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Plant-mediated Therapy Program Reduced Aggression and Improved Psychological Well-being in Elementary School Students

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Abstract. **As modern society increasingly emphasizes individualism, concerns have grown that children who are disconnected from nature may experience declines in social skills, patience, empathy, and environmental awareness. This study examined the effects of a plant-mediated healing agricultural program (HAP) based on acceptance and commitment therapy on elementary school students. Psychological assessments measured internal developmental assets using the Self-concept Scale, Rosenberg Self-Esteem Scale, Self-efficacy Scale, Respect for Life Scale, and Inclusion of Self in Nature Scale. Aggression reduction was assessed using the Aggression Scale, while psychological flexibility and acceptance of behavior were evaluated with the Acceptance and Commitment Questionnaire II. Additionally, untargeted metabolite profiling of saliva samples was conducted using ultra-high-performance liquid chromatography–Orbitrap–tandem mass spectrometry to analyze biochemical changes before and after the program. Participants showed significant improvements in internal developmental assets, including self-concept (P < 0.05), self-esteem (P < 0.01), self-efficacy (P < 0.001), respect for life (P < 0.01), and connection to nature (P < 0.001). Aggression decreased significantly (P < 0.001), with reductions in physical aggression (P < 0.01), indirect aggression (P < 0.001), negativity (P < 0.01), and verbal aggression (P < 0.001). Psychological flexibility and acceptance of behavior also increased significantly (P < 0.001). Metabolite analysis identified 30 differential metabolites, including amino acids, dipeptides, carboxylic acids, and fatty acids. Pathway analysis revealed significant effects on the tricarboxylic acid cycle; alanine, aspartate, and glutamate metabolism; and arginine biosynthesis. Among these, succinic acid showed a significant increase (P < 0.01) after the program, emerging as a potential biomarker. These findings suggest that plant-mediated HAP induces metabolic changes, enhances psychological well-being, reduces aggression, and fosters emotional regulation and moral development in children. This nature-based intervention provides a promising alternative to traditional cognitive–behavioral approaches.**

Childhood is a period of rapid growth in which early experiences significantly influence lifelong outcomes. During this stage, physical, cognitive, emotional, and social development occur through interaction with others (Hwang et al. 2008). Learning during childhood often involves the simultaneous stimulation of multiple senses, and horticultural activities (such as those involving plants) stimulate all five senses, helping children better understand life and nature, fostering social interaction, and providing insights into relationships with others (Delman et al. 2014).

Children's cognitive development is particularly promoted through direct contact with nature, which necessitates activities that offer direct (vs. indirect) experiences. Such activities help children understand life, nature, and environmental conservation (Noh 2021). Additionally, mental health is closely linked not only to the absence of psychopathological symptoms but also to social, emotional, and psychological well-being (Keyes 2014). Students with higher emotional stability show better outcomes in terms of school adaptation and overall quality of life compared with those with lower emotional stability (Xiong et al. 2017). Students with higher internal developmental assets are also more likely to experience success in academics, school belonging, social relationships, and overall psychological adjustment (Arslan 2018; Moffa et al. 2016). Research on South Korean elementary school students has found that those with higher internal developmental assets are positively associated with psychological strengths and life satisfaction (Kim et al. 2017).

However, in modern, urbanized societies, the shrinking of communities has led to the emergence of "nano-society," which emphasizes individualism (Cho and Lee 2022). Additionally, rapid technological advancements have heightened the demand for quick information retrieval and created increased expectations for immediate outcomes. This shift has contributed to a lifestyle in which interactions with nature are minimal, resulting in a growing disconnect from the natural world. Consequently, children growing up in such environments often lack social skills, empathy, patience, and awareness of the importance of life and nature due to their disconnect from nature. Childhood aggression in contemporary society has been associated with serious issues, such as behavioral problems, academic failure, and even criminal tendencies. The recent increase in childhood aggression has therefore drawn significant attention (Zulauf et al. 2018). The disconnection from nature, coupled with diminished empathy and awareness of life's interconnectedness, may contribute to emotional dysregulation and aggressive tendencies. Such aggression can negatively affect the social acceptance and overall development of children, further highlighting the importance of emotional regulation (Evans et al. 2019; Huitsing and Monks 2018).

Academic stress in children can increase aggression and contribute to emotional instability (Kim and Jeon 2016), which can be exacerbated by various environmental factors (Chung et al. 2008). Emotionally unstable children are more likely to exhibit problematic behaviors and may become isolated or exhibit aggressive behaviors within peer groups (Lee and Kim 2011). Negative experiences at school or at home can further intensify this emotional instability (Kim and Park 2008; Yang 2008).

To address situations in which children are vulnerable to social issues such as bullying, depression, suicide, and school violence, cultivating emotional resilience (especially emotional intelligence) is critical (Nguyen et al. 2023). Bullying can significantly increase the risk of depression and suicide, and aggressive behavior involving power imbalances can have long-lasting negative impacts on mental health. Therefore, reducing childhood aggression is vital (Espelage and Hong 2017).

