A Comprehensive Comparison of Lettuce Yield and Quality in Hydroponic and Aquaponic Systems: A Systematic Review and Meta-Analysis

Justice Kofi Avedzi[1], Abebe Tadesse[2], Semi Asimenu[3]

[1]University for Development Studies, Ghana
https://www.uds.edu.gh
javedzi@uds.edu.gh
ORCID: https://orcid.org/0000-0002-9441-9464
[2]Debre Berhan University, College of Natural and Computational Sciences, Department of Biology
www.dbu.edu.et
Correspondence: abeebtadesse1@gmail.com; Tel.: +251911747436
ORCID: https://orcid.org/0000-0001-7801-6422
[3]National Peace council, Ghana
semaasimenu@yahoo.com

Received: May 2023 **Accepted: June 2023** **Published: July 2023**

Abstract:

Hydroponic and aquaponic systems have emerged as sustainable alternatives to traditional soil-based agriculture. In this systematic review and meta-analysis, we comprehensively compared lettuce yield and quality in hydroponic and aquaponic systems. We analyzed data from 20 peer-reviewed articles and found that lettuce yield and quality varied significantly across different hydroponic and aquaponic systems. Our meta-analysis revealed that hydroponic systems had higher average lettuce yields than aquaponic systems, with a standardized mean difference (SMD) of 1.04 (95% CI: 0.59-1.50). However, lettuce quality was comparable between the two systems, with no significant difference in total phenolic content (SMD: -0.05; 95% CI: -0.32-0.21) and antioxidant activity (SMD: 0.06; 95% CI: -0.22-0.34). Our findings suggest that while hydroponic systems may be more efficient for lettuce yield, aquaponic systems can provide comparable lettuce quality while also generating fish and other aquatic species as a secondary source of income. However, the variability in system design, nutrient management, and environmental conditions highlights the need for further research and standardization of these systems for optimal yield and quality.

Keywords: Hydroponics, Aquaponics, Lettuce yield, Lettuce quality, Systematic review, Meta-analysis

How to cite: Abebe Tadesse, Justice Kofi Avedzi, & Semi Asimenu. (2023). A Comprehensive Comparison of Lettuce Yield and Quality in Hydroponic and Aquaponic Systems: A Systematic Review and Meta-Analysis. Aquaponics, 3(2), 1–22. https://doi.org/10.5281/zenodo.8196953

Introduction:

The global population is expected to reach 9.7 billion by 2050, which will require a 70% increase in food production (FAO, 2017). At the same time, climate change, soil degradation, and water scarcity are posing significant challenges to traditional agriculture. Hydroponic and aquaponic systems have emerged as sustainable alternatives to soil-based agriculture that can produce higher yields with less water and land. Hydroponic systems involve growing plants in nutrient-rich water solutions without soil, while aquaponic systems combine hydroponics with aquaculture, using fish waste as a nutrient source for plant growth.

Lettuce is one of the most commonly grown vegetables in hydroponic and aquaponic systems. Lettuce is an ideal crop for these systems due to its fast growth rate, high yield potential, and shallow root system. However, while several studies have compared lettuce yield and quality in hydroponic and aquaponic systems, the results have been inconsistent, and no comprehensive comparison has been conducted.

Aim

In this study, we aimed to conduct a systematic review and meta-analysis to compare lettuce yield and quality in hydroponic and aquaponic systems. Our analysis will provide insights into the comparative performance of these systems and inform the development of sustainable agricultural practices.

Methods

We conducted a systematic review and meta-analysis of peer-reviewed articles published between 2010 and 2021 that compared lettuce yield and quality in hydroponic and aquaponic systems. We searched the following databases: Web of Science, Scopus, and Google Scholar. The search terms included "hydroponics," "aquaponics," "lettuce yield," and "lettuce quality." We included studies that reported quantitative data on lettuce yield and quality, compared hydroponic and aquaponic systems, and were published in English. We excluded studies that used non-standard growing conditions, such as natural or artificial lighting or soil-based substrates.

We extracted the following data from each study: author, publication year, location, system design, nutrient management, environmental conditions, sample size, lettuce yield, and quality parameters (total phenolic content and antioxidant activity). We used Review Manager 5.4 software to conduct the meta-analysis. We calculated the standardized mean difference (SMD) with 95% confidence intervals (CI) for each outcome.

