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Biofertiliser Effects on Lettuce Morphological Traits for Fresh Consumption and Processing in Two Distinct Soil Types

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INTRODUCTION & AIM

Lettuce is a leafy vegetable consumed fresh or processed in ready-to-eat products, supporting lifestyle trends favouring quick, healthy, and convenient meals.

Morphological traits impact yield, processing efficiency, shelf life, and product quality by reducing enzymatic browning, preserving flavour and nutrients, and helping maintain quality during production and storage, and thereby minimising waste and economic losses.

Biofertilisers are gaining attention as eco-friendly, sustainable alternatives that enhance soil fertility, increase microflora diversity, stimulate plant growth, and reduce pollution in all agricultural systems.

Anthropogenic soils free of contaminants, combined with sustainable practices like biofertiliser use, offer a promising way to expand arable land area.

This study aimed to investigate the effect of biofertilisers on lettuce morphology traits important for fresh consumption and processing.

MATERIALS & METHODS

Six lettuce cultivars ('Kiribati', 'Murai', 'Aquino', 'Gaugin', 'Aleppo', 'Carmesi') were grown over three seasons (autumn, winter, spring) in a greenhouse without additional heating and lighting, using two soils: GL- Mollic Gleysol (Calcaric) and AT- Hortic Anthrosol (Terric, Transportic). Two biofertilisers, EM Aktiv and Vital Tricho, were applied alone or combined to soil and foliar via a battery sprayer; the control received no fertilisation.

GL soil (complete block design, triplicate): 2 m × 1 m plots (256 m² total), 25 cm × 25 cm density, distances between replicates and treatments were 50 cm and 100 cm. Soil treatments: 150 mL EM Aktiv, 21 g Vital Tricho, and their combination (150 mL + 21 g) in 10 L of water. Foliar: 30 mL EM Aktiv, 12 g Vital Tricho, and combination (30 mL + 12 g) in 6 L of water (four times during vegetation).

AT soil (complete block design, triplicate): 0.75 m × 1 m plots (144 m²), 25 cm × 25 cm density, distances between replicates and treatments were 50 cm and 100 cm. Soil treatments: 75 mL EM Aktiv, 10.5 g Vital Tricho, and combination (75 mL + 10.5 g) in 5 L of water. Foliar: 15 mL EM Aktiv, 6 g Vital Tricho, and combination (15 mL + 6 g) in 3 L of water (four times during vegetation).

Morphological parameters measured post-harvest: dry leaf weight (dried at 70 °C/72 h), fresh leaf weight in g; rosette diameter (cm, ruler); stem diameter (mm, caliper); core ratio = stem length/rosette height.

Standard agronomic practices (hoeing, weeding, ventilation, and irrigation) were applied. Air temperature and relative humidity were monitored over 24 h using RC-4HC Data Loggers. Photoperiod ranged from 11-9 h in autumn, 9-13 h in winter, and 14-15 h in spring during the vegetation period.

Pearson correlation analysis was used to assess linear relationships among parameters via a heatmap.

RESULTS

GL SOIL

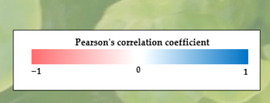
Table 1. Lettuce morphological parameters affected by cultivar, biofertiliser, and season in the GL soil