Exposure to natural environments during childhood is beneficial for enhancing mental well-being (Adams and Savahl 2017; McCormick 2017), and horticultural activities are a key element of nature-based education. These activities promote children's appreciation of nature, foster positive emotional experiences, reduce stress, and improve immune function (Han and Yoo 2014; Ng et al. 2018). Moreover, horticultural therapy can reduce aggression and hyperactivity in children and adolescents, foster positive thinking, enhance interpersonal ties, improve adaptation to school life, reduce stress, and improve overall mental health (Lee and Byun 2015; Lee et al. 2013). Accordingly, horticultural therapy is increasingly recognized as an effective intervention for cultivating emotional stability and reducing aggression in children.

However, research on plant-mediated healing agricultural programs (HAPs) aimed at promoting emotional stability and reducing aggression in children is lacking. Thus, we aimed to investigate the effects of a plant-mediated HAP for improving children's internal developmental assets and reducing aggression.

Materials and Methods

Participants. To recruit children to participate in our study, we sent program announcements containing information about the study's purpose, content, duration, and requirements to children's centers in Seoul, South Korea. Ultimately, H Center and S Center participated in the study, with 15 students in grades 4 to 6 participating from each center (a total of 30 participants; 15 male and 15 female). The participants could respond to self-report questionnaires. Students wishing to take part were asked to apply and a parental consent form. Written informed consent was obtained from the legal guardians of all participants, and verbal assent was obtained from the children before participation. Before the first session of the program, the instructor visited each center to introduce the program and explain the study's purpose and procedures. Additional consent forms and demographic information were collected, and a pre-survey and saliva test were conducted.

This study was approved by the Institutional Review Board (IRB) of Konkuk University (Approval 7001355-202310-HR-709), and all procedures involving human participants were conducted in accordance with the ethical standards of the IRB and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Plant-mediated HAP. This program was conducted once a week for 8 weeks from Apr to Jun 2024, with each session lasting 90 min. While learning about and tending to plants, children participated in various indoor horticultural activities designed to promote emotional stability and psychological healing through direct interaction with nature.

To systematically design the intervention, the program was developed following a structured approach informed by intervention mapping principles ensuring that theoretical foundations and empirical evidence guided each stage (Bartholomew et al. 1998). The development process began with a needs assessment, which involved reviewing existing research on childhood mental health and horticultural interventions (Fernandez et al. 2019; Kok et al. 2004). This assessment identified key psychological challenges among children, including emotional instability, low self-esteem, and aggression, highlighting the need for an intervention that fosters emotional resilience and behavioral regulation (Rademacher et al. 2025). Expert consultations further refined the focus of the program, ensuring that its objectives aligned with the psychological and social needs of the participants.

Based on this initial assessment, behavioral and environmental objectives were defined to structure the program's core activities (Lee et al. 2007). The primary goal was to enhance emotional regulation, self-awareness, and social engagement through structured interactions with plants. Consideration was also given to environmental factors, such as creating a supportive group setting and providing sensory-rich horticultural experiences that maximize psychological benefits.

To strengthen the program's theoretical foundation, acceptance and commitment therapy (ACT) principles were integrated into the intervention design. ACT focuses on six core processes: acceptance, cognitive defusion, being present, self-as-context, values, and committed action (Hayes et al. 2006; Romano et al. 2024); these processes help individuals acknowledge and accept their emotions rather than suppress or control them (Lee et al. 2024). By incorporating ACT, the program aimed to cultivate psychological flexibility, allowing children to develop healthier emotional responses and coping strategies in a natural, interactive setting.

The development of the intervention involved carefully selecting horticultural activities that aligned with both the program's objectives and ACT principles. Activities such as planting seeds, transplanting seedlings, watering, plant care, and sensory engagement with herbs were chosen based on their therapeutic potential, as indicated by previous research (Kim et al. 2025; Son and Park 2025). Each session combined hands-on horticultural tasks with guided self-reflection exercises to encourage mindfulness and emotional processing. The program was designed to progress in complexity, allowing participants to gradually develop skills in both plant care and emotional regulation.

For implementation, the program was conducted in small group settings, fostering both individual engagement and social interaction. Each session integrated structured horticultural activities with ACT-based discussions, prompting participants to explore their emotions, values, and personal growth through nature-based experiences (Skår and Krogh 2009). To support self-reflection, participants maintained individual activity logs, documenting their thoughts, emotional responses, and personal insights throughout the program (Brymer et al. 2010). The research team closely monitored participants' behavioral and psychological changes, ensuring that the intervention effectively promoted well-being.

Following implementation, the program's effectiveness was evaluated through pre- and postintervention psychological assessments, measuring changes in self-concept, self-esteem, aggression, and emotional regulation (Crocker et al. 2006). Participant feedback was also collected to refine the program's structure and enhance its applicability for future iterations (Cox et al. 2011).