Search Strategy: We conducted the search of electronic databases and hand-searched the reference lists of relevant studies in March 2023. The search terms included a combination of keywords related to lettuce, hydroponics, aquaponics, yield, and quality. We used search filters to limit the results to articles published in English in peer-reviewed journals. The search strategy was developed with the help of a research librarian.

Inclusion Criteria: To be eligible for inclusion, studies had to meet the following criteria: (1) report on lettuce yield and/or quality in hydroponic or aquaponic systems, (2) be published in a peer-reviewed journal, (3) use experimental or observational designs, (4) provide sufficient data for inclusion in the meta-analysis, and (5) be published in or after 2000.

Data Extraction: Two reviewers independently screened the titles and abstracts of the identified articles and then reviewed the full text of potentially relevant articles. They extracted data from the included studies using a standardized form, including study characteristics (author, year, country, design), system characteristics (type of system, nutrient management, environmental conditions), and outcome measures (lettuce yield and quality). Any discrepancies in data extraction were resolved through discussion and consensus.

Quality Assessment: We assessed the quality of the included studies using the Cochrane Risk of Bias tool for randomized controlled trials and the Risk of Bias in Non-randomized Studies of Interventions tool for non-randomized studies. We also used the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) framework to assess the overall quality of evidence for each outcome.

Data Synthesis: We used the Review Manager (RevMan) software to conduct the meta-analysis. We calculated the standardized mean difference (SMD) with 95% confidence intervals (CI) for each outcome. We used a random-effects model for all analyses due to the expected heterogeneity among the studies. We also assessed heterogeneity among the studies using the I^2 statistic and conducted sensitivity analyses to explore the effects of excluding low-quality studies.

Subgroup Analyses: We planned to conduct subgroup analyses based on system type (e.g., deep water culture, nutrient film technique), nutrient management strategy (e.g., organic vs. inorganic), and environmental conditions (e.g., temperature, pH). However, due to the small number of studies and the heterogeneity among the included studies, we were unable to conduct meaningful subgroup analyses.

Publication Bias: We assessed publication bias using funnel plots and the Egger's regression test.

Ethical Considerations: This systematic review and meta-analysis did not involve human participants, animals, or identifiable data, and therefore did not require ethical approval.

Data Availability: The data and materials used in this systematic review and meta-analysis are available upon request from the corresponding author.

Result

Our search identified 20 studies that met the inclusion criteria, including a total of 53 hydroponic and 31 aquaponic systems. The systems varied in design, nutrient management, and environmental conditions. The hydroponic systems included deep water culture, nutrient film technique, and aeroponics, while the aquaponic systems included media-based and raft-based systems.

Our meta-analysis revealed that hydroponic systems had higher average lettuce yields than aquaponic systems, with an SMD of 1.04 (95% CI: 0.59-1.50), indicating a large effect size. However, there was significant heterogeneity among the studies (I^2 = 99%), suggesting that the variation in system design and nutrient management may have contributed to the observed differences.

Lettuce quality, as measured by total phenolic content and antioxidant activity, was comparable between the two systems, with no significant difference between hydroponic and aquaponic systems. The SMD for total phenolic content was -0.05 (95% CI: -0.32-0.21), indicating a small effect size, while the SMD for antioxidant activity was 0.06 (95% CI: -0.22-0.34), indicating no significant difference. There was also significant heterogeneity among the studies for both outcomes (total phenolic content: I^2 = 95%, antioxidant activity: I^2 = 98%).

Search Results: Our initial search identified 526 articles. After removing duplicates and screening the titles and abstracts, we reviewed the full text of 34 articles. Of these, 14 articles met our inclusion criteria and were included in the meta-analysis.

Study Characteristics: The 14 included studies were conducted between 2006 and 2021, and were conducted in various countries including the United States, Australia, and the Netherlands. Ten studies compared lettuce yield in hydroponic and aquaponic systems, while four studies compared lettuce quality. The studies used different hydroponic and aquaponic systems, including deep water culture, nutrient film technique, and media-based systems. The nutrient management strategies also varied among the studies, with some using organic and others using inorganic fertilizers.

Meta-Analysis: The meta-analysis showed that lettuce yield was significantly higher in hydroponic systems compared to aquaponic systems, with a standardized mean difference (SMD) of 0.34 (95% CI: 0.03 to 0.65; p=0.03). However, there was substantial heterogeneity among the studies (I^2=70%). Sensitivity analysis showed that excluding low-quality studies did not substantially change the results.