Parameters	Rosette diameter (cm)	Fresh leaf weight (g)	Stem diameter (mm)	Dry leaf weight (g)	Core ratio
Main Factors					
Cultivar					
Kiribati	31.8±0.8 **d**	199.4±10.1 **d**	16.6±0.5 **b**	10.80±0.64 **d**	0.27±0.01 **c**
Murai	30.9±0.7 **c**	146.9±7.2 **b**	17.6±0.7 **c**	9.86±0.64 **c**	0.25±0.01 **b**
Aquino	25.7±0.5 **a**	191.4±7.9 **cd**	24.5±0.8 **e**	10.31±0.55 **cd**	0.30±0.01 **d**
Gaugin	25.0±0.5 **a**	125.1±4.7 **a**	18.7±0.5 **d**	6.81±0.48 **a**	0.37±0.02 **e**
Aleppo	29.1±0.6 **b**	189.0±9.9 **c**	15.9±0.6 **b**	10.89±0.81 **d**	0.24±0.01 **b**
Carmesi	28.8±0.7 **b**	132.0±7.3 **a**	11.4±0.3 **a**	8.10±0.61 **b**	0.18±0.01 **a**
Fertiliser					
Control	27.8±0.7 **a**	162.4±8.4	17.1±0.6	9.09±0.69 **a**	0.26±0.02 **a**
EM Aktiv	28.7±0.6 **b**	161.6±7.1	17.6±0.6	9.38±0.57 **ab**	0.27±0.01 **b**
Vital Tricho	28.7±0.5 **b**	167.1±8.7	17.6±0.6	9.90±0.65 **b**	0.27±0.01 **ab**
EM Aktiv + Vital Tricho	28.9±0.6 **b**	164.8±7.3	17.4±0.6	9.48±0.58 **ab**	0.28±0.01 **b**
Growing season					
Autumn	27.2±0.6 **a**	95.9±4.8 **a**	12.4±0.4 **a**	6.59±0.49 **a**	0.15±0.01 **a**
Winter	30.6±0.7 **c**	190.6±10.6 **b**	20.3±0.7 **c**	10.69±0.73 **b**	0.27±0.01 **b**
Spring	27.8±0.6 **b**	205.4±8.2 **c**	19.6±0.6 **b**	11.10±0.64 **b**	0.39±0.02 **c**
Significance					
Cultivar (C)	***	***	***	***	***
Fertiliser (F)	***	ns	ns	**	***
Growing season (GS)	***	***	***	***	***
Interaction factors					
C × F	***	**	***	ns	**
C × GS	***	***	***	***	***
F × GS	***	***	***	***	***
C × F × GS	***	***	***	ns	***

The data show the means (n = 9) ± SE for rosette diameter, fresh leaf weight, stem diameter, core ratio, and (n = 3) ± SE for dry leaf weight. Values followed by the same letter are not significantly different at the 0.05% level of probability according to Tukey's test. Groups of the same factors with no letters are not different from each other. Asterisks indicate significant differences at * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns, non-significant.

Table 2. Initial GL soil analysis

pH (H_2O)	N (%)	P_2O5 (mg/100g)	K_2O (mg/100g)	Soil organic matter (%)
7.8	0.22	58.35	32.45	5.02



	DLW	RD	FLW	SD	CR
DLW	1				
RD	0.45**	1			
FLW	0.90**	0.37**	1		
SD	0.53**	-0.01	0.61**	1	
CR	0.41**	-0.11	0.56**	0.66**	1

Figure 1. The heat map correlation matrix shows correlations among lettuce morphological parameters in GL soil. Their correlated levels were represented with blue (strong positive relationship) to red (strong negative relationship). Each cell in the correlation matrix is represented by a Pearson's correlation coefficient (r). Asterisks indicate significant differences at * p ≤ 0.05, ** p ≤ 0.01. DLW: dry leaf weight, RD: rosette diameter, FLW: fresh leaf weight, SD : stem diameter, CR: core ratio.

Leaf fresh weight showed a very strong positive correlation with dry leaf weight, a strong correlation with stem diameter, a moderate correlation with core ratio, and a weak correlation with rosette diameter.

Green cultivars 'Kiribati' and 'Aleppo' showed the highest values of leaf fresh and dry weight, rosette diameter, with 'Gaugin' showing the highest core ratio.

Application of all biofertilisers led to significantly increased rosette diameter by 2.9-3.9%, Vital Tricho increased dry leaf weight by 8.9%, and EM Aktiv and combined fertilisers led to increased core ratio by 3.8% and 7.7%, respectively.

Autumn experiment yielded the lowest level of all morphological parameters compared to winter and spring trials.

AT SOIL

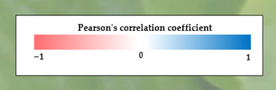
Table 3. Lettuce morphological parameters affected by cultivar, biofertiliser, and season in the AT soil