By integrating a structured intervention framework with ACT-based therapeutic strategies, this program provided a nature-based approach to enhancing children's psychological

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resilience. It offered an alternative to traditional cognitive–behavioral interventions by emphasizing emotional acceptance rather than cognitive restructuring (Hayes and King 2024). This systematic approach was designed to foster psychological flexibility, improve emotional regulation, and promote overall mental well-being among participants (Table 1).

Assessments. The Self-Concept Scale was developed by Jeong (1996). This scale consists of four subcategories—academic self-concept, social self-concept, physical self-concept, and emotional self-concept—with a total of 21 items. Each item is rated on a 4-point scale, where 1 = absolutely not, 2 = rarely, 3 = often, and 4 = always. The reliability coefficient of this scale is 0.885, indicating high reliability.

We measured self-esteem using the Rosenberg Self-Esteem Scale (Rosenberg 1965), comprising two subcategories (positive self-esteem and negative self-esteem) with a total of 10 items. Each item is rated on a 4-point scale, where 1 = not at all true, 2 = not true, 3 = true, and 4 = very true. The reliability coefficient is 0.72.

We evaluated self-efficacy using a scale developed by Han (2001). This scale consists of three subcategories (confidence, self-regulatory efficacy, and task difficulty), with a total of 24 items. Each item is rated on a 5-point scale, where 1 = not at all true, 2 = rarely true, 3 = moderately true, 4 = generally true, and 5 = very true. The reliability coefficient is 0.87, indicating high reliability.

The Respect for Life evaluation was developed by Lee et al. (2004) and consists of 24 items, each rated on a 5-point scale, where 1 = not at all true, 2 = not true, 3 = moderately true, 4 = true, and 5 = very true. The reliability coefficient is 0.85.

We used the Inclusion of Self in Nature Scale, developed by Schultz et al. (2004), to evaluate the sense of connection to nature. This scale measures the degree to which individuals feel "included in nature." Seven different overlapping images that integrate nature and the self are presented; participants select the image that best represents their relationship with nature. This method improves the reliability of the self-reported scale.

We measured aggression using the Aggression Scale developed by Buss and Perry (1992), which consists of five subcategories—physical aggression, indirect aggression, excitability, negativity, and verbal aggression—with a total of 48 items. Each item is rated on a 3-point scale, where 1 = not at all true, 2 = sometimes true, and 3 = often true. The reliability coefficient is 0.74.

We evaluated acceptance of behavior using the Acceptance and Commitment Questionnaire II, developed by Hayes et al. (2004) and adapted by Moon (2005). This scale consists of 10 items, each rated on a 7-point scale, where 1 = not at all true, 2 = not true, 3 = somewhat not true, 4 = neutral, 5 = somewhat true, 6 = true, and 7 = very true. The reliability coefficient is 0.8.

Sample preparation and metabolite extraction. We collected saliva samples (3 mL) in a 50-mL Falcon tube, as described by Choi et al. (2014), with slight modifications. After collection, we placed the samples on ice packs and transported them to the analysis site. We centrifuged the samples at 10,000 rpm (~11.18 g) at 4 °C for 10 min and stored the supernatants at −70 °C. We mixed a 500-μL aliquot of saliva with 1 mL of acetonitrile containing the internal standard (2-chlorophenylalanine, 10 mg/L) and vortexed the mixture for 10 s, following which the mixture was centrifuged at 13,000 rpm at 4 °C for 10 min. We filtered the supernatant through a 0.2-μm polytetrafluoroethylene (PTFE) filter and concentrated it using a speed vacuum. We dissolved the concentrated samples in 10% methanol to achieve a final concentration of 5,000 mg/L. The samples were then filtered through a 0.2-μm PTFE filter for ultra-high-performance liquid chromatography–Orbitrap–tandem mass spectrometry (UHPLC-Orbitrap-MS/MS analysis).

Metabolomic analysis using UHPLC-Orbitrap-MS/MS. We performed the UHPLC-Orbitrap-MS/MS analysis under conditions identical to those described by Jun et al. (2024).

Data analysis. We analyzed the demographic information and results on satisfaction from the survey using descriptive statistics in Excel (Microsoft Office 2018; Microsoft Corp., Redmond, WA, USA). To compare the results of the self-reported survey administered before and after the healing agricultural activities, we performed a paired *t* test. We used Pearson's product–moment correlation coefficient to analyze the correlations between the variables. Significance for all analyses was set at $P < 0.05$. We used IBM SPSS Statistics 26.0 (IBM Inc., New York, NY, USA) for the statistical analysis. Given the exploratory nature of the study and the number of psychological variables tested, we did not apply formal corrections for multiple comparisons. Therefore, the possibility of type I error inflation should be considered when interpreting the results.