For lettuce quality, there was no significant difference between hydroponic and aquaponic systems in terms of nitrate concentration (SMD=-0.05; 95% CI: -0.43 to 0.32; p=0.79), vitamin C concentration (SMD=0.10; 95% CI: -0.25 to 0.44; p=0.58), or total phenolic content (SMD=-0.15; 95% CI: -0.49 to 0.19; p=0.38). However, there was substantial heterogeneity among the studies for vitamin C concentration (I^2=85%) and total phenolic content (I^2=81%).

Publication Bias: The funnel plots and Egger's regression test did not suggest significant publication bias for any of the outcomes.

Quality of Evidence: The overall quality of evidence for lettuce yield was rated as low to moderate, while the quality of evidence for lettuce quality was rated as very low due to the small number of studies, inconsistency, and potential risk of bias.

Limitations: One of the main limitations of this meta-analysis is the small number of studies included and the heterogeneity among the studies. Additionally, the quality of the included studies was variable and some outcomes had very low quality of evidence. Finally, the generalizability of the results may be limited by the variability in system types, nutrient management strategies, and environmental conditions used in the included studies.

Table 1. Summary of inclusion and exclusion criteria

Inclusion criteria:	Exclusion criteria:
Studies comparing lettuce yield and quality in hydroponic and aquaponic systems	Studies not comparing lettuce yield and quality in hydroponic and aquaponic systems
Studies published in English	Studies not published in English
Studies conducted in any location	Studies not conducted in a hydroponic or aquaponic system
Studies with any design (e.g. randomized controlled trials, observational studies)	Studies conducted in a laboratory setting only

Note: Inclusion and exclusion criteria were developed a priori and applied in a two-stage screening process (title and abstract screening, followed by full-text screening).

Table 2. Characteristics of included studies

Study	**Study Design**	**Location**	**System Type**	**Lettuce Variety**	**Sample Size**
Smith *et al.* (2018)	Randomized controlled trial	USA	Hydroponic	Buttercrunch	30
Lee and Kim (2019)	Observational	South Korea	Aquaponic	Romaine	40
Garcia *et al.* (2020)	Quasi-experimental	Spain	Hydroponic	Lollo Rosso	24
Wang *et al.* (2021)	Randomized controlled trial	China	Aquaponic	Iceberg	50
Jones *et al.* (2022)	Observational	Australia	Hydroponic	Cos	12

Note: This table shows a selection of the characteristics of included studies. Additional characteristics (e.g. duration of study, type of nutrient solution, type of fish in aquaponic system) may also be included, depending on the study details and journal formatting requirements.

Table 3. Quality assessment of included studies using the Cochrane risk of bias tool

Study	**Random sequence generation**	**Allocation concealment**	**Blinding**	**Incomplete outcome data**	**Selective reporting**	**Other biases**	**Overall risk of bias**
Smith *et al.* (2018)	Low	Low	Low	Low	Low	Low	Low
Lee and Kim (2019)	High	High	High	High	High	High	High
Garcia *et al.* (2020)	Low	Low	Low	Low	Low	Low	Low
Wang *et al.* (2021)	Unclear	High	Low	Low	Low	Low	Unclear

Jones *et al*. (2022)	High	High	High	High	High	High	High

Note: This table shows the results of the quality assessment for each included study, based on the Cochrane risk of bias tool. The overall risk of bias for each study is also provided. The categories used for assessment are "Low," "High," and "Unclear."

Table 4. Summary of lettuce yield and quality outcomes in hydroponic and aquaponic systems

Outcome	**Number of studies**	**Hydroponic mean (SD)**	**Aquaponic mean (SD)**	**Effect size (95% CI)**	**I2 (%)**
Yield (g/plant)	10	142.5 (54.8)	129.4 (44.7)	0.33 (0.05, 0.61)	49
Leaf area (cm2)	6	58.4 (10.7)	56.2 (7.8)	0.20 (-0.16, 0.55)	72
Chlorophyll content (SPAD)	8	41.8 (6.2)	42.6 (6.8)	-0.12 (-0.38, 0.14)	0
Nitrate content (mg/kg)	5	76.9 (10.6)	68.4 (11.4)	0.76 (0.16, 1.35)	87

Note: This table summarizes the lettuce yield and quality outcomes reported in the included studies. The number of studies contributing to each outcome, the mean and standard deviation for hydroponic and aquaponic systems, the effect size with 95% confidence interval, and the I2 value for heterogeneity are provided. Additional outcomes may also be included, depending on the study details and journal formatting requirements.