Parameters	Rosette diameter (cm)	Fresh leaf weight (g)	Stem diameter (mm)	Dry leaf weight (g)	Core ratio
Main Factors					
Cultivar					
Kiribati	30.8±0.8 **d**	185.4±10.3 **d**	15.2±0.7 **b**	11.02±0.75 **d**	0.27±0.01 **c**
Murai	30.0±1.0 **cd**	133.8±7.5 **b**	15.5±0.5 **b**	9.47±0.49 **c**	0.24±0.02 **b**
Aquino	24.9±0.5 **a**	157.7±9.1 **c**	20.1±0.8 **d**	9.17±0.85 **c**	0.29±0.01 **c**
Gaugin	24.2±0.4 **a**	118.4±5.0 **a**	17.1±0.6 **c**	6.74±0.32 **a**	0.36±0.02 **d**
Aleppo	28.8±0.7 **b**	188.6±10.5 **d**	15.6±0.6 **b**	11.19±0.84 **d**	0.23±0.01 **b**
Carmesi	29.6±0.7 **bc**	134.1±8.2 **b**	11.9±0.4 **a**	7.96±0.51 **b**	0.18±0.01 **a**
Fertiliser					
Control	28.7±0.6 **b**	166.9±8.2 **b**	17.2±0.7 **c**	9.49±0.70	0.27±0.01 **b**
EM Aktiv	28.4±0.6 **b**	152.3±7.5 **a**	16.1±0.5 **b**	9.29±0.55	0.27±0.01 **b**
Vital Tricho	27.6±0.7 **a**	147.8±8.9 **a**	15.4±0.6 **a**	9.12±0.66	0.26±0.01 **a**
EM Aktiv + Vital Tricho	27.6±0.7 **a**	145.1±9.2 **a**	15.0±0.6 **a**	9.12±0.60	0.25±0.01 **a**
Growing season					
Autumn	28.0±0.5 **b**	101.2±5.3 **a**	12.2±0.4 **a**	7.13±0.36 **a**	0.16±0.01 **a**
Winter	30.1±0.9 **c**	190.7±11.4 **c**	18.8±0.7 **c**	10.84±0.93 **c**	0.29±0.01 **b**
Spring	26.1±0.6 **a**	167.1±8.7 **b**	16.7±0.7 **b**	9.80±0.59 **b**	0.34±0.02 **c**
Significance					
Cultivar (C)	***	***	***	***	***
Fertiliser (F)	***	***	***	ns	***
Growing season (GS)	***	***	***	***	***
Interaction factors					
C × F	***	**	***	ns	***
C × GS	***	***	***	***	***
F × GS	ns	***	**	ns	**
C × F × GS	***	***	***	ns	***

The data show the means (n = 9) ± SE rosette diameter, fresh leaf weight, stem diameter, core ratio, and and (n = 3) ± SE for dry leaf weight. Values followed by the same letter are not significantly different at the 0.05% level of probability according to Tukey's test. Groups of the same factors with no letters are not different from each other. Asterisks indicate significant differences at * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns, non-significant.

Table 4. Initial AT soil analysis

pH (H_2O)	N (%)	P_2O5 (mg/100g)	K_2O (mg/100g)	Soil organic matter (%)
8.1	0.14	33.92	18.69	2.83



	DLW	RD	FLW	SD	CR
DLW	1				
RD	0.39**	1			
FLW	0.86**	0.33**	1		
SD	0.41**	-0.16*	0.56**	1	
CR	0.26**	-0.40**	0.41**	0.63**	1

Figure 2. The heat map correlation matrix shows correlations among lettuce morphological parameters in AT soil. Their correlated levels were represented with blue (strong positive relationship) to red (strong negative relationship). Each cell in the correlation matrix is represented by a Pearson's correlation coefficient (r). Asterisks indicate significant differences at * p ≤ 0.05, ** p ≤ 0.01. DLW: dry leaf weight, RD: rosette diameter, FLW: fresh leaf weight, SD : stem diameter, CR: core ratio.

Leaf fresh weight showed a very strong positive correlation with dry leaf weight, a moderate correlation with stem diameter and core ratio, and a weak correlation with rosette diameter.

Similar to GL soil, green cultivars 'Aleppo' and 'Kiribati' showed the highest morphological parameters, while 'Gaugin' had the highest core ratio.

In AT soil (unlike GL soil), all fertilisers significantly reduced leaf fresh weight (8.7-13.1%) and stem diameter (5.3-11.7%); Vital Tricho and the combination further decreased rosette diameter (3.9%, 4.1%) and core ratio (3.7%, 7.4%), respectively.

Autumn experiment yielded the lowest level of all morphological parameters compared to winter and spring trials, except in rosette diameter.

CONCLUSION

Green cultivars 'Kiribati' and 'Aleppo' excelled in leaf fresh/dry weight, while red cultivar 'Gaugin' showed the highest core ratio (<0.5, optimal for processing) in both soils across all seasons.

Biofertiliser effects were soil-dependent: generally enhancing agronomic parameters in GL soil but reducing performance in AT soil. Although fertiliser did not influence all parameters, the interaction among all factors was significant, except for dry leaf weight in both soils, indicating the need to optimise biofertiliser application according to soil type.

Seasonal variation played a decisive role, with spring and winter favouring morphological growth.

Future research should investigate long-term biofertiliser effects on morphological parameters, optimise application strategies, and explore factor interactions across soil types.

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