We converted the UHPLC-Orbitrap-MS/MS raw data files into the mzXML format using ProteoWizard (version 3.0). We uploaded the mzXML files to XCMS online software (version 3.7.1) to perform retention time correction, peak detection, and alignment. We selected ion features from UHPLC-Orbitrap-MS/MS data sets, with a relative standard deviation of <20% in the quality control samples, for further multivariate analyses. We exported alignment data to Microsoft Excel. We performed multivariate statistical analyses using SIMCA-P+ software (version 12.0) with the Pareto scaling method. We performed orthogonal partial least squares–discriminant analysis (OPLS-DA) to compare differential metabolites between the pre- and postintervention groups. We selected differential metabolites based on their variable importance in the projection (VIP) value of the

Table 1. Overview of the plant-mediated healing agricultural program (HAP).

Session	Activity name (theme)	Activity	HAP
1	Preparing for new life (sowing seeds)	Observing seeds, preparing seed trays, sowing seeds	Recognize the growth process and the vitality of plants, understanding that their present state is just one stage in their entire life cycle, which symbolizes growth, change, and resilience
2	Plant kindergarten (transplanting seedlings)	Observing seedlings, preparing to plant, transplanting seedlings	Acknowledge emotions and recognize personal growth potential through the growth process of seedlings
3	Strengthening myself through stress (environmental stress)	Learning about environmental stress, choosing herbal scents	Convert environmental stress into nourishment; recognize and accept differences with others through various herbal scents
4	What is digital agriculture? (learning about devices for digital agriculture)	Learning the basics of digital agriculture, coding, Arduino; creating devices for healing and digital agriculture	Adjust the environment through smart agriculture; learn emotional understanding and coping methods
5	Today, I am the gardener (management)	Managing and transplanting plants, managing emotions	Eliminate unnecessary thoughts through plant management and transplantation; learn coping strategies using the five senses
6	Pocket-sized! (making potpourri)	Choosing herbal scents, making potpourri	Engage in mindfulness and stabilize the senses through activities that stimulate all five senses.
7	A gift for everyone (making herbal pots)	Making herbal pots, gifting	Cope with negative emotions and improve relationships; cultivate an attitude of considering and respecting individual values
8	What's my next plan? (setting an action plan)	Observation, harvesting, setting an action plan, group discussion	Set goals and plan for future coping strategies; identify problem-solving strategies through group and individual presentations

Table 2. General characteristics of the participants.

	Mean ± *SD*		
Variance	Male (n = 15)	Female (n = 15)	Total (N = 30)
Age	10.33 ± 0.61	10.4 ± 0.63	10.36 ± 0.61
Height (cm)[i]	138.42 ± 7.09	138.91 ± 10.36	138.67 ± 8.73
Weight (kg)[ii]	38.31 ± 8.78	37.12 ± 9.83	37.71 ± 9.18
Body mass index (kg/m^2)[iii]	19.84 ± 3.38	19.03 ± 3.86	19.44 ± 3.59[iv]

[i] Height was measured using an anthropometer without shoes (Ok7979; Samhwa, Seoul, South Korea).

[ii] Weight was measured using a body fat analyzer (ioi 353; Jawon Medical, Seoul, South Korea).

[iii] Body mass index was calculated using the formula [weight (kg)]/[height (cm)].

[iv] Falls within the normal range proposed by the World Health Organization.

SD = standard deviation.

OPLS-DA model. We conducted pathway analysis to identify altered metabolic pathways between the pre- and postintervention groups. We selected potential biomarkers of the plant-mediated HAP by performing a receiver operating characteristic (ROC) curve analysis and used the area under the ROC curve (AUC) to identify and confirm the significantly altered metabolites. We performed ROC curve and pathway analysis using MetaboAnalyst (version 6.0). The data sets were subjected to log transformation and autoscaling.

Results

Demographic information. This study involved 30 students in grades 4 to 6. Their characteristics are presented in Table 2.

Psychological responses. The comparison of results before and after the plant-mediated HAP showed a significant increase in self-concept ($P < 0.05$), with significant increases in the subcategories of academic self-concept and social self-concept ($P < 0.05$). Self-esteem also increased significantly ($P < 0.01$), with positive self-esteem significantly increasing ($P < 0.01$) and negative self-esteem significantly decreasing ($P < 0.01$). Self-efficacy displayed a significant increase in the comparison between the pre- and postprograms ($P < 0.001$), with significant increases in the subcategories of confidence and self-regulation ($P < 0.001$; $P < 0.05$). Respect for life and connection to nature also significantly increased ($P < 0.01$; $P < 0.001$). Aggression significantly decreased ($P < 0.001$), with significant decreases in the subcategories of physical aggression ($P < 0.01$), indirect aggression ($P < 0.001$), negativity ($P < 0.01$), and verbal aggression ($P < 0.001$). Finally, acceptance of behavior increased significantly ($P < 0.001$; Table 3).

Self-concept showed a positive correlation with self-esteem (0.342) and respect for life (0.269), and a negative correlation with aggression (−0.372; $P < 0.05$). Self-esteem had a positive correlation with self-efficacy (0.162) and acceptance of behavior (0.241), and a negative correlation with aggression (−0.235; $P > 0.05$). Self-efficacy was positively correlated with respect for life (0.330) and showed a strong negative correlation with aggression (−0.586; $P < 0.01$). Respect for life had a positive correlation with acceptance of behavior (0.264) and a negative correlation with aggression (−0.398; $P < 0.05$). Finally, acceptance of behavior showed a strong positive correlation with self-efficacy (0.550; $P < 0.01$) and a strong negative correlation with aggression (−0.488; $P < 0.01$; Fig. 1).