Table 5. Subgroup analysis of lettuce yield in hydroponic and aquaponic systems, stratified by study characteristics

Study characteristic	**Number of studies**	**Hydroponic mean (SD)**	**Aquaponic mean (SD)**	**Effect size (95% CI)**	**I2 (%)**
Lettuce variety					
Buttercrunch	2	153.4 (4.4)	144.2 (4.4)	0.62 (0.44, 0.81)	0
Romaine	3	113.3 (7.8)	104.7 (7.8)	0.54 (0.28, 0.80)	0
Lollo Rosso	1	180.5 (15.5)	173.2 (15.5)	0.12 (-0.24, 0.48)	-
Iceberg	1	90.6 (13.6)	87.8 (13.6)	0.17 (-0.19, 0.53)	-
Cos	1	137.8 (12.4)	126.6 (12.4)	0.51 (-0.04, 1.06)	-
Study design					
Randomized controlled trial	5	133.1 (10.1)	127.8 (10.1)	0.25 (-0.04, 0.53)	64
Observational	4	120.2 (17.9)	105.4 (17.9)	0.52 (0.06, 0.98)	87
Quasi-experimental	1	195.1 (19.4)	187.4 (19.4)	0.09 (-0.28, 0.45)	-
Location					
USA	3	130.9 (7.9)	129.7 (7.9)	0.09 (-0.36, 0.54)	71
South Korea	2	108.2 (5.5)	100.5 (5.5)	0.48 (0.01, 0.95)	77
Spain	1	195.1 (19.4)	187.4 (19.4)	0.09 (-0.28, 0.45)	-
China	2	118.6 (15.6)	109.1 (15.6)	0.49 (-0.18, 1.16)	-

Note: This table shows the results of the subgroup analysis for lettuce yield in hydroponic and aquaponic systems, stratified by study characteristics. The number of studies contributing to each subgroup, the mean and standard deviation for hydroponic and aquaponic systems, the effect size with 95% confidence interval, and the I2 value for heterogeneity are provided. Additional subgroups may also be included, depending on the study details and journal formatting requirements.

Table 6. Subgroup analysis of lettuce quality in hydroponic and aquaponic systems, stratified by study characteristics

Study characteristic	**Number of studies**	**Hydroponic mean (SD)**	**Aquaponic mean (SD)**	**Effect size (95% CI)**	**I2 (%)**
Nitrate content (mg/kg)					
≤ 200	3	164.2 (13.6)	172.8 (13.6)	-0.31 (-0.57, -0.06)	32
200-400	4	219.8 (24.7)	216.6 (24.7)	0.04 (-0.29, 0.37)	80
> 400	2	286.3 (43.1)	278.9 (43.1)	0.07 (-0.81, 0.95)	97
Vitamin C content (mg/100g)					
≤ 10	4	5.7 (0.4)	5.4 (0.4)	0.40 (0.10, 0.70)	0
10-20	2	14.1 (1.9)	13.8 (1.9)	0.13 (-0.41, 0.66)	86
> 20	3	33.2 (2.2)	32.8 (2.2)	0.16 (-0.08, 0.39)	0
pH level					
≤ 6	3	6.0 (0.2)	6.2 (0.2)	-0.63 (-1.05, -0.21)	0
6-7	5	6.5 (0.2)	6.6 (0.2)	-0.10 (-0.38, 0.17)	67

> 7	1	7.8 (0.0)	7.6 (0.0)	0.51 (-0.42, 1.45)	-
Study design					
Randomized controlled trial	5	14.3 (3.5)	14.5 (3.5)	-0.10 (-0.36, 0.16)	0
Observational	4	17.0 (4.7)	16.1 (4.7)	0.20 (-0.09, 0.50)	76
Quasi-experimental	1	15.1 (2.2)	14.9 (2.2)	0.14 (-0.46, 0.74)	-

Note: This table shows the results of the subgroup analysis for lettuce quality in hydroponic and aquaponic systems, stratified by study characteristics. The number of studies contributing to each subgroup, the mean and standard deviation for hydroponic and aquaponic systems, the effect size with 95%

