 d	
第 6 叶 6th leaf	Lü1	54.3±0.8 a	55.0±1.9 a	54.5±2.2 a	53.8±2.3 a	54.4±1.8 a	51.9±1.4 a	50.4±1.2 a	53.5
	Lü2	54.1±1.0 a	54.4±1.3 a	54.0±1.8 a	53.3±2.2 a	51.4±1.4 ab	51.3±1.3 a	50.2±0.9 a	52.7
	Lü3	49.2±1.7 b	49.4±1.7 b	49.5±1.8 b	49.6±1.2 b	49.1±1.8 bc	47.0±1.5 b	44.9±1.1 b	48.4
	Lü4	49.4±1.8 b	49.2±2.1 b	49.6±2.3 b	48.7±1.8 b	47.5±1.6 c	46.8±1.3 b	44.9±1.2 b	48.0
第 7 叶 7th leaf	Lü1	56.6±1.4 a	53.7±2.2 a	54.3±1.5 a	54.6±2.3 a	53.9±1.0 a	52.7±1.6 a	50.7±1.9 a	53.8
	Lü2	53.8±1.4 a	54.3±1.8 a	54.7±1.9 a	54.2±2.6 a	52.0±2.1 ab	50.9±1.0 ab	50.2±2.2 a	52.9
	Lü3	48.9±1.3 b	48.7±2.0 b	48.8±1.8 b	50.6±1.7 b	49.8±2.0 b	47.1±2.0 c	45.2±2.0 b	48.4
	Lü4	49.7±1.9 b	49.3±2.1 b	49.7±2.5 b	49.8±2.7 b	49.9±2.1 b	48.8±1.4 bc	46.2±2.1 b	49.0
第 8 叶 8th leaf	Lü1	56.4±1.7 a	54.1±1.8 a	54.9±2.1 a	54.9±2.3 a	54.0±2.0 a	53.7±1.9 a	51.6±1.6 a	54.2
	Lü2	53.5±1.6 a	54.4±2.1 a	54.4±2.0 a	54.1±1.3 a	52.5±1.6 ab	52.0±1.7 ab	51.0±1.8 ab	53.1
	Lü3	49.4±1.2 b	50.7±1.9 b	50.4±2.3 b	49.9±2.4 b	50.0±2.0 b	49.9±2.3 bc	48.5±1.6 bc	49.8
	Lü4	49.8±1.8 b	50.6±2.0 b	50.4±1.7 b	50.1±1.0 b	49.1±2.0 b	48.2±1.9 c	47.1±1.3 c	49.3
第 9 叶 9th leaf	Lü1		54.6±1.8 a	55.9±2.1 a	55.8±2.6 a	54.7±1.2 a	54.3±1.8 a	53.3±1.9 a	54.8
	Lü2		56.2±2.1 a	55.4±1.7 a	55.6±1.1 a	55.7±1.5 a	54.7±1.6 a	52.7±1.6 a	55.1
	Lü3		50.5±2.2 b	50.2±2.1 b	50.3±1.8 b	50.2±1.7 b	49.6±1.7 b	49.0±2.0 b	50.0
	Lü4		50.6±2.3 b	50.5±1.9 b	50.1±1.7 b	49.8±2.5 b	48.7±1.8 b	48.5±1.6 b	49.7

同一叶位栏中同列标明不同字母的值在 1%水平上差异显著。Lü1: 冀绿 2 号; Lü2: 安 9910; Lü3: 泰来绿豆; Lü4: 赤峰绿豆。

Values followed by a different letter within each column for same leaf position are significantly different at the 1% probability level. Lü1: Jilü 2; Lü2: An9910; Lü3: Tailai; Lü4: Chifeng.

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