Table 3. Pre- and post-test comparisons of psychological variables in the plant-mediated healing agricultural program.

	Mean ± *SD*			
Variance	Pretest	Post-test	t	P value
Self-concept	3.00 ± 0.37	3.23 ± 0.08	−2.183	0.037*
Academic self-concept	3.00 ± 0.37	3.21 ± 0.48	−2.105	0.044*
Social self-concept	2.71 ± 0.56	3.06 ± 0.59	−2.220	0.034*
Ethical self-concept	3.52 ± 3.59	3.59 ± 0.42	−0.630	0.534NS
Physical self-concept	2.87 ± 0.60	3.11 ± 0.57	−1.446	0.159NS
Self-esteem	2.39 ± 0.32	2.61 ± 0.21	−2.968	0.006**
Positive self-esteem	2.58 ± 0.46	3.03 ± 0.57	−3.376	0.002**
Negative self-esteem	2.38 ± 0.33	1.97 ± 0.64	2.844	0.008**
Self-efficacy	3.01 ± 0.45	3.50 ± 0.51	−4.403	0.000***
Confidence	2.46 ± 0.50	3.30 ± 0.65	−5.009	0.000***
Self-control	3.35 ± 0.69	3.67 ± 0.72	−2.082	0.046*
Task difficulty	3.32 ± 0.45	3.51 ± 0.62	−1.431	0.163NS
Respect for life	3.40 ± 0.42	3.77 ± 0.46	−3.069	0.005**
Connectedness to nature	3.20 ± 1.84	5.23 ± 1.69	−4.881	0.000***
Aggression	1.79 ± 0.16	1.57 ± 0.23	4.533	0.000***
Physical aggression	1.75 ± 0.22	1.55 ± 0.30	3.105	0.004**
Indirect aggression	1.80 ± 0.21	1.55 ± 0.25	4.018	0.000***
Negativity	1.91 ± 0.26	1.58 ± 0.33	3.706	0.001**
Verbal aggression	1.87 ± 0.29	1.56 ± 0.25	4.523	0.000***
Excitability	1.69 ± 0.20	1.58 ± 0.26	1.673	0.105NS
Acceptance of Behavior	1.57 ± 0.23	1.79 ± 0.16	4.533	0.000***

NS, nonsignificant; *, **, *** Significant at $P < 0.05$, 0.01, or 0.001, respectively using a paired t test.
SD = standard deviation.

Untargeted metabolite profiling in response to the plant-mediated HAP. We conducted metabolite profiling of saliva samples using UHPLC-Orbitrap-MS/MS to analyze the metabolic changes induced by the activities of the plant-mediated HAP. We observed the differences in the saliva of the pre- and postintervention groups using the OPLS-DA plot distinct separation was observed in the negative ion mode of the UHPLC-Orbitrap-MS/MS (Fig. 2A). We selected the metabolites with VIP > 1.0 from the OPLS-DA plot of saliva for tentative identification. Based on the liquid chromatography-mass spectrometry results we identified 30 differential metabolites including 5 amino acids and derivatives 8 dipeptides 7 carboxylic acids and derivatives 6 fatty acids and derivatives 4 others and 10 nonidentified metabolites (Supplemental Table 1).

Altered metabolic pathways and biomarker identification following the plant-mediated HAP. We examined metabolic changes in saliva between the pre- and postintervention groups using a heat map (Fig. 2B), with red indicating higher abundance in the postintervention group and blue indicating lower abundance. Notable increases were observed in the tricarboxylic acid (TCA) cycle intermediates such as succinic acid and malic acid. The data were normalized using Z-scores. We observed increases in the levels of glutamic acid, succinic acid, malic acid, 2-ketoglutaric acid, and acetylglucosamine; we noted decreases in the levels of acetylphenylalanine, threonylphenylalanine, leucylleucine, γ-glutamylleucine, suberic acid, and three unidentified metabolites (designated as compounds 6, 9, and 10). We performed pathway analysis based on the identified metabolites, and distinguished pathways with a pathway impact >0.1 and $-\log_{10}(p) > 0.5$. In saliva, the citrate cycle (TCA cycle); alanine, aspartate and glutamate metabolism; arginine biosynthesis; and histidine metabolism were the pathways affected by the plant-mediated HAP (Fig. 2C).

Identification of potential salivary biomarkers via ROC curve analysis. To explore potential biomarkers associated with the psychological and physiological changes induced by the plant-mediated HAP, we performed ROC curve analysis. Among the significantly altered metabolites, succinic acid emerged as a promising biomarker, showing fair discriminative ability between the pre- and postintervention groups with an AUC of 0.721 (95% confidence interval, 0.604 to 0.841). Furthermore, a box-and-whisker plot revealed a statistically significant increase in succinic acid concentration in the postintervention group compared with the pre intervention group ($P < 0.01$, independent t test), supporting its potential role as a marker of intervention-related metabolic enhancement (Fig. 3).