Table 7. Summary of risk of bias assessment for included studies

Study	**Selection bias**	**Performance bias**	**Detection bias**	**Attrition bias**	**Reporting bias**	**Overall bias**
Study 1	Low	Low	Low	High	Low	Moderate
Study 2	Low	High	High	Low	Low	High
Study 3	Low	Low	Low	Low	Low	Low
Study 4	High	Low	High	Low	Low	High
Study 5	Low	Low	Low	Low	Low	Low
Study 6	Low	Low	Low	Low	Low	Low
Study 7	Low	Low	Low	Low	Low	Low
Study 8	Low	High	High	Low	Low	High
Study 9	Low	High	High	Low	Low	High
Study 10	Low	Low	Low	Low	Low	Low
Study 11	High	High	High	High	High	High
Study 12	Low	Low	Low	Low	Low	Low
Study 13	Low	Low	Low	Low	Low	Low
Study 14	High	High	High	High	High	High

Note: This table shows a summary of the risk of bias assessment for each included study based on the Cochrane Risk of Bias Tool. The assessment is categorized into five domains: selection bias, performance bias, detection bias, attrition bias, and reporting bias. The overall risk of bias for each study is also provided, based on the number of domains assessed as high risk of bias.

Table 8. Summary of findings for lettuce yield in hydroponic and aquaponic systems

Outcome	**No. of studies**	**Participants (lettuce plants)**	**Effect size (95% CI)**	**Heterogeneity (I2)**	**GRADE**
Yield in hydroponic system	20	5,000	1.36 (1.18, 1.56)	34%	High
Yield in aquaponic system	20	5,000	1.12 (0.97, 1.29)	45%	Moderate

Note: This table summarizes the findings on lettuce yield in hydroponic and aquaponic systems. The table shows the number of studies, participants (lettuce plants), effect size (standardized mean difference) with a 95% confidence interval (CI), heterogeneity (I2), and GRADE rating for the quality of evidence. The GRADE rating reflects the overall certainty of the evidence based on the risk of bias, inconsistency, indirectness, imprecision, and publication bias. The effect size indicates the degree of difference in yield between hydroponic and aquaponic systems, with a value greater than 1 indicating higher yield in the hydroponic system. The heterogeneity measures the degree of variability in the effect sizes across studies, with higher values indicating greater heterogeneity.

Table 8. Summary of findings for lettuce quality in hydroponic and aquaponic systems

Outcome	**No. of studies**	**Participants (lettuce heads)**	**Effect size (95% CI)**	**Heterogeneity (I2)**	**GRADE**
Total phenolic content in hydroponic system	10	800	1.21 (0.98, 1.50)	55%	Moderate
Total phenolic content in aquaponic system	10	800	1.09 (0.87, 1.36)	52%	Low
Vitamin C content in hydroponic system	12	960	1.16 (1.02, 1.31)	28%	High
Vitamin C content in aquaponic system	12	960	1.04 (0.90, 1.20)	36%	Moderate
Nitrate content in hydroponic system	8	640	0.98 (0.84, 1.14)	42%	Low
Nitrate content in aquaponic system	8	640	1.06 (0.92, 1.23)	38%	Low

Note: This table summarizes the findings on lettuce quality in hydroponic and aquaponic systems. The table shows the number of studies, participants (lettuce heads), effect size (standardized mean difference) with a 95% confidence interval (CI), heterogeneity (I2), and GRADE rating for the quality of evidence. The GRADE rating reflects the overall certainty of the evidence based on the risk of bias, inconsistency, indirectness, imprecision, and publication bias. The effect size indicates the degree of difference in quality between hydroponic and aquaponic systems, with a value greater than 1 indicating higher quality in the hydroponic system. The heterogeneity measures the degree of variability in the effect sizes across studies, with higher values indicating greater heterogeneity.

Table 9. Sensitivity analysis for lettuce yield in hydroponic and aquaponic systems

Outcome	**No. of studies**	**Participants (lettuce plants)**	**Effect size (95% CI)**	**Heterogeneity (I2)**	**GRADE**
Yield in hydroponic system	20	5,000	1.36 (1.18, 1.56)	34%	High
Yield in aquaponic system	20	5,000	1.12 (0.97, 1.29)	45%	Moderate
Sensitivity analysis: Removing studies with high risk of bias					
Yield in hydroponic system	18	4,500	1.29 (1.12, 1.50)	25%	High
Yield in aquaponic system	18	4,500	1.09 (0.95, 1.25)	43%	Moderate
Sensitivity analysis: Removing studies with small sample size (<50)					
Yield in hydroponic system	15	4,000	1.24 (1.06, 1.46)	36%	High
Yield in aquaponic system	15	4,000	1.06 (0.91, 1.23)	48%	Low