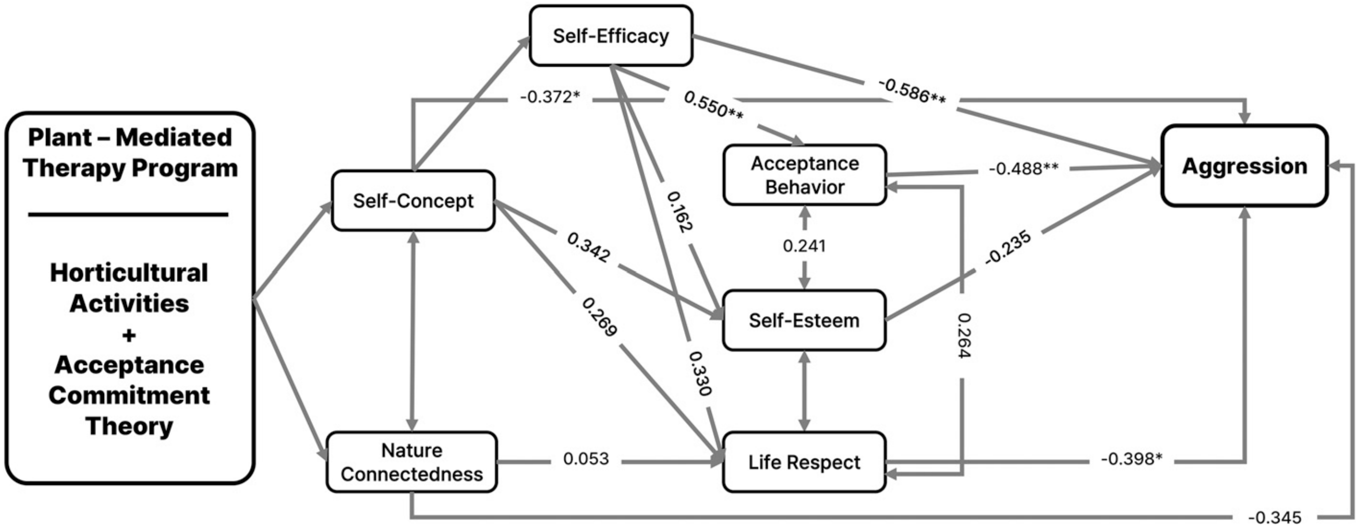

Fig. 1. Multiple mediator model derived from analysis of the correlations between changes in aggression, pre- and post-test, after eight sessions of the plant-mediated healing agricultural program.

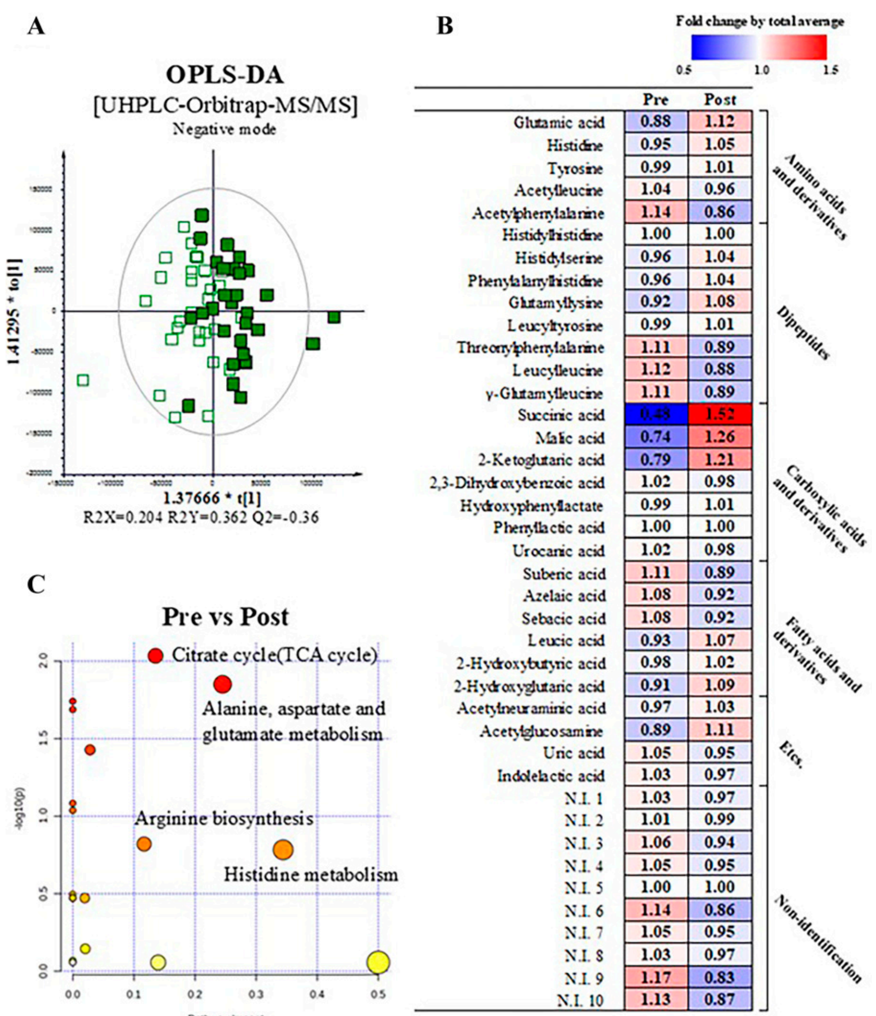

Fig. 2. (**A**) Orthogonal partial least squares–discriminant analysis (OPLS-DA) score plot of saliva sample using ultra-high-performance liquid chromatography–Orbitrap–tandem mass spectrometry (UHPLC-Orbitrap-MS/MS). Open squares = preintervention group; closed squares = postintervention group. (**B**) Heat map analysis for the relative abundance of differential metabolites. (**C**) Pathway analysis of the altered metabolites based on KEGG (Kyoto Encyclopedia of Genes and Genomes) pathway networks. TCA = tricarboxylic acid.

Discussion

This study confirmed that the plant-mediated HAP is an effective method for enhancing the internal developmental assets of elementary school students, consistent with the findings of previous research (Park and Huh 2010; Ryu et al. 2013). Activities involving plants provide opportunities for children to foster understanding and cooperation with their peers, promoting emotional growth (Park et al. 2016).

The significant increase in self-concept highlights the important role horticultural activities play in shaping children's self-awareness. Self-concept forms the foundation of children's overall mental health, and the improvement in academic and social self-concept helps children gain confidence in learning and social interactions. This suggests that horticultural activities go beyond merely engaging with nature and play a crucial role in fostering internal growth in children (Bohlmann and Weinstein 2013; Pesu et al. 2016).

The increase in self-esteem appears to contribute to enhancing children's emotional stability and their ability to accept themselves. Self-esteem is a key psychological indicator of how children evaluate and accept themselves. The observed increase in positive self-esteem and the decrease in negative self-esteem in this study demonstrate the positive impact of horticultural activities on shaping children's self-esteem (Brummelman and Sedikides 2020; Nguyen and Shaw 2020). This suggests that horticultural activities can improve children's emotional stability by helping them view themselves more positively (Miller and Cho 2018).

The increase in self-efficacy plays a significant role in helping children feel more confident in their abilities and adopt a positive attitude toward challenges (Falco and Summers 2019). The significant increase in self-efficacy observed in this study, particularly in confidence and self-regulation, indicates that

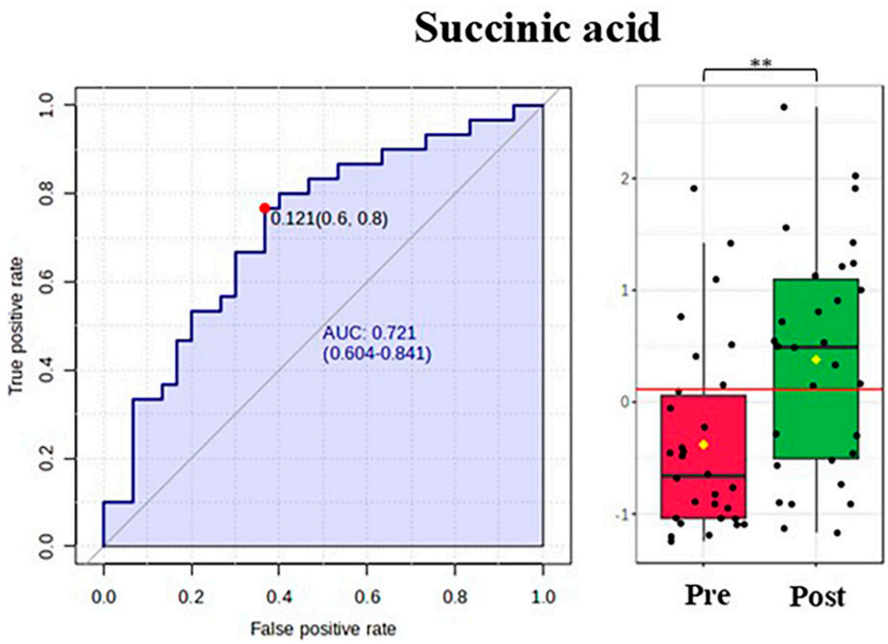

Fig. 3. Receiver operating characteristic (ROC) curve (left panel) and box-and-whisker plot (right panel) illustrating a potential metabolite biomarker distinguishing the preintervention from the post-intervention group [area under the ROC curve (AUC) = 0.721, P = 0.0025]. Statistical significance was assessed using an independent t test, with asterisks denoting significant differences in metabolite levels. ** = $P < 0.01$.

horticultural activities can strengthen children's self-efficacy and enhance their problem-solving abilities (Schunk and DiBenedetto 2021).