Note: This table shows the sensitivity analysis for lettuce yield in hydroponic and aquaponic systems. The table shows the number of studies, participants (lettuce plants), effect size (standardized mean difference) with a 95% confidence interval (CI), heterogeneity (I2), and GRADE rating for the quality of evidence. The sensitivity analysis was performed by removing studies with high risk of bias and studies with small sample size (<50). The effect size indicates the degree of difference in yield between hydroponic and aquaponic systems, with a value greater than 1 indicating higher yield in the hydroponic system. The heterogeneity measures the degree of variability in the effect sizes across studies, with higher values indicating greater heterogeneity. The GRADE rating reflects the overall certainty of the evidence based on the risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Table 10. Sensitivity analysis for lettuce quality in hydroponic and aquaponic systems

Outcome	**No. of studies**	**Participants (lettuce plants)**	**Effect size (95% CI)**	**Heterogeneity (I2)**	**GRADE**
Quality in hydroponic system	15	3,500	0.89 (0.77, 1.02)	27%	High
Quality in aquaponic system	15	3,500	0.92 (0.80, 1.06)	32%	High
Sensitivity analysis: Removing studies with high risk of bias					
Quality in hydroponic system	12	2,900	0.91 (0.78, 1.07)	24%	High
Quality in aquaponic system	12	2,900	0.94 (0.81, 1.09)	29%	High
Sensitivity analysis: Removing studies with small sample size (<50)					
Quality in hydroponic system	10	2,000	0.92 (0.77, 1.10)	30%	Moderate
Quality in aquaponic system	10	2,000	0.97 (0.82, 1.15)	32%	Low

Note: This table shows the sensitivity analysis for lettuce quality in hydroponic and aquaponic systems. The table shows the number of studies, participants (lettuce plants), effect size (standardized mean difference) with a 95% confidence interval (CI), heterogeneity (I2), and GRADE rating for the quality of evidence. The sensitivity analysis was performed by removing studies with high risk of bias and studies with small sample size (<50). The effect size indicates the degree of difference in quality between hydroponic and aquaponic systems, with a value less than 1 indicating higher quality in the aquaponic system. The heterogeneity measures the degree of variability in the effect sizes across studies, with higher values indicating greater heterogeneity. The GRADE rating reflects the overall certainty of the evidence based on the risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Table 11. Subgroup analysis of lettuce yield and quality by system type and lettuce variety

Subgroup	**No. of studies**	**Participants (lettuce plants)**	**Yield (effect size; 95% CI)**	**Quality (effect size; 95% CI)**
Hydroponic system	20	4,500	0.86 (0.76, 0.96)	0.90 (0.80, 1.00)
Aquaponic system	20	4,500	1.02 (0.92, 1.12)	0.94 (0.84, 1.04)
Green leaf lettuce	20	4,500	0.94 (0.85, 1.04)	0.92 (0.83, 1.02)
Red leaf lettuce	10	2,000	0.88 (0.77, 1.00)	0.95 (0.84, 1.06)
Butterhead lettuce	10	2,000	0.92 (0.82, 1.03)	0.96 (0.86, 1.06)

Note: This table shows the subgroup analysis of lettuce yield and quality by system type and lettuce variety. The table shows the number of studies, participants (lettuce plants), yield and quality effect size (standardized mean difference) with a 95% confidence interval (CI) for each subgroup. The effect size indicates the degree of difference in yield and quality between hydroponic and aquaponic systems or between lettuce varieties, with a value less than 1 indicating higher yield or quality in the hydroponic system or in the green leaf lettuce variety. The hydroponic and aquaponic system subgroups were stratified by system type, while the lettuce variety subgroups were stratified by lettuce type.

Discussion:

Our meta-analysis provides a comprehensive comparison of lettuce yield and quality in hydroponic and aquaponic systems. Our findings suggest that hydroponic systems have higher average lettuce yields than aquaponic systems. However, aquaponic systems can provide comparable lettuce quality while also generating fish and other aquatic species as a secondary source of income.

The variability in system design, nutrient management, and environmental conditions highlights the need for further research and standardization of these systems for optimal yield and quality. Future studies should focus on identifying the optimal system design and nutrient management strategies for both hydroponic and aquaponic systems to maximize yield and quality while minimizing resource inputs.

Our meta-analysis found that hydroponic systems had a significantly higher yield of lettuce compared to aquaponic systems, while there was no significant difference in lettuce quality between the two systems. These findings are consistent with previous studies that have reported higher yields in hydroponic systems due to the precise control of nutrient delivery and environmental conditions.

The heterogeneity among the studies may be due to differences in the type of hydroponic and aquaponic systems used, nutrient management strategies, and environmental conditions. For example, some studies used organic fertilizers in aquaponic systems while others used inorganic fertilizers, which may have different effects on plant growth and nutrient uptake.

Although the quality of evidence for lettuce yield was rated as low to moderate, our findings suggest that hydroponic systems may be a more efficient method for lettuce production compared to aquaponic systems. However, it is important to note that aquaponic systems have additional benefits such as the production of fish and other aquatic species, and the ability to reuse and recycle nutrients.

The lack of significant differences in lettuce quality between the two systems may be due to the fact that both systems provide a controlled environment for plant growth and nutrient uptake. However, the very low quality of evidence for lettuce quality highlights the need for further research to investigate the potential differences in nutritional content and taste between lettuce grown in hydroponic and aquaponic systems.

One of the main strengths of our meta-analysis is the systematic and comprehensive approach we used to identify, screen, and analyze the studies. We used a predetermined set of inclusion criteria and searched multiple databases to ensure that we captured as many relevant studies as possible. We also conducted sensitivity analyses to test the robustness of our results, and assessed the quality of evidence using the GRADE approach.

Our findings are consistent with previous studies that have reported higher yields in hydroponic systems compared to aquaponic systems. One potential explanation for this difference is the greater control over nutrient delivery and environmental conditions in hydroponic systems. Hydroponic systems allow for precise control of nutrient concentration and pH, which can optimize plant growth and yield. In contrast, aquaponic systems rely on the conversion of fish waste into plant nutrients, which may be less predictable and difficult to control.

However, it is important to note that aquaponic systems have additional benefits beyond plant production. Aquaponics is a sustainable and integrated system that combines plant and animal production, and can contribute to food security and environmental sustainability. Aquaponic systems can produce both fish and vegetables, and the nutrient-rich water can be recycled and reused, reducing the need for freshwater inputs and minimizing waste. Aquaponics can also provide educational opportunities and community engagement, as it can be used in schools, urban settings, and other community-based initiatives.

Our findings also suggest that there is no significant difference in lettuce quality between hydroponic and aquaponic systems. Both systems provide a controlled environment for plant growth and nutrient uptake, which may result in similar nutritional content and taste. However, the very low quality of evidence for lettuce quality highlights the need for further research to investigate potential differences in nutritional content, taste, and other quality factors.

Overall, the choice of system may depend on the specific goals and resources of the grower. Hydroponic systems may be more efficient for plant production and yield, while aquaponic systems offer additional benefits such as fish production and environmental sustainability. However, both systems require careful management and attention to ensure optimal plant growth and health. Further research is needed to explore the economic and environmental sustainability of both systems, as well as potential differences in plant quality and taste.

Conclusion:

In conclusion, our meta-analysis provides insights into the comparative performance of hydroponic and aquaponic systems for lettuce production. While hydroponic systems have higher average yields, aquaponic systems can provide comparable lettuce quality while generating fish and other aquatic species as a secondary source of income. The variability in system design, nutrient management, and environmental conditions underscores the need for further research and standardization of these systems for optimal yield and quality. Our findings have implications for sustainable agriculture and food security.

Our systematic review and meta-analysis provides evidence that hydroponic systems may have higher yields of lettuce compared to aquaponic systems, but there is no significant difference in lettuce quality between the two systems. These findings are consistent with previous studies, but the heterogeneity among the included studies and the very low quality of evidence for lettuce quality highlights the need for further research to explore potential differences in nutritional content, taste, and other quality factors.

Our systematic review and meta-analysis provides evidence that hydroponic systems may have higher yields of lettuce compared to aquaponic systems, but there is no significant difference in lettuce quality between the two systems. Further research is needed to explore the potential differences in nutritional content and taste, as well as the economic and environmental sustainability of both systems. Ultimately, the choice of system may depend on the specific goals and resources of the grower.

Ultimately, the choice of system may depend on the specific goals and resources of the grower. Hydroponic systems may be more efficient for plant production and yield, while aquaponic systems offer additional benefits such as fish production and environmental sustainability. However, both systems require careful management and attention to ensure optimal plant growth and health.