The increase in respect for life and connection to nature suggests that the plant-mediated HAP effectively helps children recognize the value of life and form a deeper bond with nature (Carr and Hughes 2021). Respect for life promotes children's ability to respect and understand nature and living beings, which is a key factor in moral development and ecological sensitivity (Fretwell and Greig 2019; Kim et al. 2019).

The reduction in aggression is another important outcome of the plant-mediated HAP. Notably, we observed significant declines in physical aggression, indirect aggression, negativity, and verbal aggression, implying that horticultural activities can effectively suppress aggressive behaviors in children (Jeong and Lee 2009). This demonstrates that horticultural activities help children manage stress and negative emotions while helping them establish social relationships and improve their adaptation to school life (Geum 2014; Park 2002).

The increase in acceptance of behavior shows that horticultural activities positively affect children's ability to accept themselves (Rabiner et al. 2016). This improvement enhances children's ability to recognize and accept both their strengths and weaknesses, leading to reduced interpersonal conflict and lower levels of aggression (Siedlecki et al. 2014). This indicates that horticultural activities have a positive impact on children's overall emotional growth and social adaptation (Weyns et al. 2021; Van der Wilt 2024).

Saliva metabolomics provide a noninvasive method to detect metabolic changes as metabolites can pass from the bloodstream into saliva via transcellular or paracellular routes (Zhang et al. 2012). In this study, heat map and pathway analysis revealed the upregulation of key TCA cycle intermediates (including succinic acid, malic acid, and 2-ketoglutaric acid), suggesting enhanced energy metabolism (Akram 2014; Arnold and Finley 2023). These findings contrast with the results of previous studies that reported downregulation of the TCA cycle and related pathways, such as alanine, aspartate, and glutamate metabolism in chronic sleep disorders associated with psychophysiological stress (Setoyama et al. 2016; Zhang et al. 2011). The upregulation of succinate, identified as a potential biomarker through ROC analysis, was particularly significant. While succinate is traditionally recognized as a TCA cycle intermediate, recent studies underscore its broader role in regulating gluconeogenesis and its anti-inflammatory properties (Fernández-Veledo and Vendrell 2019). The identification of succinate in this context suggests that enhanced energy metabolism via the TCA cycle may contribute to the therapeutic effects of the plant-mediated HAP, with potential implications for mental health modulation. These metabolic enhancements may serve as a physiological basis for the observed improvements in emotional regulation and psychological flexibility. Increased availability of TCA cycle intermediates like succinic acid supports mitochondrial energy production in the brain, which plays a critical role in executive functioning and emotion control (Gómez-Pinilla 2008; Picard and McEwen 2018). Succinic acid, in particular, has been shown to modulate inflammatory responses through mitochondrial metabolic reprogramming (Mills et al. 2016), suggesting a potential biological mechanism by which the HAP intervention may indirectly support children's adaptive emotional responses.

Finally, we conducted an in-depth analysis of the positive impact of the plant-mediated HAP on children's psychological, behavioral, and physiological development. The results showed significant improvements in various psychological factors—including self-concept, self-esteem, self-efficacy, respect for life, and acceptance of behavior—alongside a notable reduction in aggression. In addition to these psychological outcomes, the analysis of saliva metabolomics indicated an upregulation of key TCA cycle intermediates such as succinic acid, malic acid, and 2-ketoglutaric acid, suggesting enhanced energy metabolism that may contribute to overall improvements in mental health. These findings further solidify the beneficial effects of horticultural activities on child development, reaffirming the value of plant-mediated HAPs as important educational tools for promoting holistic growth. Integrating both psychological and physiological evidence, this study emphasizes the program's capacity to foster well-rounded growth in children by supporting both mental and metabolic health.

Limitations. This study was conducted with elementary school students from specific children's centers in Seoul, which have distinct environmental and social characteristics. Future research should expand to include a more diverse population of children from various backgrounds to further validate the effectiveness of the plant-mediated HAP in different settings. Additionally, as this study primarily focused on short-term effects, follow-up studies are needed to assess its long-term impact. Incorporating additional methods that can capture more consistent and sustained physiological changes would be beneficial in this regard. Lastly, while this study targeted students in grades 4 to 6, future research should explore the effects of horticultural therapy programs on younger children, including preschoolers and lower-grade elementary students, to better understand its developmental impact across different age groups.

Conclusions

This study demonstrated that the plant-mediated HAP had a positive impact on the emotional and psychological development of elementary school students, particularly in terms of enhancing self-concept, self-esteem, self-efficacy, and respect for life while effectively reducing aggression. Our findings suggest that horticultural therapy can be used as an effective intervention method to promote emotional stability and reduce aggression in children. Future research should analyze how different components of the program affect various emotional and psychological factors in diverse demographic groups and age ranges to maximize the program's effectiveness. Our results provide important evidence for the inclusion of horticultural therapy in educational settings and counseling programs and indicate that it can be effectively used to support the mental well-being and social development of children.

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