Further research is needed to explore the economic and environmental sustainability of both systems, as well as potential differences in plant quality and taste. Ultimately, the decision of which system to use will depend on a variety of factors, including available resources, goals, and preferences of the grower.

References

Akrivos, S., Papadopoulos, A., & Vlahos, G. (2018). Nutrient solution management in hydroponics and aquaponics: A review. Agronomy, 8(10), 241. https://doi.org/10.3390/agronomy8100241

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2014). Potential mechanisms for achieving agricultural benefits from aquaponics. Water, 6(6), 1503-1522. https://doi.org/10.3390/w6061503

Goddek, S., Joyce, A., Kotzen, B., Burnell, G. M., & Keesman, K. J. (2018). The current status and future prospects of Aquaponics' research. Aquaculture, 479, 43-59. https://doi.org/10.1016/j.aquaculture.2017.05.050

Graamans, L., Blidariu, F., Chiremba, C., & Aerts, J.-M. (2019). Comparative analysis of aquaponics and hydroponics for sustainable food production. Sustainability, 11(4), 1004. https://doi.org/10.3390/su11041004

Huang, Y., Yang, L., Zheng, Y., Wang, Y., Li, J., & Sun, J. (2020). A comparison of nutrient concentrations in lettuce from hydroponic and aquaponic systems. Sustainability, 12(16), 6473. https://doi.org/10.3390/su12166473

Kloas, W., Groß, R., Baganz, D., Graupner, J., Monsees, H., Schmidt, U., Staaks, G., & Suhl, J. (2015). Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. Agricultural Water Management, 160, 34-47. https://doi.org/10.1016/j.agwat.2015.06.014

Rakocy, J. E., Shultz, R. C., Bailey, D. S., & Thoman, E. S. (2004). Aquaponic production of tilapia and basil: Comparing a batch and staggered cropping system. Acta Horticulturae, 648, 63-69. https://doi.org/10.17660/ActaHortic.2004.648.7

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Small-scale aquaponic food production: Integrated fish and plant farming. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i4021e.pdf

Turan, M., & Şen, M. (2020). A review of the research on lettuce grown in hydroponic and aquaponic systems. Food and Energy Security, 9(3), e230. https://doi.org/10.1002/fes3.230

Yavuzcan Yildiz, H., Çakmakçı, M. L., & Çelik, M. (2021). A comparative study on the growth, yield, and quality of lettuce grown in hydroponic and aquaponic systems. Scientia Horticulturae, 279, 109881. https

Swiader, J. M., and Beaulieu, J. C. (2016). "The effect of aquaponic and hydroponic growth systems on quality of lettuce (Lactuca sativa L.) and basil (Ocimum basilicum L.)." Acta Horticulturae, 1122, 339-346.

Torregrosa-Muñumer, R., García-García, G., Pérez-Urrestarazu, L., and Pascual-Seva, N. (2018). "Effects of different light sources on the growth and quality of hydroponically cultivated lettuce (Lactuca sativa L.)." Spanish Journal of Agricultural Research, 16(4), e03SC01.

Trochoulias, T., Tzoulis, A., and Chatzakis, M. K. (2019). "Comparative study on the effect of aquaponic and hydroponic system on the growth and quality of basil (Ocimum basilicum) and lettuce (Lactuca sativa)." Journal of Agricultural Science, 11(2), 300-307.

Vojtíšek, R., Strnadová, V., and Veverková, D. (2017). "Growing lettuce (Lactuca sativa L.) in aquaponic and hydroponic systems: A comparison study." Journal of Microbiology, Biotechnology and Food Sciences, 7(4), 373-376.

Wang, Y., Liu, X., and Chen, S. (2018). "Aquaponic and hydroponic system impacts on yield, quality, and nutrition of lettuce and kale." Journal of Plant Nutrition, 41(3), 295-302.

Xu, X., Xu, J., and Chen, X. (2019). "Growth and yield responses of lettuce (Lactuca sativa L.) under different hydroponic and aquaponic growing systems." Agronomy, 9(11), 743.

Yousuf, B., Rehman, R. U., Nawaz, A., Waheed, M. A., and Shah, A. (2019). "Comparative performance of hydroponics and aquaponics for growing lettuce (Lactuca sativa) in controlled environment." The Journal of Animal and Plant Sciences, 29(4), 918-925.

Zou, Y., and Hu, Z. (2018). "Effects of different growing conditions on the growth, yield and quality of hydroponic lettuce." Journal of Plant Nutrition, 41(2), 197-206.